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EFFICIENCY OF LABOR OPERATIONS WHEN FEEDING MIXTURE ON FEEDING TABLES

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The article presents the results of the analysis of labor operations carried out in the process of mechanized distribution and feeding of feed mixtures in free housing of animals The article presents the results of the analysis of labor operations carried out in the process of mechanized distribution and feeding of feed mixtures in free housing of animals The article presents the results of the analysis of labor operations carried out in the process of mechanized distribution and feeding of feed mixtures in free housing of animals, free housing. When comparing the above manual methods of pusher feed mixtures, it was established that when using a shovel for 100 cows at a time, 5.01 minutes of working time were spent, when using forks – 8.12 minutes, and when using a hand scraper – only 2.12 minutes. In modern complexes, the fastest way to hill feed is with a tractor. This takes 1.02 minutes per 100 cows. The "Butler Gold" robot works much more slowly. It takes 4.96 minutes for this operation.

It was found that the feeding behavior of dairy cows depended on feeding management factors, including the frequency of feed distribution and its pusher. The activation of the feeding behavior of animals was characterized by an increase in the number of animals near the feed table when performing the technological operations of feed distribution and pushing (moving feed to the animal on the feeding table). Performing the technological operation of distributing feed mixtures twice a day led to an increase in the number of cows near the feed table by 20.9 % – 22.0 % of the total number of animals in the pen (126±5.2 heads). Performing the technological operation

of pusher feed also led to an increase in the number of cows near the feed table by 2.3 % – 11.3 % of the total number of animals in the group. The remains of feed removed beyond the border of the feed table were perceived by the animals as fresh bedding for rest, which led to a reduction in the total feeding front.

Keywords: dairy cattle, free housing, feed table, manual technological operations, feed pusher, feeding behavior of cows.

ЕФЕКТИВНІСТЬ ТРУДОВИХ ОПЕРАЦІЙ ПРИ ЗГОДОВУВАННІ КОРМОСУМІШЕЙ НА КОРМОВИХ СТОЛАХ

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У статті викладено результати аналізу трудових операцій, що здійснювались у процесі механізованого роздавання та згодовування кормосумішей при безприв'язному утриманні тварин. На основі даних проведеного фотохронометражу встановлено, що технологічні операції складалися із наборів елементарних трудових рухів та мали певну циклічність виконання у часі. При виконанні механізованого роздавання кормів персонал виконував тривалі піші переходи вздовж кормових столів, а також трудові операції з відкриттям-зачиненням різного роду воріт. Підгортання кормів здійснювалось працівниками ферм за допомогою різних інструментів. При порівняні вищенаведених ручних способів підгортання кормосумішей встановлено, що при використанні лопати на 100 корів за один раз було витрачено 5,01 хвилини робочого часу, за використання вил – 8,12 хвилини, а при використанні упору – лише 2,12 хвилини. На сучасних комплексах найбільш швидко корм підгортається трактором. При цьому витрачається 1,02 хвилини на 100 корів. Робот Butler Gold працює значно повільніше. Він витрачає на цю операцію 4,96 хвилин.

Встановлено, що кормова поведінка молочних корів залежала від факторів управління годівлею, включаючи частоту роздавання корму та його підгортання. Активізація кормової поведінки тварин характеризувалась збільшенням кількості тварин біля кормового столу при виконанні технологічних операцій роздавання та підгортання кормів. Виконання технологічної операції роздавання кормосумішей двічі на добу приводило до збільшення чисельності корів біля кормового столу на 20,9 %–22,0 % від загальної кількості тварин у загоні (126±5,2 голів). Виконання технологічної операції підгортання корму також приводило до збільшення чисельності корів біля кормового столу на 2,3 % – 11,3 % від загальної кількості тварин групи. Залишки кормів віддалені за бордюр кормового столу сприймалися тваринами як свіжа підстилка для відпочинку, що приводило до скорочення загального фронту годівлі.

Ключові слова: молочна худоба, безприв'язне утримання, кормовий стіл, ручні технологічні операції, підгортання кормів, кормова поведінка корів.

Introduction. Identifying factors that influence dairy farm performance is crucial for improving cow productivity and profitability, as well as protecting animal welfare and the environment (Bava L. et al., 2014; Skevas T. et al., 2020). Management techniques at the individual cow or herd level can increase herd milk production, improve dairy farm efficiency, and reduce production costs (Britt J. H. et al., 2018; Pulina G. et al., 2020). As dairy farms continue to grow in size, monitoring and managing cows becomes increasingly complex and requires improved management skills (Edwards et al., 2014; Bewley, 2016). The use of automation and sensors, commonly referred to as precision technologies, is increasingly providing farmers with the means to reduce labor requirements and improve management of large herds (Eastwood et al., 2015).

A significant part of all farm costs is feeding costs. Full-fledged balanced feeding of cows affects the efficiency of milk production and farm economics (Bach A. et al., 2020). Therefore, the development of effective feeding strategies is one of the main problems for dairy farms around the world, since feeding is the main factor that affects both the milk yield of cows and the quality of milk (Khanal A.R. et al., 2010). Increasing the efficiency of using feed resources in livestock farming is associated with the introduction of industrial milk production technology, year-round uniform feeding, mechanization and automation of feed distribution, specialization and individualization of feeding according to need, taking into account a complex of endogenous and exogenous factors (Deming J. A. et al., 2013; Ericksona Peter S. et al., 2020). Feeding management on modern dairy farms is becoming increasingly important from an economic and technological perspective, as well as from a dairy cow comfort and welfare perspective (Mattachini G. et al., 2019). Feed distribution stimulates dairy cows to consume feed (DeVries T. J. et al., 2005; King M. T. M. et al., 2016) regardless of the time of day and milking.

It is well known that dairy cow behavior is influenced by feeding management factors, including feed frequency and feeding time (King M. T. M. et al., 2016), although the effect of feeding time on behavioral patterns is less clear. Research suggests that providing fresh feed has a greater effect on stimulating feeding behavior than returning cows from milking. Changes in feeding management can affect both feeding and lying behavior in dairy cows (DeVries T. J. et al., 2005). There is evidence that feeding manipulation around the time of milking increases the percentage of cows lying down after milking compared to feeding manipulation hours after milking (Watters M. E. A. et al., 2013). Other researchers have also found a positive relationship between feed toss frequency and total daily lying time of cows, suggesting that improved feed availability may allow cows to feed more efficiently and spend more time lying down (Deming J. A. et al., 2013). Studies have also found that as the feeding front of cows at the feed table decreases, they are more likely to be at the feed table (Lobeck-Luchterhand K. M. et al., 2015; Krawczel P. D. et al., 2012), namely, they spend more time standing in the feeding area (Wang, F. X. et al., 2016), consume less feed (Huzzey J. M. et al., 2006), and eat faster (Olofsson J., 1999). These changes in feeding patterns may affect feeding efficiency, as rapid feed consumption is associated with lower feeding efficiency (Faith S. R. et al., 2024). Cows that are lower in the social hierarchy are more easily displaced from the feed table, especially when there is insufficient feed frontage (Huzzey J. M. et al., 2006). Thus, these cows tend to eat at different times, which are offset from the time of feed distribution. Other researchers have also concluded that herds with improved access to feed, including increased feed table area, feed distribution frequency, and its pusher, have higher average milk production per group and show less feed sorting (Sova A. D. et al., 2013). It has been established that the implementation of technological operations of distributing and staking feed activates the general activity of

animal feeding behavior (Greben L. G., 2009). Therefore, periodic staking of feed is a common practice in feed table management. Establishing the full composition and time spent on performing staking operations manually and using mechanization and automation is necessary to assess the effectiveness of its implementation and optimize the overall technological process. Therefore, the purpose of the work is to study the effectiveness of labor and mechanized operations when feeding feed mixtures on feed tables.

Materials and methods. The studies were conducted under conditions of mechanized distribution of feed mixtures by mobile mixers to feed tables of the dairy farm of the State Enterprise "Kutuzivka" in the Kharkiv region with free housing of cows on deep straw bedding and the farm of LLC "OLTO" in the Kirovograd region with box housing. The studies determined the list and features of the personnel's performance of manual operations related to the mechanized distribution and feeding on feed tables in free housing, as well as the definition of labor operations that affect the behavior of animals.

The obtained data were processed using standard methods of variational statistics using computer programs.

Research results. Based on the data of the conducted photo-chronometry, it was established that technological operations consist of sets of elementary labor movements and have a certain cyclicality of execution in time.

The activation of the feeding behavior of animals was characterized by an increase in the number of animals at the feed table and was manifested when performing technological operations related to the distribution and pushing of feed. Performing the technological operation of distributing feed mixtures twice a day led to an increase in the number of cows at the feed table by 20.9% - 22.0% of the total number of animals in the pen (126 heads) with each pusher. Performing the technological operation of distributing additional feed (molasses) led to an increase in the number of cows at the feed table by 10.2% - 5.3% of the total average number of animals in the pen. Performing the technological operation of pusher feed also led to an increase in the number of cows at the feed table by 2.3% - 11.3% of the total number of animals in the group.

When performing mechanized feed distribution, the staff performed long walking movements along the feed tables, as well as labor operations with opening and closing various types of gates. These are unproductive labor movements, since they are aimed only at servicing the work of the mobile feed dispenser. In this case, the animals actively reacted not to the presence of the employee walking along the feed table, but only to the freshly distributed feed.

When performing the technological operation of pushing the already distributed feed, the worker performed a different set of labor movements, which depended on the tool he used. The analysis showed that these movements were periodically repeated during the technological process. The set of movements that were repeated periodically made up a full cycle of labor movements. As the feed was cleared and hilled in front of him, the worker moved along the border of the feed table from beginning to end.

The full cycle of the technological operation of shoveling feed with a shovel included the following set of labor movements: shovel withdrawal 0.49±0.005 s, arm extension 0.43±0.007 s, lifting the shovel with feed up 0.72±0.01 s, arm rotation 0.51±0.007 s. Of all the above operations, the longest and most difficult was lifting the shovel with feed residues. Its duration was 9.76-13.48% longer than other labor operations of the cycle ($p<0.05$) (Fig. 1). However, in the cycle, labor movements not directly related to lifting the shovel with feed residues occupied a greater proportion.

The average duration of a full cycle of labor movements associated with shoveling feed was 2.15±0.029 s. At the same time, on each meter of the feed table length, the farm worker performed an average of 2.33 full cycles of such labor movements.

The labor movements that make up the cycle of the technological operation of pushing feed with forks included the following set of movements: retracting and lowering the forks 0.50±0.003 s, advancing the forks forward 0.50±0.005 s, raising the forks with the feed up 0.2 s, which respectively accounted for 41.0%, 41.0%, 18.0% of the duration of the full cycle of this technological operation (Fig. 2). The data show that the greatest proportion was occupied by labor movements not directly related to retracting and lowering the forks and advancing the forks forward.

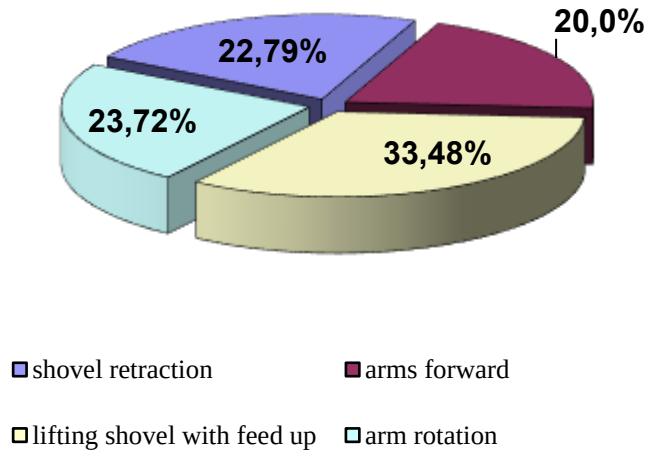

Fig. 1. **Time spent on labor movements when performing the technological operation of pushing feed with a shovel**

The average duration of the cycle of labor movements associated with pushing feed with forks was 1.22±0.058 s. On one meter of feed table length, personnel performed an average of 6.7 complete cycles of labor movements.

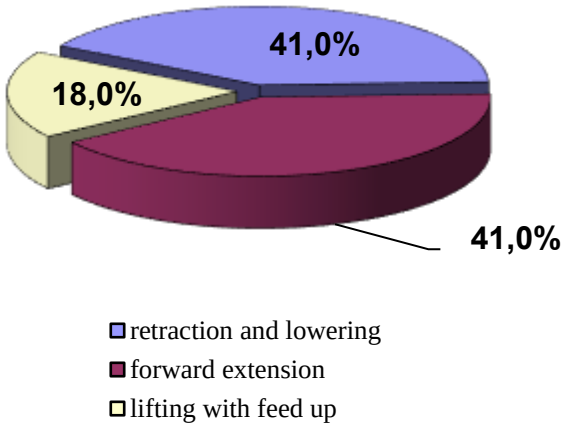

Fig. 2. **Time spent on labor movements when performing the technological operation of pushing feed with a pitchfork**

The technological operation of hilling the feed with a wide hand scraper was performed cyclically and included two operations. The withdrawal and lowering of the wide hand scraper took 0.70±0.008 s, and the advancement of the wide hand scraper forward took 0.71±0.007 s. This was 50.0% and 50.0% of the duration of the full cycle, respectively (Fig. 3).

The average duration of the cycle of labor movements associated with pushing the feed with a wide hand scraper was 1.41±0.037 s. At the same time, for each meter of the feed table length, the farm worker performed an average of 1.5 complete cycles of such labor movements.

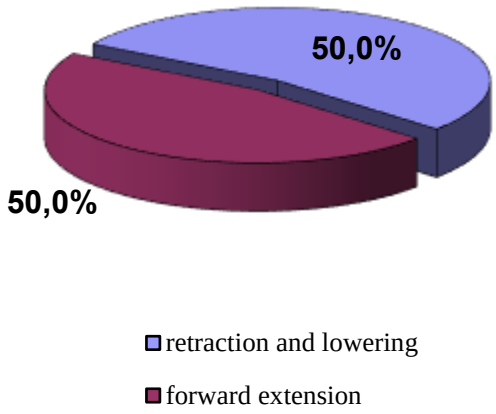

Fig. 3. **Time spent on labor movements during the technological operation of pushing feed with a wide hand scraper**

It should be noted that although the technological operation of pusher feed using a wide hand scraper was characterized by the smallest composition of labor movements and the duration of their execution, it required significant force efforts from the worker. Therefore, when the feed mixtures had a humidity of more than 65% and a bulk density of more than 750 kg/m^3, pusher feed was performed by the sequential use of two tools: first with a shovel (fork), and then with a wide hand scraper.

When comparing the above manual methods of pusher feed mixtures, it was found that when using a shovel, 5.01 minutes of working time was spent on 100 cows at a time, when using a pitchfork – 8.12 minutes, and when using a wide hand scraper – only 2.12 minutes.

On modern farms, the operation of hilling fodder is performed using mechanization tools - a tractor with a slanting bulldozer shovel, and automation - “Butler Gold” robot (Fig. 4).

Fig. 4. **Means of mechanization and automatization of pushing forage**

The fastest pushing to feed is with a tractor. It takes 1.02 minutes per 100 cows. The “Butler Gold” robot works more slowly. It takes 4.96 minutes for this operation. It is important to note that the robot works without a human and needs free access to all feed tables for normal operation.

It is important to consider the monetary costs incurred by a dairy company for pusher feed for 100 cows if this operation is performed 6 times per day. Given a performer’s monthly salary of 20 thousand UAH per month, a minute of human work will cost 1.59 UAH. When working with a shovel, the costs for 100 cows are 47.8 UAH (1.59×5.01×6), and when pusher with a pitchfork – 77.46 UAH (1.59×8.12×6).

The average life of a tractor is 5000 hours. With a tractor costing about 1 million UAH, a minute of depreciation costs 3.33 UAH. (1000000/5000/60). If fuel consumption is 6 liters per hour, then at a price of 1 liter of 50 UAH. per minute, fuel is used for 5 UAH. (6×50/60). Together with the tractor driver's salary, 60.77 UAH is spent on pusher feed for 100 cows with a tractor. ((3.33+5.00+1.59) ×1.02×6).

If the life of the robot is equal to the tractor, then the depreciation costs for one minute of its use are 4.17 UAH (1250000/5000/60), with electricity costs of 0.29 kW or 2.18 UAH per pusher. All costs, respectively, are 137.18 UAH ((4.17×4.96+2.18) ×6).

Thus, the work of a person with a shovel to hill the feed mixture on the feed table is the least expensive.

The final operation in the distribution of feed and feeding is the technological operation of removing feed residues from the surface of the feed table. In production conditions, this technological operation is carried out, as a rule, in the morning before the moment of feed distribution. On the farm where the observations were made, this technological operation was carried out in the morning from 4 to 5 a.m. before the distribution of feed. The removal of feed residues was carried out by a farm worker by scooping the feed residues onto a shovel and throwing them over the side of the feed table border to the pen section. According to the data obtained on the basis of the analysis of the performance of the technological operation of removing feed residues, the average duration of one cycle of labor movements was 1.59±0.15 s.

It was established that the list of labor movements that made up the cycle of the technological operation for removing feed residues beyond the curb of the feed table included the following set: pushing the shovel forward 0.32±0.01 s, raising the feed 0.37±0.01 s, lowering the shovel 0.51±0.02 s, throwing the feed over the curb 0.39±0.15 s, as well as other operations. These included other body movements - straightening the torso, tilting the torso, and others. Their duration in the cycle occupied only 0.61% of the duration of the full cycle of this technological operation (Fig. 5). At the same time, on each meter of the length of the feed table, the farm worker performed an average of 5.0 full cycles of such labor movements.

It was found that with the manual method of removing feed residues with a shovel for 100 cows at a time, it is necessary to spend 7.59 minutes (1.59×3×100/60) of working time. In monetary equivalent, the costs are 12.06 UAH (7.59*1.59). The tractor removes feed residues from the feed table for 100 cows for 1.02 minutes. Total monetary costs for fuel, tractor driver's salary and depreciation for performing this operation for 100 cows by tractor are 10.11 UAH (5.00+1.59+3.33)×1.02). This is 1.95 UAH cheaper than the manual method of removing feed residues. In addition, removing feed residues from the surface of the feed table to the surface of the pen had a specific effect on the behavior of the animals. A peculiarity of the behavior was that the removed food residues in the pen were perceived by the animals as freshly introduced bedding for resting.

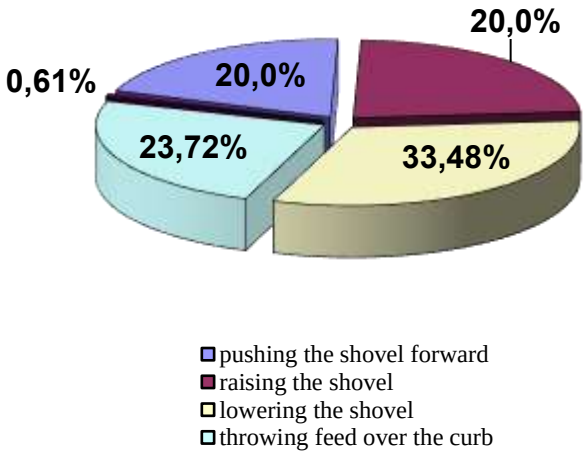

Fig. 5. **Labor movements in the structure of the cycle of the technological operation of removing feed residues**

Observations showed that during the day, from two to six animals (a total of 127 animals in the group) constantly lay near the feeding table. When lying down to rest on the leftover feed, the animals placed their bodies along the edge of the feeding table.

Fig. 6. **Reducing the feeding front while animals rest on feed residues near the border of the feed table**

One animal lying along the feed table line reduces the feeding front by 2-2.5 meters and prevents other animals from freely accessing the feed.

Discussion. Dairy cow welfare has become a hot topic in recent years, especially given the growth in the number of large dairy farms. Increasing the production efficiency of dairy cows by improving their health is impossible without proper feeding and maintenance (Martins L. F. et al., 2022). The involvement of people and technical devices is a characteristic feature of technological processes in dairy farming (Gaworski M., 2021). Modern and innovative concepts in dairy cattle production technology are closely related to the level of mechanization. The claim that a high level of mechanization on dairy farms allows for increased comfort of working conditions and the production of high-quality milk requires clarification of what is meant by the term “high level” and

what the boundary is between high and medium levels of mechanization (Romaniuk W. et al., 2021). We investigated the full cycle of labor movements of a worker when performing the technological operation of raking distributed feed with various manual tools, mechanized and automated raking. It was found that human work with a shovel for raking the feed mixture on the feed table is the least expensive. The essence of the technological index level is to compare mechanical labor costs with manual labor costs spent in this technological process. Of course, other factors can also be selected to assess production technology, including descriptive factors related, for example, to various aspects of modernity. Precision dairy production technologies are one such example (John A. J. et al., 2016). The purpose of implementing these technologies is to reduce the demand for labor (Gargiulo J. I. . et al., 2018). The demand for manual labor is included in the formula for determining the level of the technological index, which thus confirms the usefulness of this index, for example, for assessing the modernity of technologies, including dairy production technologies. It is well known that dairy cow behavior is influenced by feeding management factors, including feed distribution frequency and raking (King M. T. M. et al., 2016), although the effect of raking on behavioral patterns is less clear. Our studies found that increased feeding behavior was characterized by an increase in the number of animals at the feed table and was manifested during technological operations related to feed distribution and raking.

Conclusions:

1. It was found that manual operations performed by personnel at feed tables during the process of distributing, raking and removing feed residues included a set of separate labor movements that made up periodically repeated cycles of labor movements.

2. It was found that the behavior of animals was influenced by the performance of manual operations related to distributing and raking feed. Auxiliary manual operations of farm workers, associated only with opening and closing gates, as well as with transitions from one feed table to another, did not affect the feeding behavior of animals.

3. The use of mechanization and automation is not always economically feasible.

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EFFECTIVE POPULATION SIZE FOR DIFFERENT TECHNOLOGIES OF POULTRY GENE POOL MAINTENANCE

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Despite military operations, the poultry industry has a huge impact on Ukraine's food security. This is achieved through the production of sufficient quantities of various types of poultry meat and table eggs, which are the most affordable components of the daily food basket of Ukrainians. In order to provide producers (micro, small, and medium-sized farms) with genetic resources for poultry, it is necessary to involve domestically bred breeds through a state program, strengthen integration with large industrial complexes, and attract investment. The research was conducted at the experimental base of the State Research Station for Poultry Farming of the Institute of Animal Husbandry of the National Academy of Agrarian Sciences of Ukraine using genetic resources of chickens of various productivity types from the collection of the national gene pool of Ukrainian poultry breeds. Current paper represents results of scientific research focused on comprehensive analysis of the economic efficiency of maintaining the gene pool of chickens of different productivity types. Based on the results of a comparative analysis, taking into account the effective population size (N≥200 heads), the number of poultry groups using different technological equipment (number of group cages from 14 to 20) is justified. Indicators were calculated for the use of standard premises (12x72; 12x84; 12x96 and 18x72; 18x84; 18x96 m) and the minimum number of gene pool groups of chickens of different productivity directions using domestically produced cage equipment (OKPB-2 type) was established, ranging from 24 (laying hens) to 17 (broilers) to 49 to 34 groups, respectively. The number of cages in the corresponding poultry houses that need to be used to complete the gene pool groups of poultry is, respectively, from 216-324 to 296-444 (for OKPB-2 type equipment) and 272-408 and 376-564 (TBR-2 type). Obtained data can be used in the future for calculations and determining directions for improving the economic efficiency of maintaining the gene pool of chicken breeds of different productivity directions.

Keywords: gene pool, chickens, husbandry technology, cage equipment, effective population size.

ЕФЕКТИВНА ЧИСЕЛЬНІСТЬ ПОПУЛЯЦІЙ ЗА РІЗНИХ ТЕХНОЛОГІЙ УТРИМАННЯ ГЕНОФОНДУ ПТИЦІ

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Галузь птахівництва, незважаючи на військові дії, має величезний вплив на формування продовольчої безпеки України. Це досягається за рахунок виробництва в достатній кількості м'яса різних видів птиці та харчових яєць, які є найбільш доступною складовою щоденного харчового кошику українця. Для забезпечення виробників (мікро-, малі- та середні господарства населення) генетичними ресурсами птиці необхідно залучати породи вітчизняної селекції за рахунок державної програми, посилення інтеграції з великими промисловими комплексами та залучення інвестицій. Дослідження проведено на експериментальній базі Державної дослідної станції птахівництва Інституту тваринництва Національної академії аграрних наук України за використання генетичних ресурсів курей різного напряму продуктивності з колекції національного генофонду птиці української селекції. В роботі представлено результати наукових досліджень спрямованих на комплексний аналіз економічної ефективності утримання генофонду курей різного напряму продуктивності. За результатами порівняльного аналізу, з урахуванням ефективної чисельності популяцій (N≥200 голів), обґрунтовано кількість груп птиці за використання різного технологічного обладнання (кількість групових кліток від 14 до 20 шт.). Розраховано показники, щодо використання типових приміщень (12х72; 12х84; 12х96 та 18х72; 18х84; 18х96 м) та встановлено мінімальну кількість генофондових груп курей різного напряму продуктивності із використанням клітkового обладнання (тип обладнання ОКПБ-2) вітчизняного виробництва, відповідно від 24 (яєчні кури) – 17 (м'ясо-яєчні) до 49 – 34 груп. Кількість кліток у відповідних пташниках, які необхідно залучати для комплектування груп генофонд птиці становить , відповідно від 216-324 до 296-444 (для обладнання типу ОКПБ-2) та 272-408 і 376-564 (типу ТБР-2). Отримані дані в подальшому можливо використовувати для розрахунків та визначення напрямів покращення економічної ефективності утримання генофонду порід курей різного напряму продуктивності.

Ключові слова: генофонд, кури, технологія утримання, кліткове обладнання, ефективна чисельність

Introduction. Agriculture is the foundation and one of the main industries that ensures food security in the country. Sustainable development of the industry requires the integration of science and business on the platform of innovative bioeconomy in the crisis economic and legal conditions of Ukraine (Volodin S. et al., 2023; Hlushkov O., Lazakovych I., 2025; Shelenko D., Madryha D., 2025) through the introduction of environmentally friendly technologies, reduction of environmental impact, and optimization of logistics (Karkach P. et al., 2023; UlychV., 2021).

Poultry farming is a sub-sector of animal husbandry that produces about 70% of animal protein (meat from various types of farm poultry and edible eggs). The share of poultry meat (99% of which is broiler chicken) of various types in the total production of meat (in live weight) of farm animals is about 58.5% (State Statistics Service of Ukraine,

2020). Therefore, these products are the most affordable and basic in the food basket of Ukrainian citizens and, accordingly, influence the formation of food security, despite regional characteristics (Savchenko T., 2023; Hryvkivska O., Krasnorutskyi O., 2023).

According to data from the State Statistics Service of Ukraine (2025), poultry farming combines two powerful sectors. First, there are specialized enterprises that produce about 50% of table eggs and about 90% of broiler chicken meat. The second part consists of small and medium-sized private farms. Specialized enterprises are fully focused on the use of foreign genetic resources and technologies, which make the poultry industry the most automated in the world (Nikolyuk O., et al., 2023; Shevchenko A. et al. 2023).

Global innovations do not always work in micro, small, and medium-sized enterprises, where there are difficulties with automated microclimate, balanced feeding, and veterinary and sanitary safety. There is also a major problem with high-quality genetic resources, as there have been no poultry breeders in the country over the past decade aimed at meeting the needs of the population. (Ladyka V. et al., 2023; Voytenko S., Vasylieva O., 2018).

We should underline that despite the seemingly satisfactory situation with gross poultry production in Ukraine, the majority of it is produced by agricultural holdings and large specialized poultry enterprises, which have recently been focusing mainly on exports (Voloshchuk K., Lisevych N., 2019; Yatsiv, S., 2021). The share of private households in the production of both meat and eggs is decreasing every year. At the same time, as global experience shows, the development of small businesses in rural areas (including backyard and farm poultry farming) is more important for the sustainable development of rural areas, as it increases employment and improves the well-being of the rural population, supports the viability of rural settlements, and develops their infrastructure (Avercheva N., 2022).

Global experience also suggests the most promising area of activity for backyard and farm poultry farms, in which they will not compete with large producers, namely the production of so-called “niche” poultry products (organic, farm eggs and chicks, etc.) (Katerynych O. et al., 2023; Lykhach V. et al., 2022; Shelenko D., Madryha D., 2025).

However, in order to realize the potential of small poultry farms, it is necessary to establish a steady supply of day-old chicks that meet the conditions for keeping and feeding in such farms and are most suitable for the production of the above-mentioned products, since currently most of the poultry in private and commercial farms in Ukraine consists of low-yielding non-purebred poultry or industrial high-yielding crossbred poultry that is not adapted to the aforementioned conditions (Polehenka M., 2019; Shulskyy M., Ramskyy I., 2024).

Unfortunately, in modern conditions, the economic component of conservation and rational use of genetic resources of both animals and poultry comes to the fore (Ruban S., Danshyn V., 2019).

At the same time, for the effective development of breeding enterprises, it is necessary not only to preserve and rationally use the best domestic genetic resources and the global gene pool of animals and poultry, but also to modernize the instruments of state support for breeding farms, strengthen integration with large industrial complexes, farms, and private peasant farms (Ibatullin M., Khakhula B., 2021; Ryabukha H., 2019; Savchenko T., 2022).

Therefore, the aim of our research was to conduct a comparative analysis, taking into account the effective population size and the number of gene pool groups of chickens of different productivity types under different husbandry technologies.

Materials and methods. Current study was conducted at the State Research Station for Poultry Farming of the Institute of Animal Husbandry of the National Academy of Agrarian Sciences, in the Department of Innovative Development of Poultry Farming and at the experimental farm "Preservation of the National Gene Pool of Agricultural Poultry". The object of the research is the technological parameters of keeping chickens of egg, egg-meat, and meat-egg productivity, which are preserved as a gene pool.

The effective population size (Ne) was calculated:

$$Ne = (4N_m * N_f)/(N_m + N_f),$$

where N_m is the number of males; N_f is the number of females.

It was used normative data on chicken stocking density (floor space per head, cm^2) on the floor (Departmental standards for technological design of poultry farms (VNTP-APK-04.05, 2005) and technological parameters of cage equipment manufacturers - OKPB-2 (manufacturer: JSC "Nizhynsilmash Plant") and TBR-2 (manufacturer: JSC "Tekhna"), which is used at the experimental farm "Preservation of the National Gene Pool of Agricultural Poultry". Usually calculations use typical room sizes (12x72; 12x84; 12x96; 18x72; 18x84; 18x96) that are partially involved in the technological processes of breeding and keeping chickens of various productivity directions at the DDSP IT NAAS.

Research results. The main task in maintaining gene pool units (populations, breeds, etc.) is to create a system that allows for the long-term preservation of maximum genetic diversity. At the same time, the effective population size (N) indicator comes to the fore in order to control the level of genetic heterogeneity and the risk of genetic diversity loss.

Theoretically, this allows for the development of strategies and programs for the conservation and rational use of the gene pool, and in practice, it reduces genetic drift and controls the genetic integrity of the population.

It is believed (Frankham et al., 2014) that about 50 individuals are sufficient to protect against a decline in viability, such as protection against inbreeding. About 300 females and 50-60 males are sufficient to preserve genetic diversity.

According to our calculations, when keeping 300 females and 60 males on the floor, the effective population size for chickens of different productivity types is 200 heads (Table 1).

Unfortunately, there are restrictions on the groups of birds that can be kept in cages, primarily related to stocking density, floor space, and other technological parameters (feeding front, watering, etc.). Therefore, we have made calculations for cage equipment that has been used for some time to keep parent flocks of adult chickens of various productivity types.

In OKPB-2 cages (manufactured by JSC "Nizhynsilmash Plant"), a value of N at a level of about 200 birds can be achieved by keeping chickens of egg, egg-meat, and meat-egg productivity in the following quantities: 504 hens and 56 roosters (14 cages); 450 hens and 60 roosters (15 cages); 360 hens and 60 roosters (15 cages). At the same time, the N value for all groups of poultry is 202, 212, and 206 birds, respectively.

Similar indicators for TBR-2 equipment (manufactured by JSC "Tekhna"), are as follows for egg-laying, egg-meat, and meat-egg chickens: 551 hens and 57 roosters (19 cages); 475 hens and 57 roosters (19 cages); 380 hens and 59 roosters (20 cages). The N indicator for poultry groups is 207, 204, and 204 heads, respectively.

Table 1.

Effective population size (N) under different systems of maintaining the gene pool of chickens of different productivity types

No	Productivity direction	Analogues	Type of maintenance	Livestock, heads		Effective number (N)
				male	female	
1	Egg-laying	Birkivska Barvysta	On the floor	60	300	200
	Egg-laying and meat-producing	Poltavska Gliniasta		60	300	200
	Meat-producing and egg-laying	White Hercules		60	300	200
2	Egg-laying	Birkivska Barvysta	OKPB-2	56	504	202
	Egg-laying and meat-producing	Poltavska Gliniasta		60	450	212
	Meat-producing and egg-laying	White Hercules		60	360	206
3	Egg-laying	Birkivska Barvysta	TBR-2	57	551	207
	Egg-laying and meat-producing	Poltavska Gliniasta		57	475	204
	Meat-producing and egg-laying	White Hercules		59	380	204

Floor space is one of the determining factors in keeping different types of poultry and productivity. For keeping laying hens (for example, Birkivska Barvysta) on the floor, 1667 cm^2 is required. The corresponding indicators for egg-meat chickens are 1818 cm^2, and for meat-egg chickens – 2222 cm^2 (Table 2).

According to the norms of VNTP – APK-0.4 – 0.5 (2005), the floor space of cage equipment per head of chickens of different productivity directions is, respectively, 600, 720, and 870 cm^2 (egg-laying, egg-meat, and meat-egg). For the OKPB-2 cage equipment available in Ukraine, the corresponding figures are 600, 706, and 857 cm^2, respectively. For similar equipment, TBR-2, the corresponding figures are 600, 686, and 873 cm^2, respectively.

Accordingly, the number of chickens of different productivity, which is given in Table 1, must be 14 (laying hens) and 10 (broilers) for OKPB-2 and TBR-2 cages, respectively, in order 1, in order to maintain an effective number of gene pool groups of poultry in OKPB-2 type battery cages, it is necessary to use 14 (laying hens) and 15 (egg-meat and meat-egg) cages. For the TBR-2 type of equipment, the corresponding figures are 19 (laying and egg-meat) and 20 (meat-egg) cages.

Table 2.

Floor space and number of cages for different systems of keeping the gene pool of chickens of different productivity directions

No	Productivity direction	Analogues	Type of maintenance	Floor space per head, cm²:	Number of cells
1	Egg-laying	Birkivska Barvysta	On the floor	1667	-
	Egg-laying and meat-producing	Poltavska Gliniasta		1818	-
	Meat-producing and egg-laying	White Hercules		2222	-
2	Egg-laying	Birkivska Barvysta	OKPB-2	600	14
	Egg-laying and meat-producing	Poltavska Gliniasta		706	15
	Meat-producing and egg-laying	White Hercules		857	15
3	Egg-laying	Birkivska Barvysta	TBR-2	600	19
	Egg-laying and meat-producing	Poltavska Gliniasta		686	19
	Meat-producing and egg-laying	White Hercules		873	20
4	Egg-laying	Birkivska Barvysta	VNTP	600	-
	Egg-laying and meat-producing	Poltavska Gliniasta		720	-
	Meat-producing and egg-laying	White Hercules		870	-

The results of a comparative analysis of cage equipment that can be used to keep gene pool flocks of chickens of different productivity types are shown in Table 3.

Table 3.

Equipment that can be used to maintain a gene pool of chickens of various productivity types

Indicators	OKPB-2 type	TBR-2 type
Number of tiers	2	2
Dimensions of the battery with feed dispenser, mm,		
- width	1600	1920
- height	1900	1907
Dimensions of cages, mm:		
- довжина- length	2400	1830
- depth	1000	1050
- height	655	653
Total cage area, cm^2	24000	19215
Number of cages in a poultry house, m:		
$12x72^1$ /$18x72^2$	216 / 324	272 / 408
$12x84^1$ / $18x84^2$	256 / 384	328/ 492
$12x96^1$ / $18x96^2$	296 /444	376 / 564

Notes: [1] - the room houses 3 cage batteries; [2] - the room houses 4 cage batteries.

The basis is two-tier cage batteries, but manufacturers have the option of creating three-tier batteries. The OKPB-2 equipment has a larger total cage area – 24,000 cm² compared to 19,215 cm² – due to its greater length (+170 mm) and shallower depth (-50 mm). It is the size of the cages that determines the number of bird families when keeping a breed or population. These are shown in the previous table (Table 3).

A standard poultry house measuring 12x96 m can accommodate 296 cages (OKPB-2) compared to 376 (TBR-2). For a poultry house measuring 18x96, the corresponding figures are 444 (OKPB-2) and 564 (TBR-2).

Based on our calculations (Table 2), taking into account the minimum number of cages for keeping separate groups of birds, we have determined the total number of gene pool units in standard poultry houses (Table 4).

Table 4.

Number of gene pool groups of chickens of different productivity types in poultry houses with different types of equipment

No	Number of cages in a poultry house, m:	Productivity of chickens from the gene pool flock					
		equipment type OKPB-2			equipment type TBR-2		
		Egg-laying	Egg-laying and meat-producing	Meat-producing and egg-laying	Egg-laying	Egg-laying and meat-producing	Meat-producing and egg-laying
1	12x72[1]	24	22	17	29	27	20
2	12x84[1]	28	26	20	35	32	24
3	12x96[1]	33	30	23	40	37	28
4	18x72[2]	36	32	25	44	41	30
5	18x84[2]	43	38	30	52	48	36
6	18x96[2]	49	44	34	61	56	42

Notes: 1 - the room houses 3 cage batteries; 2 - the room houses 4 cage batteries.

According to our calculations, a 12x72 poultry house using OKPB-2 cage equipment can accommodate 24 gene pool populations, groups, breeds, etc. of egg-laying chickens (the Ukrainian equivalent of Birkovskaya Barvysta). The corresponding indicators for egg-meat (Poltavska Gliniasta) and meat-egg (White Hercules) productivity are 22 and 17 storage facilities. When using TBR-2 type equipment, the corresponding indicators are 29, 27, and 20 gene pool units of different productivity types.

Thus, a comparative analysis of the existing cage equipment was carried out and the number of cages for keeping a gene pool flock of chickens of different productivity (from 14 to 20) was established, taking into account the effective population size (N≥200 heads).

Discussion. Currently, despite the state of war, Ukraine is a powerful producer of poultry products and satisfies both domestic and foreign markets. The industry produces a wide range of high-quality poultry products, which allows it to have a constant impact on the formation of stable food security in the country. Unfortunately, to meet the genetic resource needs of enterprises (egg-laying hens and broiler chickens), only poultry breeders that meet their own needs operate in the country.

Despite high production rates of food eggs and meat from various types of farm poultry, the population does not have the opportunity to form and improve its own material and technical base and ensure breeding products. Therefore, along with highly specialized enterprises, micro, small, and medium-sized farms have enormous potential that needs to be realized. It is precisely for this sector of the economy that a state program

is needed, which, together with increased integration with large industrial complexes, will attract investment and increase the gross production of poultry products.

Preserving the gene pool is not an economic but a strategic direction in the economy. Almost every country has its own “special” gene pool of plants and animals, which is part of the nation's identity. Unfortunately, especially for countries with “transitional” economies, the economic component of genetic resource conservation is paramount. Given the low profitability, and in most cases the negative value of this indicator, indigenous breeds and varieties lose out to their highly productive “relatives.”

Preserving the gene pool, and especially its reproduction, research, and dissemination, is losing its economic appeal, leading to the destruction of breeds, populations, and so on. For example, there are currently no officially operating breeding enterprises for various types of domestic poultry in Ukraine. Our research emphasizes the need to comply with the relevant quantitative indicators when keeping poultry using modern equipment. Unfortunately, a decrease in the number of individuals in poultry groups will lead to gene drift, reduced heterogeneity, and disruption of the genetic structure.

Thus, the data we have obtained are the basis for further calculations aimed at improving or refining the technology of keeping and preserving the gene pool using various keeping technologies.

Conclusions.

1. Based on the results of a comparative analysis, taking into account the effective population size (N≥200 heads), quantitative indicators for maintaining gene pool groups of poultry using different technological equipment (number of group cages from 14 to 20) were calculated.

2. A comprehensive use of technological indicators for keeping poultry (stocking density, floor area, cage sizes, etc.) is provided for selecting a strategy for preserving the gene pool of chickens of different productivity types.

3. Calculated indicators have been established for the use of standard premises for keeping the optimal number of gene pool groups of chickens of different productivity directions using domestically produced cage equipment.

4. Basic data on calculations for maintaining the poultry gene pool are presented to improve further research on improving the economic efficiency of maintenance by improving technological solutions.

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OPERATIONAL VALUE AND PRODUCTIVITY OF LARGE WHITE BREED SOWS OF THE FRENCH SELECTION BY THE "AXIOM" COMPANY

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The study presents the results of research on the lifespan, breeding longevity, and reproductive performance of Large White sows of French selection with varying operational value, as well as the calculation of the economic efficiency of their use. The research was conducted at the pedigree breeding farm for Large White pigs of LLC "Agroprime Holding" in the Odesa region and in the Animal Husbandry Laboratory of the State Institution "Institute of Grain Crops" of the National Academy of Agrarian Sciences of Ukraine. The study presents the results of research on the lifespan, breeding longevity, and reproductive performance of Large White sows of French selection by the "AXIOM" company with varying operational value, as well as the calculation of the economic efficiency of their use. The research was conducted at the pedigree breeding farm for Large White pigs of LLC "Agroprime Holding" in the Odesa region and in the Animal Husbandry Laboratory of the State Institution "Institute of Grain Crops" of the National Academy of Agrarian Sciences of Ukraine. It was established that the lifespan of Large White sows of French selection by the "AXIOM" company is 34.1 months, while their breeding longevity is 26.3 months. In terms of prolificacy and litter weight at weaning at 60 days of age, they exceed the minimum requirements for the elite class by an average of 18.46%. Considering intrabreed differentiation by the "operational value of the sow" index (Kh1), a significant difference was found between sows of groups I and III in lifespan (10.2 months), breeding longevity (10.6 months), number of farrowings obtained (2.1), number of live piglets obtained during the breeding period (40.9 head), prolificacy (2.8 head), number of piglets at weaning at 28 days of age (1.9 head), litter weight at weaning at 28 days of age (10.1 kg), and litter weight at weaning at 60 days of age (29.3 kg). The piglet survival rate to weaning at 28 days of age among sows of groups I, II, and III ranged from 89.8% to 95.4%. The proportion of significant pairwise correlation coefficients between the Kh1 index, long-term adaptation traits, and reproductive performance of sows was 100%. The highest additional product gain was obtained from sows of group I, amounting to +5.77%, with a value of +367.23 UAH per head per farrowing. The selection criterion for the leading group of sows by the "operational value of the sow" index (Kh1) is its value in the range of 84.41–105.88 points.

Keywords: sow, genotype, lifespan, duration of breeding use, reproductive qualities, operational value.

ЕКСПЛУАТАЦІЙНА ЦІННІСТЬ ТА ПРОДУКТИВНІСТЬ СВИНОМАТОК ВЕЛИКОЇ БІЛОЇ ПОРОДИ ФРАНЦУЗЬКОЇ СЕЛЕКЦІЇ КОМПАНІЇ «АХІОМ»

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У роботі наведено результати досліджень тривалості життя, тривалості племінного використання та відтворювальних якостей свиноматок великої білої породи французької селекції компанії «АХІОМ» різної експлуатаційної цінності та розраховано економічної ефективності їх використання. Дослідження проведено в умовах племінного заводу з розведення свиней великої білої породи ТОВ «Агропрайм Холдинг» Одеської області та лабораторії тваринництва Державної установи Інституту зернових культур НААН. Установлено, що тривалість життя свиноматок великої білої породи французької селекції компанії «АХІОМ» становить 34,1 міс, тривалість племінного використання – 26,3 міс, а за багатоплідністю і масою гнізда на час відлучення у віці 60 діб переважають мінімальні вимоги класу еліта в середньому на 18,46 %. З урахуванням внутріпородної диференціації за індексом «експлуатаційна цінність свиноматки» (Kh_1) достовірну різницю установлено між свиноматками I і III піддослідних груп за тривалістю життя (10,2 міс), тривалістю племінного використання (10,6 міс), кількість одержаних опоросів становить (2,1), кількістю живих поросят, одержаних за період племінного використання (40,9 гол), багатоплідністю (2,8 гол), кількістю поросят на час відлучення у віці 28 діб (1,9 гол), масою гнізда на час відлучення у віці 28 діб (10,1 кг), масою гнізда на час відлучення у віці 60 діб (29,3 кг). Показник збереженості поросят до відлучення у віці 28 діб свиноматок I, II і III піддослідних груп коливається у межах від 89,8 до 95,4 %. Кількість достовірних коефіцієнтів парної кореляції між індексом Kh_1, ознаками довготривалої адаптації та відтворювальних якостей свиноматок становить 100 %. Максимальну прибавку додаткової продукції одержано від свиноматок I піддослідної групи. Вона становить +5,77 %, а її вартість дорівнює +367,23 грн. / гол / опорос. Критерієм відбору свиноматок провідної групи тварин за індексом «експлуатаційна цінність свиноматки» (Kh_1) є його значення на рівні 84,41-105,88 бала.

Ключові слова: свиноматка, генотип, тривалість життя, тривалість племінного використання, відтворювальні якості, експлуатаційна цінність.

Introduction. The realization of the genetic potential of animals of foreign selection–particularly regarding the reproductive qualities of sows and boars, as well as the fattening and meat qualities of their offspring–is possible under conditions of compliance with optimal, scientifically substantiated feeding and housing standards. These paratypic factors help to reduce the impact of stressors and, accordingly, increase lifespan, breeding longevity, and productive traits (Hetia A.A., 2009; Dudka O.I., 2009; Shulha Yu.I. et al., 2011; Kyslynska A.I., 2012, 2013; Cheng J. et al., 2018; Pelykh N.L., Plokhova A.V., 2019; Vashchenko P.A., 2019; Yen N. et al., 2019; Dudka O.I., 2020; Pasiuta A.H. et al., 2020; Kremez M.I. et al., 2022; Berezovskyi M.D., Vashchenko P.A., 2022).

Thus, the research results of R.L. Susol indicate that Pietrain sows of French selection by the "ADN" company, based on the results of their first farrowing, are characterized by high reproductive performance (Susol R.L., 2010). The average age at puberty in Pietrain replacement gilts is 173.54 ± 11.17 days, the estrus cycle length is 21.08 ± 3.44 days, the age at first successful insemination is 244.45 ± 9.76 days, and the age at first farrowing is 361.95 ± 7.39 days. The author states that the above indicators demonstrate the good adaptive capacity of Pietrain pigs to the climatic conditions of southern Ukraine and to the technological conditions of the farm.

Voloshchuk V. and Vasyliv A. note that, according to the breeding value index and adaptation index, Large White sows outperform Landrace, Duroc, Hampshire, and Pietrain sows by +10.7%, +22.7%, +28.6%, and +31.6%, and by +20.1%, +35.7%, +41.2%, and +47.6%, respectively (Voloshchuk V., Vasyliv A., 2014). An assessment of the operational value of sows showed that Large White and Landrace sows are the most suitable for intensive use under industrial complex conditions. In terms of the number of viable piglets per inseminated sow, animals of these breeds fall into the "high operational value" category. For this indicator, the difference between Landrace and Large White sows, and Duroc, Hampshire, and Pietrain breeds is 0.1, 6.2, 5.3, and 5.3 points, respectively.

Thus, the chosen research direction is relevant and has practical significance for the further development of the pig breeding industry.

The aim of the study was to investigate the lifespan, breeding longevity, and reproductive performance of Large White sows of French selection by the "AXIOM" company, as well as their operational value and the economic efficiency of their use under the conditions of the pedigree breeding farm for Large White pigs of LLC "Agroprime Holding" in the Odesa region.

Materials and methods. The research was conducted under the conditions of the pedigree breeding farm for Large White pigs of LLC "Agroprime Holding" in the Odesa region and the Animal Husbandry Laboratory of the State Institution "Institute of Grain Crops" of the NAAS of Ukraine (2023–2025). The work was carried out in accordance with the research program of the National Academy of Agrarian Sciences of Ukraine No. 31 *"Genetic improvement of farm animals, their reproduction, and biodiversity conservation"* (Genetics, conservation, and reproduction of bioresources in animal husbandry).

The evaluation of Large White sows of French selection (company "AXIOM") was performed taking into account the following quantitative traits: lifespan (months), breeding longevity (months), total number of farrowings obtained, total number of live piglets obtained (head), prolificacy (head), number of piglets at weaning at 28 days of age (head), litter weight at weaning at 28 days of age (kg), litter weight at weaning at 60 days of age (kg), and piglet survival rate to weaning at 28 days of age (%). Litter weight at weaning at 60 days of age was determined according to Appendix 10 to paragraph 4.4.7 of the *Instruction on Pig Appraisal* (*Instruction on Pig Appraisal; Instruction on Breeding Record Keeping in Pig Production*, 2003) in the modification by V.I. Khalak (Khalak, 2009) (Table 1).

Table 1.

Correction coefficients for adjusting litter weight at weaning at 60 days of age

Age at weaning, days	Coefficient	Age at weaning, days	Coefficient
21	3,000	41	1,708
22	2,976	42	1,656
23	2,952	43	1,604
24	2,928	44	1,552
25	2,904	45	1,500
26	2,880	46	1,460
27	2,804	47	1,420
28	2,728	48	1,380
29	2,652	49	1,340
30	2,500	50	1,300
31	2,428	51	1,275
32	2,356	52	1,250
33	2,284	53	1,225
34	2,212	54	1,200
35	2,140	55	1,150
36	2,064	56	1,120
37	1,988	57	1,090
38	1,912	58	1,060
39	1,836	59	1,030
40	1,760	60	1,000

The selection index of sow reproductive traits (SISRT) (1) and the operational value index of the sow (2, 3) were calculated using the following mathematical models:

$$SISRT = (6,0 \times X_1) + \left[9,34 \times \left(\frac{X_2}{X_3} \right) \right] \quad (1)$$

where: SISRT – selection index of sow reproductive traits, points; X_1 – prolificacy, head; X_2 – litter weight at weaning, kg; X_3 – age at weaning, days (Akimov O.V. et al., 2023);

$$Kh_1 = \left[\frac{(W \times P) + F}{G + F} \right] + N \quad (2) \qquad \text{де: } F=S+K \quad (3)$$

where: Kh_1 – "operational value of the sow" index, points; W – breeding longevity (from the beginning of the first pregnancy to the last weaning of piglets), months; G – lifespan of the sow (from birth to the last weaning of piglets), months; P – number of farrowings; S – service period (from the date of weaning to the date of insemination), days; K – period from the date of insemination to the confirmation of pregnancy by ultrasound diagnosis (USD), days; N – total number of live piglets obtained, head (Khalak V.I., 2025).

The feeding and housing conditions for the sows of the experimental groups were identical and complied with zootechnical standards. The economic efficiency of the research results was calculated using the following data: purchase price per unit of production according to current prices in Ukraine; average animal productivity; average increase in primary production (%), expressed as a percentage per head when applying a new or improved breeding achievement compared to the productivity of animals under baseline use (Ladyka V.I. et al., 2023).

Biometric processing of the obtained data was carried out according to generally accepted methods (Kovalenko V.P. et al., 2010; Petrovska I.R. et al., 2022). The strength of the correlations between traits was determined according to Chaddock's scale (Sydorova A.V. et al., 2003) (Table 2).

Table 2.

Chaddock's scale for grading the strength of the correlation between quantitative traits

Correlation coefficient value	Strength of correlation
0,1-0,3	Weak
0,3-0,5	Moderate
0,5-0,7	Noticeable
0,7-0,9	High
0,9-0,99	Very high

Research results. Analysis of primary zootechnical records and the results of our study indicate that the lifespan of Large White sows of French selection (n=40) is 34.1 ± 0.85 months (Cv = 15.79%), breeding longevity – 26.3 ± 0.98 months (Cv = 23.84%), total number of farrowings – 5.5 ± 0.16 (Cv = 19.00%), total number of live piglets obtained – 69.3 ± 2.76 (Cv = 25.23%), prolificacy – 12.6 ± 0.26 head (Cv = 13.41%), number of piglets at weaning at 28 days of age – 11.6 ± 0.15 head (Cv = 8.58%), litter weight at weaning at 28 days of age – 89.8 ± 1.49 kg (Cv = 10.55%), litter weight at weaning at 60 days of age – 237.6 ± 3.88 kg (Cv = 10.35%), and piglet survival rate to weaning at 28 days of age – 92.1 ± 0.45%. The selection index of sow reproductive traits (SISRT) is 103.38 ± 2.036 points (Cv = 12.46%).

The results of the study on lifespan, breeding longevity, and reproductive performance of sows with different differentiation levels according to the Kh_1 index are presented in Table 3. It was found that sows of group I (Kh_1 = 84.41–105.88 points) outperformed sows of groups II (Kh_1 = 66.12–82.69 points) and III (Kh_1 = 40.30–58.89 points) in lifespan by 5.0 (td = 3.49; $P < 0.01$) and 10.2 months (td = 8.36; $P < 0.01$), and in breeding longevity by 3.6 (td = 2.15; $P < 0.05$) and 10.6 months (td = 4.90; $P < 0.01$), respectively.

The difference between the animals of the specified groups in terms of the number of farrowings obtained was 0.8 (td = 3.33; $P < 0.01$) and 2.1 (td = 8.07; $P < 0.001$); in the number of live piglets obtained during the breeding period – 17.6 (td = 6.76; $P < 0.001$) and 40.9 head (td = 16.61; $P < 0.001$); in prolificacy – 1.2 (td = 2.55; $P < 0.05$) and 2.8 head (td = 4.67; $P < 0.001$); in the number of piglets at weaning at 28 days of age – 0.8 (td = 2.35; $P < 0.05$) and 1.9 head (td = 5.13; $P < 0.001$); in litter weight at weaning at 28 days of age – 5.3 kg (td = 1.76; $P > 0.05$) and 10.1 kg (td = 2.70; $P < 0.05$); in litter weight at weaning at 60 days of age – 13.5 kg (td = 1.58; $P > 0.05$) and 29.3 kg (td = 3.09; $P < 0.01$); and in the selection index of sow reproductive traits (SISRT) – 8.52 points (td = 2.30; $P < 0.05$) and 19.09 points (td = 4.07; $P < 0.001$). The highest piglet survival rate to weaning at 28 days of age (95.4 ± 0.86%) was recorded in sows of group III.

The coefficient of variation (Cv, %) for lifespan, breeding longevity, and absolute reproductive performance indicators of sows in the experimental groups ranged from 6.52% (number of piglets at weaning at 28 days of age in sows of group II) to 27.82% (breeding longevity in sows of group III).

Table 3.

Lifespan, breeding longevity, and reproductive performance of sows with different differentiation levels according to the Kh_1 index

Indicators, units of measurement	Biometric indicators	Kh_1 index, points		
		84,41-105,88	***66,12-82,69***	***40,30-58,89***
		Groups		
		I	II	III
		operational value		
		high	medium	low
	n	11	15	14
Lifespan, months	$X \pm Sx$	39,5±0,881	34,5±1,13	29,3±0,85
	$\sigma \pm S_\sigma$	2,93±0,624	4,40±0,804	3,20±0,604
	$C_v \pm S_{Cv}$, %	7,41±1,579	12,75±2,330	10,92±2,064
Duration of breeding use, months	$X \pm Sx$	31,3±1,52	27,7±0,71	20,7±1,54
	$\sigma \pm S_\sigma$	5,05±1,076	2,75±0,502	5,76±1,088
	$C_v \pm S_{Cv}$, %	16,13±3,439	9,92±1,813	27,82±5,258
Total farrowings obtained during breeding period	$X \pm Sx$	6,6±0,20	5,8±0,14	4,5±0,17
	$\sigma \pm S_\sigma$	0,67±0,142	0,56±0,102	0,65±0,122
	$C_v \pm S_{Cv}$, %	10,15±2,164	9,65±1,764	14,44±2,729
Total live piglets obtained, head	$X \pm Sx$	90,2±2,17	72,6±1,45	49,3±1,48
	$\sigma \pm S_\sigma$	7,19±1,533	5,62±1,027	5,54±1,047
	$C_v \pm S_{Cv}$, %	7,97±1,699	7,74±1,414	11,23±2,122
"Operational value of the sow" index (Kh_1), points	$X \pm Sx$	92,59±2,217	74,98±1,482	51,12±1,48
	$\sigma \pm S_\sigma$	7,35±1,567	5,74±1,049	5,56±1,051
	$C_v \pm S_{Cv}$, %	7,93±1,690	7,65±1,398	10,87±2,054
Prolificacy, head.	$X \pm Sx$	13,7±0,41	12,5±0,25	10,9±0,46
	$\sigma \pm S_\sigma$	1,36±0,289	1,00±0,182	1,72±0,325
	$C_v \pm S_{Cv}$, %	9,92±2,115	8,00±1,462	15,77±2,981
± to elite class	*гол*	*+2,7*	*+1,5*	*-0,1*
	%	*+19,70*	*+12,0*	*-0,90*
Number of piglets at weaning at 28 days of age, head	$X \pm Sx$	12,3±0,29	11,5±0,19	10,4±0,23
	$\sigma \pm S_\sigma$	0,97±0,206	0,75±0,137	0,87±0,164
	$C_v \pm S_{Cv}$, %	7,88±1,680	6,52±1,191	8,36±1,580
Litter weight at weaning at 28 days of age, kg	$X \pm Sx$	95,3±2,36	90,0±1,86	85,2±2,90
	$\sigma \pm S_\sigma$	7,84±1,671	7,20±1,316	10,85±2,051
	$C_v \pm S_{Cv}$, %	8,22±1,752	8,00±1,462	12,73±2,406
Litter weight at weaning at 60 days of age, kg	$X \pm Sx$	252,9±6,87	239,4±5,01	223,6±6,52
	$\sigma \pm S_\sigma$	22,80±4,861	19,41±3,548	24,40±4,612
	$C_v \pm S_{Cv}$, %	8,97±1,912	8,10±1,480	10,91±2,062
± to elite class	*кг*	*+72,9*	*+59,4*	*+43,6*
	%	*+28,82*	*+24,81*	*+19,49*
Piglet survival rate to weaning, %	$X \pm Sx$	89,8±0,67	92,0±0,51	95,4±0,86
SISRT, points	$X \pm Sx$	113,22±3,097	104,7±2,030	94,13±3,52
	$\sigma \pm S_\sigma$	10,27±2,189	7,86±1,436	13,17±2,489
	$C_v \pm S_{Cv}$, %	9,07±1,933	7,50±1,371	13,99±2,644

The calculations of pairwise correlation coefficients between lifespan, breeding longevity, reproductive performance indicators of sows, and the Kh_1 index indicate considerable variability of this biometric parameter (–0.547 ± 0.1109 to +0.999 ± 0.0003) (Table 4).

Table 4.

Pairwise correlation coefficients between lifespan, breeding longevity, reproductive performance indicators of sows, and the Kh_1 index

Trait		Biometric indicators		Strength of correlation
x	***y***	***r±Sr***	***tr***	
Kh_1, бала	1	+0,777±0,0627***	12,39	High
	2	+0,721±0,0760***	9,49	High
	3	+0,863±0,0404***	21,37	High
	4	+0,999±0,0003***	3158,42	Very high
	5	+0,644±0,0926***	6,95	Moderate
	6	+0,977±0,0072***	135,79	Very high
	7	+0,451±0,1260**	3,58	Moderate
	8	+0,527±0,1143***	4,61	Moderate
	9	-0,547±0,1109***	4,93	Moderate

Note: *1 – lifespan, months; 2 – breeding longevity, months; 3 – total number of farrowings obtained; 4 – total number of live piglets obtained, head; 5 – prolificacy, head; 6 – number of piglets at weaning at 28 days of age, head; 7 – litter weight at weaning at 28 days of age, kg; 8 – litter weight at weaning at 60 days of age, kg; 9 – piglet survival rate to weaning at 28 days of age, %; ** – P < 0.01; *** – P < 0.001*

Significant correlation relationships were established between the following pairs of traits: Kh_1 × lifespan (r = +0.777, tr = 12.39); Kh_1 × breeding longevity (r = +0.721, tr = 9.49); Kh_1 × total farrowings obtained (r = +0.863, tr = 21.37); Kh_1 × total live piglets obtained (r = +0.999, tr = 3158.42); Kh_1 × prolificacy (r = +0.644, tr = 6.95); Kh_1 × number of piglets at weaning at 28 days of age (r = +0.977, tr = 135.79); Kh_1 × litter weight at weaning at 28 days of age (r = +0.451, tr = 3.58); Kh_1 × litter weight at weaning at 60 days of age (r = +0.527, tr = 4.61); Kh_1 × piglet survival rate to weaning at 28 days of age (r = −0.547, tr = 4.93).

Calculations of the coefficients of linear regression ($R_{x/y}$, $R_{y/x}$) between the Kh_1 index, lifespan, breeding longevity, prolificacy, and litter weight at weaning at 28 days of age in Large White sows of French selection ranged from 0.040 (breeding longevity × Kh_1 index) to 6.763 (Kh_1 index × prolificacy) (Table 5).

Table 5.

Linear regression coefficient between the Kh_1 index, lifespan, breeding longevity, prolificacy, and litter weight at weaning at 28 days of age in Large White sows of French selection, n = 40

Trait		Biometric indicators	
x	***y***	$R_{x/y}$	$R_{y/x}$
Lifespan, months	*Kh_1 index, points*	0,235	2,563
Breeding longevity, months		0,040	2,044
Prolificacy, head		0,061	6,763
Litter weight at weaning at 28 days of age, kg		0,240	0,845

The calculation of the economic efficiency of the research results shows that the highest additional product gain was obtained from sows of group I (Kh_I = 84.41–105.88 points) (Table 6).

Table 6.

Economic efficiency of the research results

Group	Kh_I index	n	Litter weight at weaning at 28 days of age, kg	± to the average population value, %	Value of additional production, UAH / head / farrowing
III	40,30-58,89	14	85,2±2,90	-5,12	-325,86
II	66,12-82,69	15	90,0±1,86	+0,22	+14,00
I	84,41-105,88	11	95,3±2,36	+5,77	+367,23

Note: The selling price of young pigs at the time of the experimental part of the study was 94.50 UAH per 1 kg of live weight.

The increase amounts to +5.77%, with a value of +367.23 UAH per head per farrowing.

Discussion. The results of our research indicate the effectiveness of using a new method for evaluating the operational value of sows, which takes into account breeding longevity and lifespan, service period length, the period from insemination to confirmation of pregnancy by ultrasound (USD), as well as the total number of farrowings and live piglets obtained during the breeding period. The distribution of animals according to the operational value index of the sow (Kh_I) shows that animals of group I, with an index ranging from 84.41 to 105.88 points, are characterized by higher indicators of long-term adaptation and productivity and belong to the "high operational value" category.

The high significance of the pairwise correlation coefficients between the Kh_I index and most productivity indicators ($r = 0.451–0.999$, $P < 0.001$) indicates its informativeness and the appropriateness of its use in breeding work. The positive and strong correlations of Kh_I with lifespan, breeding longevity, prolificacy, and litter weight at weaning at 28 days confirm the complex nature of this index as an integrated measure of productive longevity and reproductive potential of sows. At the same time, the identified negative correlation of Kh_I with piglet survival to 28 days of age ($r = –0.547$) may be explained by management factors or physiological limitations of highly productive animals.

The linear regression coefficients (0.040–6.763) demonstrate varying degrees of influence of individual traits on the Kh_I index, providing a basis for targeted improvement of key reproductive traits through selection.

The economic analysis confirmed the practical significance of using the Kh_I index for animal selection: the highest additional product gain (+5.77%, or +367.23 UAH/head/farrowing) was obtained from sows of group I, which have the highest index values. This indicates a direct relationship between the comprehensive assessment of operational value and production profitability.

The effectiveness of evaluating sows by the "operational value" trait for animals with different operational value levels is also confirmed by the results of the experiment by Dudka O.I. (Dudka O.I., 2009, 2020). The author established that, with increasing age and number of farrowings, the adaptation ability index of sows decreases. It was found that the lifespan and breeding longevity of Ukrainian Steppe White sows range from 18.9 to 128.0 and from 5.9 to 116.2 months, respectively; for Ukrainian Steppe Spotted sows,

these indicators are 20.1–99.8 and 5.8–85.8 months, respectively. Over the breeding period, sows of these breeds produced 6.95 and 6.65 farrowings and a total of 74.3 and 64.6 live piglets, respectively. The quantitative difference in operational value indicators, calculated per sow for all viable piglets, between breeding lines of Ukrainian Steppe White sows was 9.3–4.9 head (28.7–15.7%), while in Ukrainian Steppe Spotted sows it was 13.0–6.3 head (36.8–17.8%). According to the operational value scale, sows of these lines meet the requirements of the medium level (21–39 head).

The obtained results regarding the lifespan (34.1 months) and breeding longevity (26.3 months) of Large White sows of French selection by the "AXIOM" company are consistent with the data of Dudka (2009, 2020), who noted that in Ukrainian Steppe White sows, these indicators may vary from 18.9 to 128.0 months and from 5.9 to 116.2 months, respectively, depending on housing conditions, feeding, and individual adaptive capacity. However, the average values recorded in our study are more stable and have a lower coefficient of variation, which may indicate a high level of herd uniformity.

In terms of prolificacy (12.6 head), our results exceed the figures reported by Pelykh and Plokhova (2019) for sows of various genotypes (10.8–11.4 head), as well as the data of Kyslynska (2013) for Large White sows of Hungarian selection (11.2 head), indicating breeding progress in enhancing reproductive capacity.

The litter weight at weaning at 60 days of age (237.6 kg) in our study significantly exceeds the results obtained by Kremez et al. (2022) for sows of different selection levels (210–225 kg), which may be attributed both to the genetic characteristics of the line and to optimized feeding under the farm's conditions.

The identified strong correlations between the Kh_1 index and the number of live piglets obtained during the productive period ($r = 0.999$) are consistent with the findings of Voloshchuk and Vasyliv (2014), who reported a high level of association between comprehensive evaluation indexes and key reproductive traits. At the same time, the negative correlation of Kh_1 with piglet survival ($r = –0.547$) partially coincides with the data of Dudka (2020), who noted that highly productive sows sometimes exhibit a higher loss of offspring due to physiological and technological factors.

These findings confirm the effectiveness of selecting highly productive sows by the "operational value" trait using both traditional and innovative evaluation methods.

Thus, the research results demonstrate the effectiveness of introducing the operational value index (Kh_1) into the sow evaluation system as a tool for simultaneously improving productivity, longevity, and the economic efficiency of the pig breeding industry.

Conclusions

1. It was established that the lifespan of Large White sows of French selection by the "AXIOM" company is 34.1 ± 0.85 months, and their breeding longevity is 26.3 ± 0.98 months. In terms of prolificacy and litter weight at weaning at 60 days of age, they exceed the minimum requirements for the elite class by 12.69% and 24.24%, respectively..

2. Taking into account intrabreed differentiation according to the "operational value of the sow" index (Kh_1), a significant difference was found between sows of groups I and III in lifespan (10.2 months; td = 8.36), breeding longevity (10.6 months; td = 4.90), number of farrowings obtained (2.1; td = 8.07), total number of live piglets obtained during the breeding period (40.9 head; td = 16.61), prolificacy (2.8 head; td = 4.67), number of piglets at weaning at 28 days of age (1.9 head; td = 5.13), litter weight at weaning at 28 days of age (10.1 kg; td = 2.70), and litter weight at weaning at 60 days of age (29.3 kg; td = 3.09). The highest piglet survival rate to weaning at 28 days of age ($95.4 \pm 0.86\%$) was recorded in sows of group III.

3. The number of significant pairwise correlation coefficients between the Kh_1

index and the absolute reproductive performance indicators of sows was 100%. The linear regression coefficient ($R_{x/\gamma}$, $R_{\gamma/x}$) between the Kh_1 index, lifespan, breeding longevity, prolificacy, and litter weight at weaning at 28 days of age in Large White sows of French selection ranged from 0.040 to 6.763.

4. The highest additional product gain was obtained from sows of group I, amounting to +5.77%, with a value of +367.23 UAH per head per farrowing. The selection criterion for the leading group of sows according to the "operational value of the sow" index (Kh_1) is a value in the range of 84.41–105.88 points.

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EFFICIENCY OF REARING REPAIR HEIFERS OF DAIRY BREEDS IN CORRELATION WITH MILK PRODUCTIVITY

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The article presents analytical data on the assessment of Holstein, Ukrainian Black-and-White dairy and Ukrainian Red-and-White dairy heifers for the development of live weight in the dynamics of rearing from birth to 18 months of age. The study was conducted in the same conditions of the herd of LLC "Kamyshevatsky dairy complex" of the Kharkiv region. The assessment of heifers by absolute and relative indicators of live weight gain showed a high level of heifers rearing on the farm. In terms of live weight of heifers in the studied age periods of 6, 9, 12, 15 and 18 months, they exceeded the target standards of the Holstein breed by 7.8; 12.5; 42.7; 43.1 and 40.4 kg, respectively, the Ukrainian Black-and-White dairy – by 5.7; 11.2; 37.8; 39.3 and 37.1 kg, and the Ukrainian Red-and-White by 8.6; 13.4; 35.7; 37.9 and 35.9 kg. According to the indicators of absolute and relative growth of live weight of repair heifers of controlled breeds in the three-month dynamics of postnatal ontogenesis, interbreed differentiation was established with a significant advantage of Holstein heifers during the entire growing period. Holstein heifers in the three-month Age periods of 3-6, 6-9 and 9-12 with a high and statistically significant difference were better than the peers of Ukrainian Black-and-White and Red-and-White dairy in terms of average daily live weight gain by 32.9 and 47.5, respectively; 15.6 and 61.7 and 25.9 and 56.4 g ($p<0.001$). However, the greatest difference in average daily growth in Holstein heifers was found in the age period of 15-18 months and amounted to 69.1 and 115.7 g ($p<0.001$) in their favor. Holstein heifers took a priority position in terms of relative live weight gain during the entire rearing period. Thus, in the 0-3-month age period, at the highest growth rate (93.7%), Holstein heifers were dominated by the peers of the Ukrainian Black-and-White dairy by 1.7 % ($p<0.001$) and the Ukrainian Red-and-White by 2.1 % ($p<0.001$). A similar excess of Holstein heifers of the same age as Ukrainian Black-and-White and Red-and-White dairy breeds in relative development was observed during all three-month growing periods and in the last 15-18 month period it was 1.4 % ($p<0.001$) and 2.4 % ($p<0.001$), respectively. A direct correlation was established between the live weight of heifers and the average daily weight gain with signs of milk productivity of first calving cow for 305 days of lactation, regardless of breed.

Keywords: Holstein, Ukrainian Black-and-White, Ukrainian Red-and-White, heifers, live weight, milk productivity, correlation.

ЕФЕКТИВНІСТЬ ВИРОЩУВАННЯ РЕМОНТНИХ ТЕЛИЦЬ МОЛОЧНИХ ПОРІД У СПІВВІДНОСНІЙ МІНЛИВОСТІ З МОЛОЧНОЮ ПРОДУКТИВНІСТЮ

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У статті наведено аналітичні дані з оцінки телиць голштинської, української чорно-рябої молочної та української червоно-рябої молочної порід за розвитком живої маси у динаміці вирощування від народження до 18-ти місячного віку. Дослідження проведено в однакових умовах стада ТОВ "Комишуватський Молочний Комплекс" Харківської області. Оцінка телиць за абсолютними та відносними показниками приросту живої маси засвідчила про високий рівень вирощування телиць у господарстві. За живою масою телиць у досліджувані вікові періоди 6, 9, 12, 15 і 18 місяців перевищували цільові стандарти голштинської породи відповідно на 7,8; 12,5; 42,7; 43,1 та 40,4 кг, української чорно-рябої молочної – на 5,7; 11,2; 37,8; 39,3 та 37,1 кг та української червоної молочної – на 8,6; 13,4; 35,7; 37,9 та 35,9 кг. За показниками абсолютного та відносного приросту живої маси ремонтних телиць підконтрольних порід у трьохмісячній динаміці постнатального онтогенезу встановлено міжпородну диференціацію з достовірною перевагою телиць голштинської породи упродовж усього періоду вирощування. Телиці голштинської породи у вікові тримісячні періоди 3-6, 6-9 та 9-12 з високою та статистично значущою різницею були кращими за одноліток українських чорно- та червоно-рябої молочних за середньодобовим приростом живої маси відповідно на 32,9 та 47,5; 15,6 та 61,7 і 25,9 та 56,4 г ($p<0,001$). Проте, найбільша різниця за середньодобовим приростом у голштинських телиць виявилася у віковий період 15-18 місяців і склала на їхню користь 69,1 та 115,7 г ($p<0,001$). За показником відносного приросту живої маси упродовж усього періоду вирощування пріоритетну позицію займали голштинські телиці. Так, у 0-3 місячний віковий період, за найвищої напруги росту (93,7 %) телиці голштинської породи переважали одноліток української чорно-рябої молочної на 1,7 % ($p<0,001$) та української червоно-рябої – на 2,1 % ($p<0,001$). Аналогічне перевищення голштинських телиць одноліток українських чорно-рябої та червоно-рябої молочних порід за відносним розвитком було упродовж усіх тримісячних періодів вирощування і в останній 15-18 місячний період воно склало відповідно 1,4 % ($p<0,001$) та 2,4 % ($p<0,001$). Встановлено пряму кореляцію між живою масою телиць і середньодобовими приростами з ознаками молочної продуктивності первісток за 305 днів лактації незалежно від породи.

Ключові слова: голштинська, українська чорно-ряба, українська червоно-ряба, телиці, жива маса, молочна продуктивність, кореляція.

Introduction. Efficient, systematic and purposeful rearing of repair heifers is one of the main and important tasks of profitable development of the dairy cattle industry (Antonenko S. F., et al. 2022; Pankieiev, S. R. and Pylypenko Yu. G., 2021). A number of scientific studies have proven the positive correlation of live weight variability of heifers during their rearing period with indicators of economically useful characteristics of cows in adulthood, in particular with the level of milk productivity (Luhovyi S. I.,

2023; Polupan Yu. P. and Pryima S. V., 2024; Siriak V. A. et al. 2019), reproductive capacity (Tytarenko I. V. et al., 2016; Polupan Yu. P. et al., 2022) and the duration of lifelong use (Babik, N. P. et al., 2017). It is also proved that the growth and development of repair young animals is significantly affected by the cultivation technology (Vedmedenko, O. V. and Fursenko M. V., 2020), breed, genotype (Borshch O. O. and Ruban S. Yu., 2017; Radchenko et al., 2008), belonging to the line (Shkurko T. P., 2010; Petryshyn M. A. et al., 2024; Kuziv M. I. et al., 2024).

Authors of the study (Tytarenko I. V. et al., 2016; Tytarenko I. V. et al., 2016; Vedmedenko O. V., 2023) note that intensive rearing of heifers and the possibility of their early involvement in breeding use can significantly reduce the unproductive period and reduce the age of first fertilization. Conducted research (Shuliar A. L. et al., 2020; Shpetnyi M. B. et al., 2021; Kuziv M. I. and Fedorovych Ye. I., 2014) confirm that the key factors for determining the optimal insemination time are not so much age as live weight and the overall level of physical development of animals. Insemination of heifers with insufficient live weight, regardless of their age, negatively affects their productivity and overall economic value.

Studying the reports of scientists regarding the indicators that relate to the growth and development of repair heifers for live weight, it is possible to observe significant variability both within breeds and experimental farms in the dynamics of its growth from birth to mating age. Thus, according to studies of heifers of the Ukrainian Ukrainian Red-and-White dairy breed (n=1075), the average live weight in the periods from newborns, at 6, 12 and 18 months, was, respectively 30,4±0,07; 169,8±0,63; 294,4±0,73 and 395.9±1.07 kg (Ilnytska O. Yu. et al., 2014). Evaluation of heifers of three breeds raised in the same farm (Polupan Yu. P. and Pryima S. V. 2024b) - Holstein, Ukrainian Black-and-White and Red Dairy, in similar age periods (n=897) was 37,5±0,10; 161±0,7; 291±1,7 and 409±2.3 kg, which exceeded the standard of the Holstein breed at the age of 12 and 18 months, by 4 and 24 kg, respectively, the Ukrainian Black-and-White dairy – by 7 and 29 kg, the Ukrainian Red Dairy –by 29 and 54 kg. Dynamics of live weight growth of Ukrainian Black-and-White dairy heifers in comparison with the standard (n=151) according to research (Vedmedenko O. V. and Fursenko M. V., 2020) for the same age periods, respectively, was: 39.15±0.29; 176.19±0.96; 301.24±1.80 and 418.83±3.32 kg, which is also higher than the breed standard at the age of 6; 12 and 18 months by 3.64; 6.07 and 10.22 kg. The intensive development of heifers of the Ukrainian Red-and-White dairy breed within six lines is reported by (Dymchuk A. V. et al., 2022) with a live weight of newborns of 32.0 - 35.1 kg, in 6 – 166,1-189,5 kg; 12 – 300,4-325,5 and 15 months-361.1-387.4 kg.

So, the analysis of scientific studies showed a certain variability in the development of dairy heifers in Ukraine by live weight, which is the leading factor in the assessment and confirmed a sufficient level of intensity of their cultivation. Our research was aimed at evaluating repair heifers raised in the conditions of one farm, in a comparative analysis of their development with the determination of the prospects for further research on the study of the correlated variability of live weight with the economically useful characteristics of cows in adulthood.

Materials and methods of research. The material for the study was the breeding information of the enterprise for breeding Ukrainian Black-and-White, Red-and-White dairy and Holstein breeds of domestic breeding of the herd LLC “Kamyshevatsky dairy complex” of the Kharkiv region. Indicators for the development of repair heifers by live weight were obtained from the database of automated breeding accounting of the sums herd management program “Intesel Orsek”.

The absolute increase in live weight of heifers was determined by the formula:

$$A = W_t - W_0,$$

where: A is the absolute increase in live weight of the animal;

W_0 - live weight at the beginning of the period;

W_t - live Mass at the end of the period.

The average daily increase in live weight was determined by the following formula:

$$X = \frac{W_t - W_0}{t_2 - t_1}$$, where

X-average daily gain (g);

t_1-age at the beginning of the control period, days;

t_2-age at the end of the control period, days.

The relative growth rate was calculated by the formula (CIT. Basovskyi M. Z. et al., 2001) proposed by S. Brody:

$$K = \frac{(W_t - W_0) \times 100}{(W_t + W_0) \div 2}$$

Evaluation indicators were calculated using the formulas given in the textbook (Ladyka V. I., et al., 2023). The reliability of the obtained data was estimated by calculating statistical errors (S.E.) and student reliability criteria (td). The degree of reliability was classified in comparison with the values of standard criteria. The results of experimental studies were considered significant for the first $p<0.05$ (1), the second $p<0.01$ (2), and the third $p<0.001$ (3) probability threshold.

Research results. Quantitative characteristics of cattle are formed on the basis of hereditary characteristics and the influence of external conditions in the process of individual development. As scientific and practical experience in the field of zootechnics proves, optimal indicators of growth and development of repair heifers during postnatal ontogenesis are an important factor that ensures high milk productivity of cows throughout the entire period of their operation.

According to the results of experimental studies in identical conditions of the herd of LLC "Kamyshevatsky dairy complex", it was established that the highest live birth weight was characterized by the offspring of the Ukrainian Black-and-White dairy breed, which with an average live birth weight of 37.8 kg exceeded the Holstein and Ukrainian Red-and-White heifers with a significant difference of 1.0 ($p<0.001$; td=10.8) and 1.1 kg ($p<0.001$; td=11.9), table. 1.

Table 1.

Development of repair heifers of Ukrainian dairy breeds for live weight in the dynamics of development from birth to 18 months, kg (x ± S.E.)

Age period	Breed			
	Holstein	Ukrainian Black-and-White dairy	Ukrainian Red-and-White dairy	on average by herd
n	1636	1657	1387	4681
new birth	36,8±0,06	37,8±0,07	36,7±0,06	37,1±0,04
3 months	102,7±0,17	103,3±0,20	100,9±0,24	102,5±0,12
6 months	182,8±0,25	180,7±0,26	178,6±0,30	181,1±0,15
9 months	246,5±0,26	245,2±0,26	242,4±0,29	244,8±0,16
12 months	330,7±0,37	325,8±0,37	319,7±0,44	326,0±0,23
15 months	381,1±0,46	377,3±0,36	371,9±0,42	376,7±0,24
18 months	425,4±0,60	422,1±0,42	415,9±0,43	420,2±0,27

However, starting from the age of six months, the priority position was taken by Holstein heifers with a live weight of 182.8 kg in this age period, which became significantly higher compared to the peers of Ukrainian Black-and-White and Red-and-White dairy breeds, respectively, by 2.1 ($p<0.001$; td=5.82) and 4.2 kg ($p<0.001$; td=10.8). This situation did not change until the end of the rearing period, and at the age of 18 months, Holstein heifers with an average live weight of 425.4 kg outnumbered the peers of Ukrainian Black-and-White and Red-and-White dairy breeds with a significantly significant difference, respectively, by 2.1 ($p<0.001$; td=5.82) and 4.2 kg ($p<0.001$; td=10.8).

The average level of live weight of controlled heifers in the studied age periods exceeds the breed standards defined in the bonitation instructions (Lytovchenko A. M. et al., 2007). At the age of 6, 9, 12, 15 and 18 months, these indicators exceed the targets of the Holstein breed by 7.8; 12.5; 42.7; 43.1 and 40.4 kg, respectively, the Ukrainian Black-and-White dairy breed — by 5.7; 11.2; 37.8; 39.3 and 37.1 kg, and the Ukrainian Red-and-White breed – by 8.6; 13.4; 35.7; 37.9 and 35.9 kg. Such indicators indicate a fairly high level of Organization of cultivation of controlled repair heifers on the farm.

When studying the absolute increase in the live weight of repair heifers of controlled breeds in the three-month dynamics of postnatal ontogenesis, which is an indicator of the intensity of animal growth, interbreeding differentiation was also established with a significant advantage of Holstein heifers during the entire growing period, with the exception of the first 0-3 month period in comparison with the peers of the Ukrainian Black-and-White dairy breed (table. 2). While during this rearing period (0-3 months), Holstein heifers were better in terms of live weight gain than Ukrainian Red-and-White annuals by 2.0 kg with a significant significance ($p<0.001$; td=6.80).

Table 2.

Development of repair heifers of Ukrainian dairy breeds for live by weight in the dynamics of absolute increments, kg (x ± S.E.)

Age period in 3-month gradation	Breed			
	Holstein	Ukrainian Black-and-White dairy	Ukrainian Red-and-White dairy	on average by herd
n	1182	1292	970	3446
0-3 months	65,6±0,17	65,2±0,21	63,6±0,24	64,9±0,12
3-6 months	81,6±0,25	78,7±0,27	77,4±0,39	79,6±0,17
6-9 months	74,7±0,33	73,3±0,29	69,1±0,42	72,6±0,20
9-12 months	79,6±0,39	77,3±0,38	74,5±0,50	77,4±0,24
12-15 months	62,3±0,51	56,9±0,37	55,6±0,42	57,8±0,25
15-18 months	54,2±0,46	48,0±0,24	43,8±0,33	47,6±0,20
0-18 months	389,0±0,64	384,5±0,44	378,8±0,43	383,0±0,28
0-6 months	146,0±0,25	142,7±0,26	141,3±0,31	143,7±0,16
6-12 months	152,8±0,44	149,0±0,43	143,7±0,59	149,2±0,28
12-18 months	109,2±0,85	101,8±0,48	99,2±0,54	102,1±0,34

Starting from the age of three months in all the evaluated age categories, Holstein heifers were better in absolute live weight gain with a difference in this age period compared to the peers of Ukrainian Black-and-White and Red-and-White dairy by 2.9 ($p<0.001$; td=7.88) and 4.2 kg ($p<0.001$; td=9.07). At the age of 15-18 months, the difference and reliability in favor of Holstein heifers increased to 6.2 ($p<0.001$; td=11.9)

and 10.4 kg (p<0.001; td=18.4), respectively. The absolute increase in live weight for the entire growing period, from birth to 18 months, was in favor of Holstein with a difference of 4.5 (p<0.001; td=5.79) and 10.2 kg (p<0.001; td=5.79), respectively.

There are effective studies to assess the development of heifers over six-month periods of live weight gain (Voitenko S. L. and Sydorenko O. V., 2021; Shuplyk V. V. and Pshybelska, A. R., 2020; Ivanov I. A., 2016), especially from six to twelve months of age, i.e. during puberty (Polupan Yu. P. and Pryima, S. V., 2024a). In the controlled herd, Holstein heifers increased their live weight by 3.3 (p<0.001; td= 0.1) and 4.7 kg (p<0.001; td=12.7), respectively, in half a year compared to the peers of Ukrainian Black-and-White and Red-and-White dairy dairy breeds. For 6-12 and 12-18 months, the difference in favor of Holstein heifers was 3.8 (p<0.001; td=6.18) and 9.1 kg (p<0.001; td=12.3) and 7.4 (p<0.001; td=7.58) and 10 kg (p<0.001; td=7.58), respectively.

Control of growth and growth is made possible by analyzing the average daily and relative growth rates, which show the energy and intensity of animal growth (Havrylenko M. S. and Kunovska N. V., 2005). Intensive development of calves during the milk period, covering the period from birth to the age of six months, plays a key role. At this time, it is important to take into account the biological features of individual development, in particular, increased growth energy during the first months of life, which is the basis for the formation of healthy and full-fledged young animals (Khmelnychyi L. M. and Bardash D. O., 2019). Yu. P. Polupan and S. V. Pryima (2024b) notes that due to the increased level of correlative variability of measurements of primiparous with the growth of heifers during puberty, special attention should also be paid to the cultivation of repair heifers during intensive puberty at the age of 6-12 months.

The level of average daily live weight gains of repair heifers of the controlled herd, regardless of breed, ensured their sufficient development during the mating age. At the same time, interbreeding variability was observed with higher indicators of average daily increments in Holstein heifers (Table 3).

Table 3.

Development of repair heifers of Ukrainian dairy breeds for live by weight in the dynamics of average daily increments, G (x ± S.E.)

Age period in 3-month gradation	Breed			
	Holstein	Ukrainian Black-and-White dairy	Ukrainian Red-and-White dairy	on average by herd
n	1182	1292	970	3446
0-3 months	729,6±1,98	724,6±2,34	706,6±2,68	721,9±1,33
3-6 months	907,5±2,77	874,6±3,04	860,0±4,43	885,1±1,90
6-9 months	830,0±3,64	814,4±3,27	768,31±4,65	806,6±2,25
9-12 months	884,9±4,35	859,0±4,27	828,5±5,59	859,6±2,72
12-15 months	692,3±5,71	632,6±4,13	618,6±4,66	643,1±2,77
15-18 months	602,8±5,09	533,7±2,72	487,1±3,67	529,4±2,22
0-18 months	713,5±1,15	701,9±0,79	692,5±0,84	700,6±0,54
0-6 months	802,4±1,38	784,5±1,47	776,2±1,70	789,8±0,88
6-12 months	839,8±2,41	818,9±2,36	789,8±3,26	819,8±1,54
12-18 months	600,0±4,68	559,6±2,66	545,1±2,95	561,1±1,87

Young animals of controlled breeds developed most intensively in the first four three-month periods, from birth to twelve months of age. The average daily weight gain of heifers was higher in representatives of the Holstein breed and amounted to a variability from 729.6 to 884.9 g, with higher results in the 3-6–month period – 907.5 g. heifers of the Holstein breed with almost the same average daily weight gain in the period 0-3 months compared to the peers of the Ukrainian Black-and-White dairy breed dominated heifers of the Ukrainian Red-and-White dairy by 23 g with a significant significance ($p<0.001$; td = 6,90).

Holstein heifers in the age three - month periods 3-6, 6-9 and 9-12 with a high and significant difference surpassed the peers of Ukrainian Black-and-White and Red-and-White dairy in terms of average daily live weight gain, respectively, by 32.9 ($p<0.001$; td=7.99) and 47.5 g ($p<0.001$; td=9.09), 15.6 ($p<0.001$; td=8.18) and 61.7 g ($p<0.001$; TD=10.4) and 25.9 ($p<0.001$; TD=4.25) and 56.4 g($p<0.001$; TD=7.96). However, the largest difference in average daily growth in Holstein heifers was found in the age period of 15-18 months and amounted to 69.1 ($p<0.001$; td=11.8) and 115.7 g ($p<0.001$; td= 8.4) in their favor.

During the dairy period of rearing, the average daily weight gain of Holstein heifers was higher compared to the peers of Ukrainian Black-and-White and Red-and-White breeds, respectively, by 17.9 ($p<0.001$; td=8.88) and 26.2 g ($p<0.001$; td=11.9). During a fairly responsible puberty period (6-12 months), a significantly significant difference in favor of Holstein heifers increased and, respectively, amounted to 20.9 ($p<0.001$; td=6.20) and 50 g ($p<0.001$; td=12.3). At the final stage of cultivation, which is an important mating period for reproduction, the priority position in terms of the intensity of the average daily increase in live weight was preserved for Holstein heifers with a predominance of the peers of Ukrainian Black-and-White and Red-and-White animals with a statistically significant difference of 40.4 ($p<0.001$; td=7.50) and 54.9 g ($p<0.001$; td=9.92), respectively.

Absolute indicators to a certain extent characterize the intensity of animal growth and are of great practical importance, since they allow you to compare actual results with planned ones, monitor compliance with the requirements of the standard or the desired type, and make calculations regarding the salary of farm employees.

Because young animals grow unevenly (Polupan Yu. P. and Pryima S. V., 2024a; 2024b; Cherniavska T. O. et al., 2017), therefore, the indicator of absolute growth does not reflect the actual intensity of growth processes, the degree of their intensity, that is, the relationship between the amount of increasing body weight and the intensity of growth. For this purpose, determine the relative increase, which is calculated as a percentage.

Based on the results of calculations of indicators of relative growth of live weight of repair heifers, its variability within the estimated breeds was established. In all age three-month periods, Holstein animals developed more intensively, table 4.

The fact that the intensive development of Holstein heifers is their biological feature is confirmed by a significant difference in the relative increase in live weight during the entire growing period. Thus, in the 0-3-month age period, at the highest growth rate (93.7%), they exceeded the peers of the Ukrainian Black-and-White dairy breed by 1.7 % ($p<0.001$; td=6.29), and the Ukrainian Red-and-White – by 2.1 % ($p<0.001$; td=7.34).

A similar excess of Holstein heifers of the same age as Ukrainian Black-and-White and Red-and-White dairy breeds in terms of relative development was observed during all three-month growing periods and in the last 15-18 month period it was 1.4 % ($p<0.001$; td=11.2) and 2.4 % ($p<0.001$; td=17.6), respectively.

Table 4.

Relative increase in repair heifers of Ukrainian dairy products rocks by live weight in age dynamics, % (X ± S.E.)

Age period in 3-month gradation	Breed			
	Holstein	Ukrainian Black-and-White dairy	Ukrainian Red-and-White dairy	on average by herd
n	1182	1292	970	3446
0-3 months	93,7±0,17	92,0±0,21	91,6±0,23	92,6±0,12
3-6 months	57,0±0,16	55,3±0,18	54,9±0,28	55,9±0,11
6-9 months	35,2±0,16	34,6±0,14	32,8±0,19	34,3±0,09
9-12 months	27,7±0,13	27,2±0,13	26,5±0,17	27,2±0,08
12-15 months	17,7±0,15	16,3±0,11	16,1±0,12	16,6±0,07
15-18 months	13,5±0,11	12,1±0,06	11,1±0,08	11,9±0,05

In the introductory part, it is noted that there is a correlation variability between the live weight in the cultivation of repair heifers and economically useful traits that are important for dairy cattle breeding. However, the most important indicators for dairy cattle are productivity in terms of milk yield, fat and protein.

According to the assessment of correlation variability between the live weight of Holstein heifers and the milk productivity of first calving cow in the age dynamics of rearing, from birth to 18 months, the existence of a positive relationship was established (table 5). With almost no association of live weight with milk yield, milk fat and protein and low reliability of newborn heifers, starting from the age of three months, the level of correlation coefficients gradually increases, reaching the maximum value and statistical significance at the age of 18 months ($r=0.282$; $p<0.001$; $td=5.42$).

There are effective studies to assess the development of heifers over six-month periods of live weight gain (Voitenko S. L. and Sydorenko O. V., 2021; Shuplyk V. V. and Pshybelska A. R., 2020; Ivanov I. A., 2016), especially from six to twelve months of age, i.e. during puberty (Polupan Yu. P. and Pryima S. V., 2024a).

Slightly higher correlation coefficients of average daily live weight gain with milk fat and protein yield for 305 days of the first lactation of Holstein animals were found in the period of three to six months ($r=0.228$; $r=0.211$; $r=0.193$). The assessment of the correlation variability of the average daily weight gain of heifers with similar signs of milk productivity of Holstein primiparous was highest at the age of 6-12 months ($r=0.262$; $r=0.251$; $r=0.242$) – this is just the period of puberty. The trend is similar to research conducted in this direction by employees of the Institute of animal breeding and genetics of the National Academy of Sciences (Polupan Yu. P. and Pryima S. V., 2024a).

Table 5.

Correlation variability of Heifer growth intensity and milk productivity of Holstein first-born cows (r±S.E.)

Correlated sign	*n*	relationship with the sign of milk productivity		
		Milk yield	milk	
			fat	protein
Live weight in age, months				
0	1825	0,065±0,023[2]	0,049±0,023[1]	0,057±0,023[1]
3	1472	0,129±0,026[3]	0,117±0,026[3]	0,122±0,026[3]
6	1396	0,191±0,027[3]	0,176±0,027[3]	0,141±0,027[3]
9	865	0,192±0,034[3]	0,172±0,034[3]	0,198±0,034[3]
12	1190	0,201±0,029[3]	0,155±0,029[3]	0,142±0,029[3]
15	528	0,230±0,043[3]	0,183±0,043[3]	0,173±0,044[2]
18	344	0,282±0,052[3]	0,245±0,053[3]	0,238±0,054[3]
Average daily increase in live weight by age, months.				
0-3	1470	0,154±0,026[3]	0,135±0,026[3]	0,093±0,027[3]
3-6	1184	0,228±0,029[3]	0,211±0,029[3]	0,193±0,029[3]
6-9	618	0,214±0,037[3]	0,207±0,040[3]	0,191±0,040[2]
9-12	738	0,121±0,037[2]	0,158±0,037[3]	0,147±0,037[3]
12-15	466	0,125±0,046[2]	0,121±0,046[3]	0,129±0,046[2]
15-18	313	0,158±0,056[2]	0,142±0,052[2]	0,141±0,051[2]
0-6	1394	0,214±0,026[3]	0,194±0,027[3]	0,208±0,027[3]
6-12	908	0,262±0,033[3]	0,251±0,039[3]	0,242±0,033[3]
12-18	276	0,215±0,059[3]	0,226±0,030[3]	0,231±0,052[3]

Note. 1 - p≤0,05; 2 - p≤0,01; 3 - p≤0,001

The level of indicators of correlated variability in the intensity of rearing repair heifers by live weight and signs of milk productivity of first-born cows of the Ukrainian Black-and-White dairy breed is shown in Table. 6.

Since young animals were raised in the same farm under the influence of the same paratypical factors, the correlation coefficients between the calculated traits coincide in direction with Holstein heifers. Low correlation coefficients were obtained between live weight and milk yield, milk fat and protein in newborn heifers. With the increase in live weight with age, there is a similar increase in indicators of correlation variability with a higher correlation coefficient at the age of 18 months (r=0.229; p<0.001; td=7.16).

Between the average daily increase in live weight and milk yield in the three-month dynamics of cultivation, variability was observed from a minimum unreliable value at the age of 0-3 months (r=0.044), to a moderate and reliable level at the age of 3-6 months (r=0.260). For six-month growth periods, correlations for these traits were more significant with higher coefficients at 6-12 months of puberty (r=0.296).

Table 6.

Correlation variability of the growth intensity of heifers and milk productivity of first-born Ukrainian Black-and-White cows dairy breed (r±S.E.)

Correlated sign	*n*	relationship with the sign of milk productivity		
		Milk yield	milk	
			fat	protein
Live weight in age, months				
0	1913	0,054±0,023[1]	0,069±0,022[2]	0,071±0,024[2]
3	1477	0,119±0,026[3]	0,107±0,024[3]	0,105±0,024[3]
6	1364	0,159±0,027[3]	0,146±0,023[3]	0,144±0,025[3]
9	1102	0,162±0,031[3]	0,158±0,029[3]	0,148±0,032[3]
12	1422	0,187±0,026[3]	0,176±0,024[3]	0,169±0,024[3]
15	1083	0,205±0,033[3]	0,198±0,031[3]	0,194±0,031[3]
18	918	0,229±0,032[3]	0,222±0,033[3]	0,208±0,030[3]
Average daily increase in live weight by age, months				
0-3	1469	0,044±0,026	0,038±0,024	0,047±0,028
3-6	1170	0,260±0,029[3]	0,263±0,026[3]	0,271±0,027[3]
6-9	792	0,120±0,035[3]	0,114±0,031[3]	0,109±0,032[3]
9-12	962	0,135±0,032[3]	0,118±0,029[3]	0,121±0,034[3]
12-15	990	0,175±0,031[3]	0,166±0,032[3]	0,158±0,033[3]
15-18	873	0,194±0,033[3]	0,188±0,031[3]	0,182±0,031[3]
0-6	1356	0,281±0,027[3]	0,269±0,025[3]	0,271±0,029[3]
6-12	1047	0,296±0,031[3]	0,281±0,030[3]	0,279±0,033[3]
12-18	820	0,291±0,035[3]	0,288±0,033[3]	0,287±0,034[3]

Note. 1-p≤0.05; 2-p≤0.01; 3-p≤0.001

The study of heifers of the Ukrainian Red-and-White dairy breed to study the correlated variability of their growth in the age dynamics of cultivation with signs of milk productivity according to the data of the first lactation revealed a similar trend similar to the results of studies of peers of Holstein and Ukrainian Black-and-White dairy breeds (Table 7).

The increase in live weight of heifers of this breed with age is directly related to an increase in positive correlations with the level of milk yield, the yield of milk fat and protein with the maximum values of coefficients at 18 months of age (r=0.288-0.295). According to the average daily weight gains, we pay attention to the obtained higher correlations with milk yield in the period of 3-6 (r=0.228) and 15-18 (r=0.239) months. During the six-month growth periods, the correlation variability of average daily weight gain with milk yield, milk fat, and protein was higher at 6-12 months of puberty (r=0.279; 0.274, and 0.272).

Table 7.

Correlative variability of the growth intensity of heifers and milk productivity of cows-the firstborn of the Ukrainian Red-and-White dairy breed (r±S.E.)

Correlated sign	*n*	Relationship with the sign of milk productivity milk		
		Milk yield	milk	
			fat	protein
Live weight in age, months				
0	1874	0,057±0,023[1]	0,044±0,021[1]	0,042±0,025
3	1125	0,192±0,030[3]	0,198±0,028[3]	0,191±0,029[2]
6	955	0,149±0,032[3]	0,133±0,031[3]	0,139±0,031[3]
9	921	0,142±0,033[3]	0,144±0,033[3]	0,146±0,029[3]
12	1019	0,202±0,031[3]	0,192±0,028[3]	0,189±0,031[3]
15	916	0,240±0,032[3]	0,233±0,033[3]	0,235±0,030[3]
18	900	0,295±0,032[3]	0,288±0,034[3]	0,291±0,033[3]
Average daily increase in live weight by age, months				
0-3	1122	0,066±0,030[1]	0,054±0,033	0,069±0,027[1]
3-6	736	0,228±0,036[3]	0,209±0,034[2]	0,214±0,032[3]
6-9	611	0,152±0,035[3]	0,148±0,031[3]	0,146±0,035[3]
9-12	690	0,170±0,038[3]	0,155±0,033[3]	0,149±0,034[3]
12-15	748	0,217±0,036[3]	0,197±0,032[3]	0,186±0,033[3]
15-18	738	0,239±0,036[3]	0,212±0,034[3]	0,196±0,031[3]
0-6	952	0,237±0,032[2]	0,214±0,031[2]	0,219±0,030[3]
6-12	685	0,279±0,038[3]	0,274±0,032[3]	0,272±0,032[3]
12-18	680	0,241±0,038[3]	0,233±0,034[3]	0,229±0,034[3]

Note. 1-p≤0.05; 2-p≤0.01; 3-p≤0.001

Discussion. The intensity of rearing repair heifers during ontogenesis has always aroused the increased interest of production practitioners and scientists, since the level of rearing depends on the indicators of reproductive capacity, productivity and longevity and, in general, the profitability of dairy cattle breeding (Bazeley K. J. et al., 2016; Bach A. and Ahedo J., 2008; Overton M. W. and Dhuyvetter K. C. 2020)). It is reported that the intensity of cultivation of repair heifers of the Ukrainian Black-and-White dairy breed in age periods provided an increase in milk productivity (Antonenko S. F., 2020; Admin, O. Y., et al., 2024; Polupan Yu. P. and Pryima S. V., 2024a), which is consistent with the

results of our studies, which established a positive statistically significant correlation variability between live weight gains of heifers of all experimental breeds with milk yield, milk fat and protein yield.

At the same time, in this aspect, scientific studies have established that the level of correlations between the live weight of heifers in the rearing process, taking into account the age period and milk yield, is characterized by significant variability, which existed in the range: -0.237...+0.111 (Shuliar A. L. et al., 2020), -0,011…+0,331 (Vedmedenko O. V., 2023), +0,059…+0,947 (Voitenko S. L. and Sydorenko O. V., 2020), -0,58…+0,89 (Radchenko N. P. et al., 2008), -0,017…+0,260 (Fedorovych V. V. et al., 2023). These highly variable indicators of correlation variability between live weight of heifers and milk yield are not consistent with the results of our studies, according to which, regardless of breed, a positive statistically significant correlation was obtained between these traits. The significant variability in the correlation levels given in the literature can only be explained by the complex interaction of biological, genetic and environmental factors.

Therefore, according to the results of our research, the growth rate of young animals can be an effective breeding indicator that allows improving the genetic potential of the herd in terms of milk productivity. Special attention should be paid to the process of raising heifers during active puberty, which falls at the age of 6 to 12 months.

Conclusions.

1. The level of rearing repair heifers in the herd of LLC "Kamyshevatsky dairy complex" for breeding Holstein, Ukrainian Black-and-White and Red-and-White dairy breeds is quite high, with the best results in Holstein cattle, which ensures the production of milk yields at the level of 8-10 thousand kg.

2. The revealed direct correlation variability between the live weight of heifers and the average daily increments with signs of milk productivity of first calving cow indicates the breeding feasibility of selecting repair heifers in terms of growth intensity indicators. Special attention should be paid to the conditions for raising heifers during active puberty at the age of 6 to 12 months.

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INFLUENCE OF GROWTH AND DEVELOPMENT INDICATORS OF HOLSTEIN HEIFERS ON THEIR PRODUCTIVITY AFTER THE FIRST CALVING

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The study analyzed the impact of growth and development parameters of Holstein heifers on their subsequent productivity after the first calving. The material was based on records of first-calf cows (n = 570) raised at STOV "Promin" (Mykolaiv region).

It was found that the live weight of heifers at birth had a statistically significant effect on the lactation duration (P = 0.047) and total milk yield per lactation (P = 0.002), whereas the relationship with the 305-day lactation yield was not significant (P = 0.162).

The analysis showed no statistically significant effect of the average daily gain of heifers from birth to 90 days of age on lactation duration (P = 0.161), total lactation yield (P = 0.700), or 305-day yield (P = 0.413).

The dependence of primiparous productivity indicators on live weight at 90 days of age also revealed no statistically significant influence on lactation duration (P = 0.826), total lactation yield (P = 0.487), or 305-day yield (P = 0.128).

According to the results, the average daily gain of heifers from birth to insemination had no significant effect on lactation duration (P = 0.306), total lactation yield (P = 0.907), or 305-day yield (P = 0.935).

The live weight of heifers at 250 days of age did not have a statistically significant effect on lactation duration (P = 0.141), total lactation yield (P = 0.220), or 305-day yield (P = 0.189).

The average daily gain of heifers from birth to insemination had no significant effect on the duration of the dry period (P = 0.167) or the calving interval (P = 0.868).

Similarly, the live weight of heifers at 250 days of age did not significantly affect the duration of the dry period (P = 0.278) or the calving interval (P = 0.374).

Keywords: primiparous, live weight, average daily gain, lactation duration, milk yield per lactation, dry period, calving interval.

ВПЛИВ ПОКАЗНИКІВ РОСТУ ТА РОЗВИТКУ ТЕЛИЦЬ ГОЛШТИНСЬКОЇ ПОРОДИ НА ЇХ ПРОДУКТИВНІСТЬ ПІСЛЯ ПЕРШОГО ОТЕЛЕННЯ

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У дослідженні проаналізовано вплив показників росту та розвитку телиць голштинської породи на їх подальшу продуктивність після першого отелення. Матеріалом слугували дані з обліку первісток (n = 570 гол.), вирощених у СТОВ «Промінь» (Миколаївська область).

Встановлено, що жива маса телиць при народженні статистично достовірно впливає на тривалість лактації (P = 0,047) та загальний надій молока за лактацію (P = 0,002), тоді як зв'язок із надоями за 305 днів лактації був недостовірним (P = 0,162).

Проведений аналіз не виявив статистично достовірного впливу середньодобового приросту первісток від народження до 90-денного віку на тривалість лактації (P = 0,161), загальний надій за лактацію (P = 0,700) та надій за 305 днів лактації (P = 0,413).

Аналіз залежності продуктивних показників первісток від їх живої маси у віці 90 днів не виявив статистично достовірного впливу цього чинника на тривалість лактації (P = 0,826), загальний надій за лактацію (P = 0,487) і надій за 305 днів лактації (P = 0,128).

За результатами аналізу, середньодобовий приріст телиць від народження до запліднення не мав достовірного впливу на тривалість лактації (P = 0,306), надій за повну лактацію (P = 0,907) та надій за 305 днів (P = 0,935).

Жива маса телиць у віці 250 днів не мала статистично достовірного впливу ні на тривалість лактації (P = 0,141), ні на надій за лактацію (P = 0,220), ні на надій за 305 днів (P = 0,189).

Середньодобовий приріст телиць від народження до запліднення не мав достовірного впливу на тривалість сухостійного (P = 0,167) та міжотельного (P = 0,868) періодів.

Жива маса телиць у віці 250 днів не мала достовірного впливу на тривалість сухостійного (P = 0,278) та міжотельного (P = 0,374) періодів.

Ключові слова: корови-первістки, жива маса, середньодобовий приріст, тривалість лактації, надій за лактацію, сухостійний період, міжотельний період.

Introduction. The success of creating a highly productive herd depends on many factors, including the level of rearing replacement stock (Abd-El Hamed, Kamel, 2021; Tschopp et al., 2021).

Calf growth traits, which are quantitative characteristics determining the profitability of cattle breeding, vary depending on genetic and environmental factors. In other words, growth traits depend on the genetics of the individual and are influenced by farm management practices (Atashi, Asaadi, 2019; Baschenko et al., 2020).

Understanding the relationships between calf birth traits and their future performance would contribute to the development of management strategies aimed at optimizing calf growth and enable the selection of replacement heifers based on measurements taken at early life stages, which are relatively easy to record (Martín et al., 2018; Admin et al., 2024; Genena, Ebrahim, 2023).

However, the intensification of rearing replacement young stock does not always guarantee higher cow productivity, since body weight gain of heifers at different ages influences it differently. Therefore, it is important to study the relationship between animal growth and their future performance to provide a scientific basis for the selection of replacement heifers (Atashi, 2021; Klimkovetskyi, Nosevych, 2020; Freetly et al., 2021). Replacement heifers represent the future of the herd, and their effective management is a crucial factor for the sustainable development of farms and the dairy industry as a whole (Aseged et al., 2023; Kusaka et al., 2022; Luhovyi, 2023).

Research on the relationship between the birth weight of heifer calves and their subsequent productivity is essential for determining the optimal birth weight (Chester-Jones et al., 2017; Lopez et al., 2020; Dymchuk, Ponko, 2022).

Easa et al. (2022) indicated that selection for high milk yield is associated with

genetic improvement in birth weight. Eldawy et al. (2021) concluded that birth weight can be used as an auxiliary trait for improving reproductive and productive characteristics in breeding and management programs.

Although calf birth weight is often considered a cause of difficult calvings, it may serve as an early-life indicator of lifetime productivity as well as a selection criterion for replacement heifers that are more likely to remain in the herd and provide optimal milk yield (Kamal et al., 2014; Easa et al., 2022; Rahbar et al., 2024). The birth weight of heifer calves may be associated with their lifetime productivity and reproductive performance (Lopez et al., 2018; Kochuk-Yashchenko et al., 2021; Tahir et al., 2023).

According to Klimkovetskyi and Nosevych (2020), low birth weight of heifer calves (<28 kg) is not a disadvantage if intensive rearing is ensured with alternating phases of accelerated and moderate growth, particularly at 3 and 9-12 months of age. Such a strategy promotes earlier calving and higher milk productivity, with live weight at 3 months being an important selection criterion.

In the studies by Kramarenko et al. (2022), a significant effect of body weight during 9-15 months of age (i.e., the post-pubertal period) was observed on total milk yield in primiparous cows. A significant influence of body weight during 3-6 months of age (i.e., the pre-pubertal period) was also detected on milk yield and milk fat output in primiparous cows.

Costa et al. (2021) reported that heifers with higher birth weight exhibited superior reproductive performance and milk production compared to lighter animals.

López et al. (2018) demonstrated that an increase in body weight in Holstein heifers is associated with a reduction in age at first calving.

Other studies have reported a positive correlation between lifetime milk yield and body weight in Holstein cows (Van De Stroet et al., 2016; Handcock et al., 2019).

New Zealand researchers highlighted the potential to enhance milk productivity in primiparous cows during the first lactation by increasing heifer body weight, as well as the advantages of balanced feeding for lighter animals to achieve greater body weight prior to calving (Handcock et al., 2019; Handcock R. et al., 2020; Martín et al., 2018).

Over the past decades, substantial improvements in management, nutrition, veterinary care, and genetic selection have led to a remarkable increase in dairy cow productivity (Martens, 2023; Öztürk et al., 2021).

However, only a limited number of studies have investigated the influence of growth and developmental traits in Holstein heifers on their subsequent performance after first calving. Therefore, the aim of the present study was to determine the relationship between growth and developmental parameters of Holstein heifers and their productivity.

Materials and methods of research. The study analyzed primary records of growth and development of first-parity Holstein heifers (n = 570) maintained at the STOV "Promin" farm in the Mykolaiv region. Average daily gain (ADG) was calculated as the difference between body weights at the first and last weighing. Body weight at 250 days of age was estimated using linear interpolation between the closest weight measurements taken before and after this age.

For statistical analysis, the dependent variables included performance traits of first-parity heifers: lactation length, total milk yield per lactation, 305-day standardized milk yield, dry period length, and calving interval.

The arithmetic mean and standard error of the Mean ($\overline{X} \pm S_{\overline{X}}$) were calculated for each quantitative indicator.

To test the hypothesis of no effect of individual factors on the dependent variables, a one-way analysis of variance (ANOVA) was performed following R. Fisher's methodology, using fixed factors. F-values were calculated to determine the significance

(P) of differences.

Data processing was conducted according to the methodological recommendations outlined by Kramarenko et al. (2019), using the PAST software package (Hammer et al., 2001).

Research results. The results of variability in milk production traits of primiparous heifers depending on their birth weight are presented in Table 1.

Table 1.

Variability of milk productivity indicators of primiparous heifers depending on their live weight at birth

Birth weight, kg	Lactation length		Total milk yield per lactation		305 days milk yield	
	n	$\overline{X} \pm Sx$**, days**	***n***	$\overline{X} \pm Sx$**, kg**	***n***	$\overline{X} \pm Sx$**, kg**
25-28	11	343,6±18,11	11	10826,5±619,19	11	9636,3±366,02
29-32	62	326,7±5,75	61	10813,9±263,07	61	10051,6±127,59
33-36	185	316,9±2,67	182	9994,7±115,71	182	9656,9±86,38
37-40	168	328,7±3,53	166	10590,8±140,01	166	9835,3±84,50
41-44	83	326,0±4,68	76	10551,6±195,60	76	9929,6±128,80
45-48	46	333,9±6,82	45	10724,7±289,07	45	9767,1±157,69
>49	12	335,9±14,89	10	11523,6±799,67	10	10254,1±344,19
	F = (6; 560) = 2,15, *P* = 0,047		*F* = (6; 544) = 3,51, *P* = 0,002		*F* = (6; 544) = 1,54, *P* = 0,162	

Note: n – number of animals; X±Sx – estimate of the arithmetic mean and its errors; F – estimate of the Fischer criterion; P – significance level.

A statistically significant effect of birth weight on lactation length was established (P = 0.047). The highest mean value was recorded in the group of cows with a birth weight above 49 kg – 335.9 ± 14.89 days, while the lowest was observed in primiparous cows with a birth weight of 33-36 kg – 316.9 ± 2.67 days. At the same time, cows born with a birth weight of 25-28 kg had the longest lactation among the main sample – 343.6 ± 18.11 days; however, the number of animals in this group was the smallest (n = 11), which reduces the reliability of this result.

The effect of birth weight on first-lactation milk yield was statistically significant (P = 0.002). The highest total milk yield was observed in the group of heifers with a birth weight above 49 kg – 11,523.6 ± 799.67 kg, exceeding the yield of all other groups. Among the weight groups, relatively high yields were also recorded for animals with birth weights of 25-28 kg (10,826.5 ± 619.19 kg), 29-32 kg (10,813.9 ± 263.07 kg), and 45-48 kg (10,724.7 ± 289.07 kg). The lowest total milk yield was recorded for heifers with a birth weight of 33-36 kg – 9,994.7 ± 115.71 kg.

When analyzing the effect of birth weight on 305-day standardized milk yield, no statistically significant influence was found (P = 0.162). Nevertheless, the highest mean 305-day yield was observed in the group of heifers with a birth weight above 49 kg – 10,254.1 ± 344.19 kg. Groups with birth weights of 29-32 kg and 41-44 kg also showed relatively high yields – 10,051.6 ± 127.59 kg and 9,929.6 ± 128.80 kg, respectively. The

lowest 305-day yield was recorded in heifers with a birth weight of 25–28 kg – 9,636.3 ± 366.02 kg.

The results indicate that birth weight of first-calf heifers has a significant effect on lactation length and total milk yield per lactation. The highest productivity parameters were observed in animals with a birth weight exceeding 49 kg; however, the number of animals in this group was the lowest (n = 10-12), which requires cautious interpretation. The most consistent results across all parameters were recorded in heifers with birth weights of 29-32 kg and 45-48 kg, which may be considered the optimal range for future milk performance.

The study also analyzed the effect of average daily weight gain of heifers during the first 90 days of life on their subsequent milk productivity (Table 2).

Table 2.

Variability of milk production parameters in primiparous heifers depending on their average daily weight gain from birth to 90 days

Average daily gain from birth to 90 days, g	Lactation length		Total milk yield per lactation		305 days milk yield	
	n	$\overline{X} \pm Sx$, **days**	***n***	$\overline{X} \pm Sx$, **kg**	***n***	$\overline{X} \pm Sx$, **kg**
500-600	13	343,8±17,69	12	10586,2±703,10	12	9379,5±430,72
601-700	49	326,5±5,89	45	10243,4±271,36	45	9655,2±186,12
701-800	102	333,1±4,99	100	10698,9±195,81	100	9836,5±111,80
801-900	214	324,0±2,86	210	10384,1±123,01	210	9760,7±73,99
901-1000	154	320,5±3,19	151	10422,8±137,94	151	9914,1±88,66
1001-1100	35	324,7±6,10	33	10565,2±295,41	33	9959,4±198,86
	F = (5; 561) = 1,59, P = 0,161		F = (5; 545) = 0,6, P = 0,700		F = (5; 545) = 1,00, P = 0,413	

The longest average lactation length was observed in heifers with an average daily gain (ADG) from birth to 90 days of 500-600 g/day – 343.8 ± 17.69 days, whereas the shortest lactation (320.5 ± 3.19 days) occurred in animals with an ADG of 901-1000 g/day. Overall, however, the variation in lactation length was minimal, and analysis of variance did not reveal a significant effect of ADG on this trait (P = 0.161).

The highest total lactation yield was recorded in heifers with an ADG of 701-800 g/day (10,698.9 ± 195.81 kg), and the lowest in those with an ADG of 601-700 g/day (10,243.4 ± 271.36 kg). Nevertheless, the difference between groups was not statistically significant (P = 0.700), indicating no systematic effect of early growth intensity on total lactation yield.

The highest average 305-day milk yield was observed in heifers with an ADG of 1001-1100 g/day – 9,959.4 ± 198.86 kg, while the lowest was in the group with an ADG of 500-600 g/day (9,379.5 ± 430.72 kg). However, in this case as well, the effect was not statistically significant (P = 0.413).

The analysis of the obtained data showed that the average daily gain (ADG) of heifers from birth to 90 days did not have a statistically significant effect on lactation length (P = 0.161), total lactation yield (P = 0.700), or 305-day milk yield (P = 0.413).

Despite some differences in mean values between groups, a clear relationship between early body weight gain and future milk performance could not be established. This indicates that while early growth is important for sexual maturity and reproduction, its impact on subsequent lactation performance requires further clarification or a more comprehensive analysis taking into account additional factors such as genetics, housing conditions, and adult feeding.

The analysis of the effect of heifers' body weight at 90 days of age on lactation length and milk performance is presented in Table 3.

Table 3.

Variability of milk productivity indicators of primiparous heifers depending on their live weight at the age of 90 days

Body weight at 90 days, kg	Lactation length		Total milk yield per lactation		305 days milk yield	
	n	$\overline{X} \pm Sx$, **days**	***n***	$\overline{X} \pm Sx$, **kg**	***n***	$\overline{X} \pm Sx$, **kg**
80-90	17	327,5±12,82	16	10221,2±428,52	16	9508,2±299,08
91-100	44	324,8±7,50	42	9978,2±313,25	42	9460,5±183,18
101-110	129	330,2±4,05	127	10601,4±166,89	127	9800,8±100,24
111-120	228	323,4±2,75	221	10497,6±123,49	221	9900,9±77,07
121-130	128	324,5±3,72	125	10475,5±152,05	125	9861,0±91,60
131-140	24	326,5±7,30	23	10242,6±292,00	23	9530,2±160,43
	F = (5; 564) = 0,43, P = 0,826		F = (5; 548) = 0,89, P = 0,487		F = (5; 548) = 1,72, P = 0,128	

The lactation length of the experimental heifers ranged from 323.4 ± 2.75 to 330.2 ± 4.05 days. The highest value was observed in heifers with a body weight of 101-110 kg at 90 days, whereas the shortest lactation was recorded in animals weighing 111-120 kg. However, according to the results of the analysis of variance, body weight at 90 days had no statistically significant effect on lactation length (P = 0.826).

The highest average milk yield for the entire lactation was recorded in cows with a 90-day body weight of 101-110 kg (10,601.4 ± 166.89 kg), while the lowest was in animals weighing 91-100 kg (9,978.2 ± 313.25 kg). Despite these variations, body weight at 90 days did not have a statistically significant effect on total lactation yield (P = 0.487).

Similarly, 305-day milk yield varied from 9,460.5 ± 183.18 kg (91-100 kg) to 9,900.9 ± 77.07 kg (111-120 kg), with higher values observed in heifers weighing 111-130 kg at 90 days. However, the effect of body weight on this parameter was not statistically significant (P = 0.128).

Thus, body weight of first-parity cows at 90 days of age had no significant influence on lactation length (P = 0.826), total lactation yield (P = 0.487), or 305-day milk yield (P = 0.128). Although certain groups, particularly heifers weighing 101-110 kg, showed higher average milk productivity, the differences were not statistically significant. This indicates relative stability of milk performance regardless of 90-day body weight, provided that subsequent rearing and feeding are adequate.

Within the study, the effect of average daily gain (ADG) of heifers from birth until the time of first insemination on lactation length, total lactation yield, and 305-day milk

yield was analyzed (Table 4).

The lactation length ranged from 314.3 ± 7.23 days (group with an average daily gain of 700-799 g/day) to 335.4 ± 7.79 days (group with a gain of 800-899 g/day). Overall, although the mean values varied slightly, the analysis of variance showed no statistically significant effect of first-calf heifers' average daily gain from birth to conception on lactation length (P = 0.306).

Table 4.

Variability of primiparous heifers milk production parameters depending on their average daily gain from birth to conception

Average daily gain of primiparous heifers from birth to conception, g	Lactation length		Total milk yield per lactation		305 days milk yield	
	n	$\overline{X} \pm Sx$, **days**	***n***	$\overline{X} \pm Sx$, **kg**	***n***	$\overline{X} \pm Sx$, **kg**
700-799	11	314,3±7,23	11	10163,5±450,29	11	9841,8±304,36
800-899	60	335,4±7,79	59	10618,4±267,68	59	9671,0±151,53
900-999	138	329,5±4,08	135	10506,3±157,94	135	9733,2±94,31
1000-1099	224	325,3±2,91	216	10464,6±134,09	216	9815,3±76,98
1100-1199	111	319,0±3,34	108	10287,6±143,13	108	9855,7±110,19
1200-1299	29	329,0±6,61	28	10474,2±261,89	28	9808,4±234,68
>1300	5	322,8±23,48	5	9960,1±799,92	5	9488,3±764,62
	F = (6; 571) = 1,20, *P* = 0,306		*F* = (6; 555) = 0,35, *P* = 0,907		*F* = (6; 555) = 0,30, *P* = 0,935	

The highest total lactation yield was observed in heifers with an average daily gain of 800-899 g/day – 10,618.4 ± 267.68 kg, and the lowest was in the group with gains above 1,300 g/day – 9,960.1 ± 799.92 kg. However, these differences were not statistically significant (P = 0.907), indicating a weak or absent relationship between pre-conception growth and milk production performance.

Yield for the standard 305-day period varied from 9,488.3 ± 764.62 kg in heifers with gains above 1,300 g/day to 9,855.7 ± 110.19 kg in the group with 1,100-1,199 g/day. Similarly, these differences were not statistically significant (P = 0.935).

These results indicate that the average daily gain of first-calf heifers from birth to conception does not have a significant effect on any milk production indicators: neither on lactation length (P = 0.306), total lactation yield (P = 0.907), nor 305-day yield (P = 0.935). Despite minor fluctuations in mean values among groups, these differences are not statistically meaningful, suggesting that with proper feeding and management after conception, early body weight gains have a limited influence on lactation performance.

The effect of heifers' body weight at 250 days of age on lactation length and milk

production is presented in Table 5.

Table 5.

Variability of milk production parameters of primiparous heifers depending on their body weight at 250 days of age

Body weight of primiparous at 250 days, kg	Lactation length		Total milk yield per lactation		305 days milk yield	
	n	$\overline{X} \pm Sx$, **days**	***n***	$\overline{X} \pm Sx$, **kg**	***n***	$\overline{X} \pm Sx$, **kg**
225-249	44	332,0±7,45	44	10365,8±322,28	44	9510,2±192,25
250-274	80	328,0±5,28	80	10771,3±214,61	80	10020,3±120,26
275-299	210	322,6±2,68	202	10251,1±118,79	202	9706,1±76,22
300-324	133	317,2±3,05	127	10180,2±140,08	127	9823,8±101,43
325-349	29	320,2±6,60	28	10356,0±295,31	28	9851,0±219,44
>350	5	348,4±20,04	5	10878,2±523,67	5	9612,4±598,44
	F = (5; 495) = 1,67, P = 0,141		F = (5; 480) = 1,41, P = 0,220		F = (5; 480) = 1,50, P = 0,189	

The longest lactation duration was observed in first-calf heifers with a body weight over 350 kg at 250 days of age (348.4 ± 20.04 days), while the shortest was recorded in the group with a body weight of 300–324 kg (317.2 ± 3.05 days). In the groups of heifers weighing 225-274 kg, the lactation duration was slightly higher than in those with average body weight. However, revealed no statistically significant differences between groups (P = 0.141), indicating a weak influence of body weight at 250 days on this parameter.

The highest total lactation yield (10,878.2 ± 523.67 kg) was recorded in heifers with body weight over 350 kg at 250 days, whereas the lowest values were observed in groups weighing 275-299 kg (10,251.1 ± 118.79 kg) and 300-324 kg (10,180.2 ± 140.08 kg). Despite some differences in mean values, the effect of body weight at 250 days on total milk yield was not statistically significant (P = 0.220).

A similar pattern was observed for the 305-day milk yield: the highest yields were in heifers weighing 250-274 kg (10,020.3 ± 120.26 kg) and 325-349 kg (9,851.0 ± 219.44 kg), while the lowest were in the groups with the lowest (9,510.2 ± 192.25 kg) and highest (9,612.4 ± 598.44 kg) body weights. Variance analysis showed no statistically significant effect (P = 0.189).

Thus, body weight of first-calf heifers at 250 days had no significant influence on lactation duration (P = 0.141), total milk yield (P = 0.220), or 305-day yield (P = 0.189). Despite fluctuations in mean values across groups, these differences were not statistically significant, suggesting that with proper feeding and management in later growth stages, the impact of body weight at 250 days on subsequent milk production is limited.

Within the study, the relationship between the length of the dry period and calving interval in first-calf heifers and their average daily gain from birth to conception was also analyzed (Table 6).

The duration of the dry period in cows ranged from 53.4 ± 3.31 to 58.4 ± 0.61 days. The shortest dry period was observed in cows with the highest growth rates (>1300 g/day), while the longest was in animals with gains of 800-899 g/day. However,

according to the results of the analysis of variance, the average daily gain of first-calf heifers from birth to conception did not have a statistically significant effect on the duration of the dry period (P = 0.167).

Table 6.

Variability of dry period and calving interval in primiparous depending on their average daily gain

Average daily gain of primiparous from birth to conception, g	Dry period		Calving interval	
	n	$\overline{X} \pm Sx$**, days**	***n***	$\overline{X} \pm Sx$**, days**
700-799	11	57,3±1,75	11	371,5±6,86
800-899	59	58,4±0,61	54	380,7±5,70
900-999	138	57,0±0,76	127	376,8±3,47
1000-1099	224	56,2±0,40	208	374,3±2,45
1100-1199	111	55,9±0,56	107	372,6±3,19
1200-1299	29	55,5±0,91	26	378,8±6,27
>1300	5	53,4±3,31	5	376,2±25,09
	F = (6; 570) = 1,53, P = 0,167		F = (6; 531) = 0,416, P = 0,868	

Analysis of the calving interval also showed no significant effect of growth intensity. The interval varied from 371.5 ± 6.86 days (group with 700-799 g/day gain) to 380.7 ± 5.70 days (group with 800-899 g/day gain), with no statistically significant differences between groups (P = 0.868).

Thus, the average daily gain of heifers from birth to conception has no significant effect on either the dry period or the calving interval. This indicates that growth rates in young cows, despite their important role in reducing age at first conception and calving, do not affect the duration of physiological stages between lactations under proper feeding and management conditions.

The study also analyzed how the live weight of Holstein first-calf heifers at 250 days of age influences the duration of physiologically important stages – the dry period and the calving interval (Table 7).

The longest dry period was observed in first-calf heifers with a live weight of 225-249 kg at 250 days of age – 58.3 ± 0.81 days, while the shortest occurred in animals weighing over 350 kg – 54.2 ± 3.09 days. In most groups (275-349 kg), the dry period remained relatively stable at approximately 56 days. However, according to the analysis of variance, the live weight of heifers at 250 days did not have a statistically significant effect on the duration of the dry period (P = 0.278).

The calving interval varied from 370.1 ± 2.69 days (in the group of heifers weighing 300-324 kg at 250 days) to 392.8 ± 22.77 days (in the group with live weight >350 kg). Although some variation in mean values was observed, particularly in the extreme groups, no statistically significant relationship was found (P = 0.374).

Thus, the live weight of first-calf heifers at 250 days of age does not have a significant effect on either the duration of the dry period or the calving interval. This indicates that these reproductive indicators are relatively independent of early-life body weight under proper management. Despite minor fluctuations in mean values, the differences were not statistically significant, suggesting that these periods remain stable under optimal technological management.

Table 7.

Variability of indicators of the duration of dry period and calving interval in primiparous heifers, depending on their live weight at the age of 250 days

Body weight of primiparous at 250 days, kg	Dry period		Calving interval	
	n	$\overline{X} \pm Sx$**, days**	***n***	$\overline{X} \pm Sx$**, days**
225-249	44	58,3±0,81	39	378,7±6,48
250-274	80	57,3±1,21	76	379,6±5,11
275-299	210	56,1±0,37	201	374,4±2,33
300-324	133	56,1±0,50	128	370,1±2,69
325-349	29	56,0±1,12	27	371,7±6,30
>350	5	54,2±3,09	4	392,8±22,77
	F = (5; 495) = 1,27, P = 0,278		F = (5; 469) = 1,07, P = 0,374	

Discussion. Increased birth weight in heifers is associated with improved performance indicators, such as higher milk yield and increased calf birth weight, but it is also accompanied by a higher risk of dystocia and a longer calving interval. No significant associations have been found with milk fat and protein content or body condition score (Atashi Hadi, 2021).

According to Luhovyi S. (2023), both birth weight and weight at 18 months are significant factors for future milk productivity. Higher birth weight was associated with greater milk fat content, while weight at 18 months correlated with increased milk yield and total milk fat. An optimal weight of at least 350 kg at 18 months was recommended to ensure high productivity.

Early-life body weight has a strong impact on the age at first calving and subsequent lactation performance (Atashi, 2021; Freetly et al., 2021). Achieving a weight above 127 kg at 3 months of age reduces the age at first calving by 2.7-3.5 months. The highest milk yields were observed in heifers with a 3-month weight of 117-127 kg and average daily gains of 902-1037 g/day, as well as in animals born with the lowest birth weight (<28 kg), highlighting the importance of early postnatal growth for developing a high-producing herd (Klimkovetskyi, Nosevych, 2020).

Hoka et al. (2019) reported that calves with higher birth weights (31-39 kg) achieved significantly greater milk yields (P<0.001) compared to lighter calves. Similarly, Hamed and ElMoghazy (2015) confirmed a significant effect of birth weight ranging from 25 to >55 kg on 305-day milk yield (305MY).

In contrast, Van Eetvelde et al. (2017) indicated that heifer birth weight was not associated with first-lactation milk productivity. Birth weight was linearly correlated with gestation length (GL) (Atashi, Asaadi, 2019); however, Hoka et al. (2019) reported only a minor influence of calf birth weight on gestation length.

The results of our study are consistent with other researchers who identified a positive relationship between heifer birth weight and subsequent productivity (Aseged et al., 2023; Kusaka et al., 2022; Luhovyi, 2023). Birth weight significantly affected lactation length and total milk yield, with the highest performance observed in heifers exceeding 49 kg at birth. The most stable results were found in animals weighing 29-32 kg and 45-48 kg, suggesting that optimizing growth within these categories can

enhance milk productivity.

Intensive rearing of heifers requires adherence to optimal growth rates. For Holstein heifers, an average daily gain of approximately 700 g is considered optimal, resulting in first-lactation milk yields of 8,300-8,500 kg. Both excessively low (<400 g) and excessively high (>800 g) gains before puberty were associated with a 10-40% reduction in milk productivity in primiparous cows (Klimkovetskyi, Nosevych, 2020), emphasizing the importance of monitoring growth rates to achieve high lactation performance.

The results of our study showed that the average daily gain (ADG) of heifers during the first 90 days of life did not have a statistically significant effect on milk production. However, there was a tendency for higher milk yields and longer lactation periods in animals with moderately high ADG (500-600 g and 701-1100 g), indicating a potential advantage of moderate early-life growth intensity.

Heifer body weight at 90 days of age also did not have a significant effect on milk productivity parameters. Nonetheless, there was a tendency for higher yields in animals weighing 101-120 kg, suggesting that maintaining this level of development may support better realization of productive potential.

Admin et al. (2024) confirmed that animals with the highest body weight gains had a significantly lower age at first insemination, the greatest body weight at first lactation, and higher milk productivity. At the same time, some reproductive challenges were observed in these animals, including a slightly extended service period.

The average daily gain (ADG) of heifers from birth to insemination did not have a statistically significant effect on milk production. However, a tendency toward decreased productivity was observed at excessively low or high gains, emphasizing the importance of maintaining an optimal growth rate for effective realization of genetic potential.

Heifer body weight at 250 days of age also did not have a significant effect on milk productivity, although there was a tendency for higher yields in animals weighing 250-274 kg. This suggests that maintaining an optimal growth rate without overfeeding may support efficient expression of productive potential.

In our study, the ADG of heifers until insemination had no significant effect on the length of the dry period or the calving interval, indicating that intensive rearing does not negatively affect the restoration of reproductive function after the first calving.

Body weight at 250 days did not show a statistically significant effect on the duration of the dry period or calving interval. Despite a slight increase in the mean calving interval in the group weighing over 350 kg, the small number of animals (n = 4-5) reduces the reliability of this observation. Thus, increased body weight at this age does not substantially affect the restoration of reproductive function after the first calving.

Conclusions.

1. The study revealed that the birth weight of primiparous heifers has a statistically significant effect on lactation duration (P = 0.047) and total milk yield over the entire lactation period (P = 0.002), while its effect on 305-day milk yield was not statistically significant (P = 0.162). The most stable productive performance was observed in heifers with birth weights of 29-32 kg and 45-48 kg, indicating the advisability of rearing replacement heifers within these weight categories to enhance dairy herd productivity.

2. Analysis showed no statistically significant effect of average daily gain from birth to 90 days of age on lactation duration (P = 0.161), total lactation milk yield (P = 0.700), or 305-day milk yield (P = 0.413). However, a tendency for higher productivity was observed in heifers with moderately high early growth rates, suggesting potential benefits of moderate growth intensity for developing a productive herd.

3. Body weight at 90 days of age did not have a statistically significant effect on lactation duration (P = 0.826), total lactation yield (P = 0.487), or 305-day milk yield (P = 0.128). Nevertheless, there was a tendency for higher milk productivity in heifers weighing 101–120 kg, indicating that maintaining this growth level may be important for the effective expression of genetic potential.

4. Average daily gain from birth to insemination did not have a statistically significant effect on lactation duration (P = 0.306), total lactation yield (P = 0.907), or 305-day milk yield (P = 0.935). At the same time, a tendency for reduced productivity was noted in heifers with either very low (<800 g) or excessively high (>1300 g) growth rates, emphasizing the importance of maintaining a moderate, controlled growth rate in replacement heifers for optimal expression of their productive potential.

5. The analysis of the obtained results showed that the body weight of primiparous heifers at 250 days of age did not have a statistically significant effect on lactation duration (P = 0.141), total lactation yield (P = 0.220), or 305-day milk yield (P = 0.189). Nevertheless, targeting a body weight range of 250-274 kg at this age appears reasonable for ensuring optimal productivity. Excessively high body weight does not confer additional benefits and may indicate a risk of overconditioning, which can negatively affect subsequent performance.

6. Average daily gain from birth to insemination did not statistically affect the duration of the dry period (P = 0.167) or the calving interval (P = 0.868). This suggests that intensified growth during the rearing period up to insemination did not negatively impact the recovery of reproductive function after the first calving.

7. Body weight of primiparous cows at 250 days of age also did not have a statistically significant effect on the duration of the dry period (P = 0.278) or the calving interval (P = 0.374). Therefore, increased body weight at this stage of development does not substantially influence the restoration of reproductive function after the first calving.

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ENERGY EFFICIENCY OF PRODUCTION OF CATTLE BREEDING PRODUCTS OF MEDIUM-CAPACITY ENTERPRISES WITHIN THE SIMULATION MODEL PARAMETER SYSTEM

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The results of monitoring the production and organizational indicators of more than 20 farms are presented with the definition of the main elements that characterize them. The relationship between the degree of technical support or technological equipment of the production process of milk production (quantitative composition of tractors, trucks, machinery, aggregates, milking equipment) and the annual productivity of cows is analyzed. Correlation coefficients indicate its moderate value (0.3<Rxy,<0.5). A simulation model of the production of cattle breeding products in the conditions of enterprises of medium production capacity has been created.

Technological elements that are characteristic of the rational process of production of products – milk, beef, live weight of animals in rearing and fattening-are substantiated. Within the technical parameters of enterprises with a number of cattle of 1000-1100 heads (350-450 cows with a capacity of 7000-9000 kg per cow), the annual total energy costs for the production of cattle products are determined.

The structure of the energy content of products by type is calculated, namely milk, live weight of culled animals, growth of reared animals, received offspring. The energy content of excrement and bedding is also taken into account. It is established that the largest share in the structure of the energy content of products suitable for nutrition belongs to the energy content of produced milk – 78.9–86.1 %, and since it is the most influential factor on the coefficients of energy efficiency of the main and general products, the functional dependences of the energy content of products on fat in milk and the relationship between the coefficients of energy content of products and milk fat are determined.

Keywords: energy consumption, energy efficiency, technology parameters, productivity, product quality.

ЕНЕРГОЕФЕКТИВНІСТЬ ВИРОБНИЦТВА ПРОДУКЦІЇ СКОТАРСТВА ПІДПРИЄМСТВ СЕРЕДНЬОЇ ПОТУЖНОСТІ В МЕЖАХ СИСТЕМИ ПАРАМЕТРІВ ІМІТАЦІЙНОЇ МОДЕЛІ

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Наведено результати моніторингу виробничо-організаційних показників понад 20 господарств з визначенням головних елементів, якими вони характеризуються. Проаналізовано зв'язок ступеня технічного забезпечення або технологічного оснащення виробничого процесу одержання молока (кількісний склад тракторів, вантажівок, техніки, агрегатів, доїльного обладнання) і річної продуктивності корів. Коефіцієнти кореляції свідчать про його помірну величину (0,3<Rxy,<0,5). Створено імітаційну модель виробництва продукції скотарства в умовах підприємств середньої виробничої потужності.

Обґрунтовані технологічні елементи, що характерні раціональному процесу виробництва продукції – молока, яловичини, живої маси тварин на вирощуванні та відгодівлі. У межах технічних параметрів підприємств з чисельністю поголів'я великої рогатої худоби 1000-1100 голів, (350-450 корів із продуктивністю 7000-9000 кг на корову) визначені річні загальні затрати сукупної енергії на виробництво продукції скотарства.

Обчислена структура енерговмісту продукції за видами – молоко, жива маса вибракуваних тварин, приріст тварин, що вирощуються, отриманий приплод. Враховані також енерговміст екскрементів і підстилки. Встановлено, що найбільша частка в структурі енерговмісту продукції, придатної для харчування належить енерговмісту виробленого молока – 78,9–86,1 %, і оскільки воно є найбільш впливовим чинником на коефіцієнти енергетичної ефективності основної і загальної продукції визначені функціональні залежності енерговмісту продукції від жиру в молоці та взаємозв'язок коефіцієнтів енерговмісту продукції і жиру молока.

Ключові слова: енерговитрати, енергетична ефективність, параметри технології, продуктивність, якість продукції.

Management in the conditions of rational use of resource potential is the key to the success of production and directly contributes to the development of the livestock industry. In today's conditions, the creation and maintenance of such a production structure is a complex, but relevant at any time task, since existing farms mostly do not sufficiently meet the requirements of the market environment – they are moderately competitive in terms of technical equipment, technological processes in production, and not always high-quality products (Gadzalo et al., 2016; Baschenko et al., 2017; Vedmedenko & Kovalenko, 2020). An increase in the load of production processes on the environment increasingly causes its reverse reaction in the form of deterioration of soil fertility, changes in climatic conditions, which in turn affects the energy efficiency of cattle production (Rudenko et al., 2008; Rudenko et al., 2017; Marchenko et al., 2020; Marchenko et al., 2023; Busenko, 2005 ; Kostenko & Kravchenko, 2019).

At the present stage of development of the cattle breeding industry, an essential point is to ensure optimal production indicators (live weight of young animals, average daily increments, gross production, etc.), in the conditions of break – even production-that is, its corresponding cost and sales price (Rudenko et al., 2008; Pankeev, 2022; Pidpala, 2008; Ruban Y. & Ruban S., 2011).

Previous studies of milk production technologies for medium-sized enterprises (with a population of 400 cows) allowed to develop their organizational, production and economic parameters in conditions of fixed high productivity (8000 kg of milk per cow per year) (Marchenko et al., 2020; Getmanets, 2012). Prior to this, consumption standards were defined separately and patterns of their changes were established under conditions of different cow productivity (from 4,000 to 9,000 kg of milk per year) (Getmanets, 2012; Baranovsky et al., 2017). At the same time, changes in climate and other global conditions indicate that the efficiency of existing technological solutions is suboptimal in terms of energy efficiency of production, including taking into account the quality of raw materials or finished products (Rudenko et al., 2008; Marchenko et al., 2019; Marchenko et al., 2023; Ibatullin et al., 2016 ; Kostenko & Kravchenko, 2019).

It should be noted that among 1,533 enterprises, 129 (8.4% of the total number) are those that keep from 1,000 to 1,499 heads of cattle and whose share in the total structure of the cattle population is 16.6 %. Currently, among the total number of 1,400 enterprises, 614 (42.7% are enterprises with 100-499 cows), the same share is 40.0%, that is, they are a significant sector both in terms of livestock and milk production (Tvarinnitstvo, 2023). At the same time, the technologies used by such enterprises for the most part do not always meet the requirements of modernity, and the quality of milk or raw materials needs to be improved to a level that ensures high competitiveness (Kostenko et al., 2010; Kostenko, 2018).

Within the specified parameters of pilot projects or their feasibility studies, it is impossible without establishing and taking into account the Basic Laws of energy efficiency formation of technological processes of production to create in practice in each specific case an energy-efficient, scientifically justified, innovatively attractive technology for the production of products of the required quality (Rudenko et al., 2008; Getmanets, 2012; DBN00037, 1995; Ibatullin et al., 2016; Bogdanov et al., 2012). The conducted research is aimed at establishing exactly such regularities in the formation of energy efficiency of technological processes for the production of high-quality livestock products in the context of climate change. They take into account the directions of savings by types of resources (including labor and material) and, as a result, have an overall positive result.

Directions for further improvement or principles of building basic technological processes in the production of cattle breeding products for medium-sized enterprises are determined using modeling and margin analysis methods. The regularities of the use of energy resources are aimed at improving or more rational their use by Type (human, material, land), respectively, taking into account the dependence of changes in product quality (Merkurieva, 1980 ; Petrenko & Syrotyuk, 2021).

The object of the study was selected agricultural enterprises for the production of milk of medium capacity with a number of cows up to 500 heads.

The purpose of the research is to find out the regularities of the formation of an energy – efficient system of parameters and standards of technological and technical solutions for the production of cattle products when creating enterprises of medium production capacity.

Materials and methods of research. According to various methods (economic-statistical, economic-mathematical, expedition surveys, modeling, etc.) using the

methodology of bioenergy assessment of production technologies (Kulik et al., 1997), as well as official reports, monitoring, analysis and generalization of the components of the production process in the conditions of tethered and loose methods of keeping cattle were carried out.

Research results. Monitoring and generalization of technological and technical solutions of enterprises of medium production capacity allowed to use technological passports of production of dairy cattle products of a number of farms-SE " DG "Agronomy" is Naas of Ukraine", SE "DG" Artemida" IC Naas of Ukraine", SE "DG Institute of Agriculture of the north-east of the NA-an", SE" DG" Gontareva "it Naas of Ukraine", SE" DG "elite" of the Mironovsky wheat institute named after V. M. Crafts of Naas", Dpdg "elite" of Kirovohrad DSGDS of Naas, Dpdg "Alexandrovskoe" SPC "soy of Naas, Dpdg "Pasechnaya", SE DG "Hristinovskoe" Irgt named after M. V. Zubets, Dpdg Shevchenko" Ibkitsb of Naas, Dpdg "Ivanovka" ISGPS of Naas, SE "DG named after January 9" of the Institute of pig breeding and APV of the Naas of Ukraine", SE "DG im. Decembrists", state enterprise "experimental base "Dachnaya". The distribution of cows according to the systems of keeping is established – free (boxed, deep bedding) – 22 %, on a leash – 78 %. Productivity - at the level of 6470 kg and 4480 kg, respectively (the advantage of the loose maintenance system is 1.4 times). Various milking technologies were analyzed – in stalls (milking buckets) – 27 %, in stalls (milk pipeline) – 51 %, in the milking parlor-22% with milk productivity of cows up to 4000 kg, up to 6000 kg and up to 7000 kg of milk per cow, respectively. The use of additional technical means for the preparation and distribution of feed makes it possible to use the feed mixture feeding system. The distribution of cows by feeding Technologies was 70 % (separate ration by Feed type), and 30 % (for the use of feed mixtures). It is established that under such conditions there is an increase in the milk productivity of cows by more than 2100 kg per head. A limiting factor in the growth of cow productivity is also the problem with reproduction with any technology, as indicated by the significant variability in the yield of calves per 100 cows-from 51% to 97 %.

The influence of the intensity of animal rearing with the achievement of a certain fatness on the energy consumption of production is studied. Data on the average daily growth of calves under various technologies of their maintenance were obtained and analyzed. So, from birth to 2 months of age, subject to the following distribution of animal maintenance technology: 29%-on a leash, 25% – in Group machines and 46% – in individual machines, respectively, productivity levels – 476 g, 409 g and 542 g of average daily growth. Fatness is average for all cases. At an older age, the productivity of young animals was 452 G on a leash, with loose content – an increase of 12.6 % (509 g). Therefore, for a pilot project, it is more appropriate to choose the technology of loose content. On the basis of statistical data for Ukraine of the last two years, the relationship between the degree of technical support or technological equipment of the production process of milk production (quantitative composition of tractors, trucks, machinery, aggregates, milking equipment) and the annual productivity of cows is analyzed. Correlation coefficients indicate its moderate value ($0.3<Rxy,<0.5$).

Thus, the generalization of data of agricultural milk producers, including information on the state enterprise DG network of the National Academy of Sciences of Kharkiv and other regions of Ukraine, allowed to substantiate the system of parameters and standards of technological and technical solutions in the creation of enterprises of medium production capacity, which showed the best results in terms of milk productivity in conditions of different technologies of maintenance, milking systems, cow feeding, intensity of young growth (Marchenko, 2020; Tvarinnitstvo, 2023).

It should be noted that since the strength of the influence of the studied

technological factors (conditions) on the overall productivity of cows and young animals is complex and complex, therefore, in the first approximation to the system of parameters and standards of technological and technical solutions for the simulation model, such, from our point of view, the most acceptable option is chosen, namely, the technology of uniform production of marketable products (milk, beef, breeding cattle). For modeling, the average annual number of cows in the range of 350-450 heads with an annual productivity of 7000-9000 kg of milk per head was taken.

The calculated volumes of feed supply, livestock and their productivity make it possible to obtain an annual shaft of milk of 2300-3800 tons. Taking into account its drinking to calves, the size of milk sales will be 2160-3570 tons (marketability of 94 %). Meat from culled and fattened cattle – 190-198 tons, in live weight, including 70-90 heifers.

Herd structure – cows-30.4 – 33.8 %; heifers-5.8 – 6.0 %; heifers older than one year-13.8 – 14.8 %; heifers up to one year-18.4 – 20.6%; bitches older than one year – 9.8%, bitches up to one year-18.4%. Rejection and replacement of the main herd – 20-22 % (actual cultivation of repair heifers), full turnover of the herd. The method of keeping livestock is loose, using straw bedding. It provides for the cultivation and fattening of bitches on the farm to a live weight of 430-450 kg (900 g of average daily growth). The age of the first insemination of heifers with a live weight of 1 head is 380-400 kg at 15-16 months. The average daily growth of heifers up to a year is at the level of 760 g, older than a year – 800 g. the care of young animals is 4-6 %.

Feed supply of cattle herds is based on a system of the same type of feeding with feed mixtures. The yield of grain and fodder crops per 1 ha of sowing: cereals on average – 35-72 C, winter wheat – 38-60 C, barley – 32-46 C, corn for grain – 56-90 C, peas – 19-26 C, corn for silage – 270-290 C, perennial grasses for hay – 45-55 C and for haylage and green fodder – 270-290 C. Initial data for determining energy costs for the production of dairy cattle products - costs for a cow with a plume: labor – 60-65 people.- H;, the average annual Head of young animals – 18.0 people.- H., electricity-680-720 kWh. Energy equivalents of other resources-according to certain or known reference values (Rudenko et al., 2008; Kulik, 1997).

To ensure the required levels of productivity, annual feed harvesting and consumption rates and their structure for cows and repair heifers have been developed, depending on their productivity (Rudenko et al., 2008). These standards are based on the norms of the need for nutrients and feeding of animals, taking into account their sex and age composition and physiological state, live weight and productivity, seasons of the year (winter and summer), requirements for the quality of milk, the need for feed to maintain life and products, biological and technological losses of feed during harvesting, storage, delivery and feeding, energy consumption for growing grain and feed crops and Feed Production, their prime cost, etc. According to the standard, to obtain milk yields of 7000-9000 kg of milk, it is necessary to prepare 78-95 centners of feed units (89-110 GJ of exchange energy) per cow per year. At the same time, the type of feeding of cows and young cattle is formed in the direction of increasing the consumption of Grain Group feed in animal diets (50-54%), and their use is only as compound feeds, which are full – fledged in composition, provide a given productivity and meet the needs of the physiological state of cows and other sex and age groups of young animals. In the composition of mixed feeds by weight, grain accounts for no more than 80% and 20% are additives. Of the total amount of grain for the production of mixed feeds, 30% of the nutritional value is occupied by corn, barley and wheat and 10% by peas, and in additives at least 50% is occupied by high - protein components (meal, cake, etc.). Feeding of all types of feed, including mixed feed as part of complete feed mixtures. The size of the

feed fund is determined in accordance with the standard of accounting for the insurance reserve – for concentrates – 8-10%, juicy and coarse feed – up to 15 %.

The total nutritional requirement for a dairy farm of 350 cows, depending on their productivity (7000-9000 kg), is respectively 4910-5870 tons of feed units, of which it is necessary to prepare in kind: mixed feed – 1608-2082 tons, silage – 4407-4919 tons, hay of perennial grasses – 949-1138 tons, hay of annual grasses – 433-569 tons, haylage of perennial grasses – 1924-1700 tons and green fodder – 2384-2539 tons.

For a dairy farm for 450 cows (depending on their productivity of 7000-9000 kg), the total nutritional requirement is 6309-7550 tons of feed units, of which it is necessary to prepare in kind: mixed feed – 2067-2677 tons, silage – 5666-6324 tons, hay of perennial grasses – 1216-1463 tons, hay of annual grasses – 557-732 tons, haylage of perennial grasses – 1527-2186 tons and green fodder – 3065-3264 tons.

Variants of calculations within the parameters of productivity (7000-9000 kg per cow) with the total number of cattle herds of 1000-1100 heads (350-450 cows) showed that the density of the average annual livestock on its own feed base per 100 hectares of farmland is respectively – cattle – 92-82 heads, including cows – 29-26 heads.

The annual total cost of total energy for production (milk, growth, Live weight) is determined.

According to the structure within the standard size of 350 cows, the total total energy costs are as follows: 9.3–7.6 % – for herd reproduction, 1.8–1.5 % – from fixed assets of production, 3.5–3.0 % – from working capital without feed and bedding. The total energy of direct and indirect labor costs is 2.0 – 1.7 %, the total energy converted in feed and litter is 83.4–86.1 %. It was found that for 350 cows with a plume with an increase in productivity from 7000 kg/head to 9000 kg/head. (by 28.6 %) total total energy costs for production increase by only 16.3 % – from 155,152 GJ to 180,346 GJ (or from 443 GJ to 515 GJ per cow).

According to the structure within the standard size of 400 cows, the total total energy costs are as follows: 9.3–7.6 % – for herd reproduction, 1.6–1.4 % – from fixed assets of production, 3.5–3.0 % – from working capital without feed and bedding. The total energy of direct and indirect labor costs is 1.8 – 1.5 %, the total energy converted in feed and litter is 83.8–86.5 %. For 400 cows with a plume with an increase in productivity in the same range (28.6%), total and specific energy costs for production increase by 16.3% from 176568 GJ to 205350 GJ (or from 441 GJ to 513 GJ per cow).

According to the structure within the standard size of 450 cows, the total total energy costs are as follows: 9.4–7.6 % – for herd reproduction, 1.6–1.4 % – from fixed assets of production, 3.5–3.0 % – from working capital without feed and bedding. The total energy of direct and indirect labor costs is 1.8 – 1.5 %, the total energy converted in feed and litter is 83.7–86.5 %. For 450 cows with a plume with an increase in productivity by the same 28.6%, the total total energy expenditure for production increases by 16.4% from 197986 GJ to 230373 GJ (or from 440 GJ to 512 GJ per cow).

Thus, if we compare the total energy costs in absolute values and within any one level of productivity of either 7000 kg, 8000 kg or 9000 kg, then they increase linearly by 42834 GJ; 46282 GJ and 50027 GJ per 100 additional cows within the limits of productivity increase-from 7000 kg to 9000 kg of milk, respectively. At the same time, per 1 cow, the cost of total energy practically does not depend on their productivity. Thus, they decrease by 0.7 % for 7000 kg and 8000 kg of milk yield and amount to 443 and 478 GJ (350 cows), respectively; 441 and 476 GJ (400 cows) and 440 and 474 GJ (450 cows). At 9,000 kg, a 0.6% reduction is 515 GJ (350 cows) versus 512 GJ (450 cows). Consequently, increasing the capacity of the enterprise by increasing the number of cows requires additional costs of total energy, depending on their productivity level of 7000

kg; 8000 kg; 9000 kg at the level of 428.3 GJ/head; 462.8 GJ/head and 500.3 GJ/head, respectively. There is no significant difference in the structure of energy costs.

So, the use of the energy efficiency assessment of production (milk, growth, Live weight) according to the indicator of annual total energy costs allowed us to determine that increasing the productivity of cows requires additional energy costs in the amount of 16.3–16.4% to the "conditionally initial base level", regardless of the standard size and per 1 kg of added milk corresponds to 0.036 GJ of total energy.

Using the developed algorithm of the MS Excel Office program within the system of parameters of the simulation model, a margin analysis by types of energy consumption was carried out and the dependences of changes in energy efficiency of production were modeled, taking into account the energy content of milk and its primary qualitative characteristic – fat (Merkurieva, 1980).

It is established that the energy content of products produced within reasonable technological parameters and directly suitable for consumption with an increase in productivity from 7000 kg to 9000 kg (28.6 %) increases from 8929 GJ to 11088 GJ. (24.2 %) for 350 cows and from 11,480 GJ to 14,256 GJ (24.2%) for 450 cows. The largest share in the structure of energy content of products suitable for food, namely, the energy content of produced milk occupies – 84.2 % (350 cows) and 87.2 % (450 cows), respectively, which is the determining factor of both the coefficient of energy efficiency of products suitable for food and the total product.

The structure of the energy content of products by type for the capacity variant of 7000 kg; 8000 kg and 9000 kg of milk per cow per year is shown in Table 1.

Table 1.

Structure of energy content of products by type, %

Energy content, GJ:	**cow productivity, kg / year**		
	7000	**8000**	**9000**
obtained milk (with a fat content of 3.8 %)	84.2	85.9	87.2
live weight of culled animals	10.0	9.0	8.2
offspring received for the year	0.9	0.8	0.7
weight gain of reared animals	4.9	4.3	3.9
products suitable for food	100	100	100

For productivity from 7000 kg to 9000 kg per cow per year with an interval of growth of fat content in milk by 0.1% from 3.8% to 4.2%, it was determined that the coefficient of energy efficiency of products suitable for nutrition slightly improves from 5.45-6.42 % (350 cows) with an increase in the number of cows to 5.49–6.46 % (450 cows). The energy efficiency coefficient of total products increases from 25.6% -26.8% to 25.8–27.0% in accordance with the standard size and productivity level of cows. Patterns of changes reflect graphical dependencies in figures 1-6.

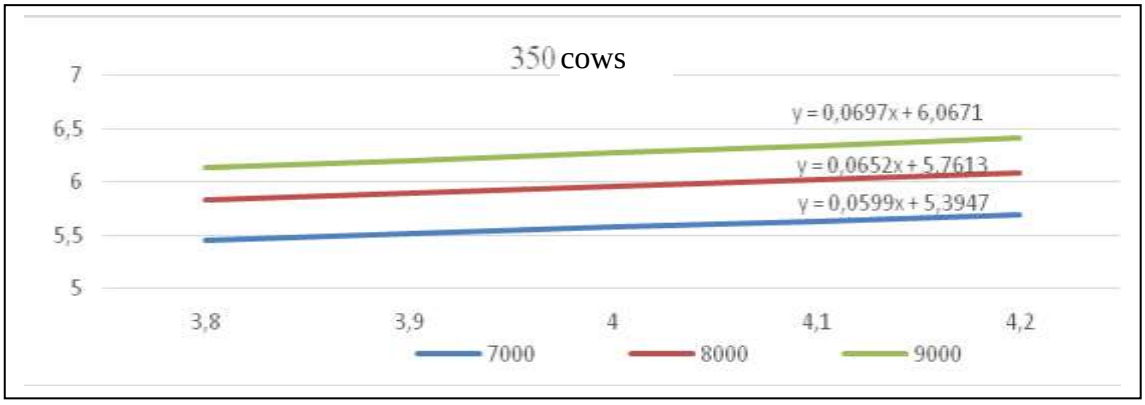

Fig. 1. **Dependence of the energy efficiency coefficient of products suitable for nutrition on the fat content in milk and productivity of cows.**

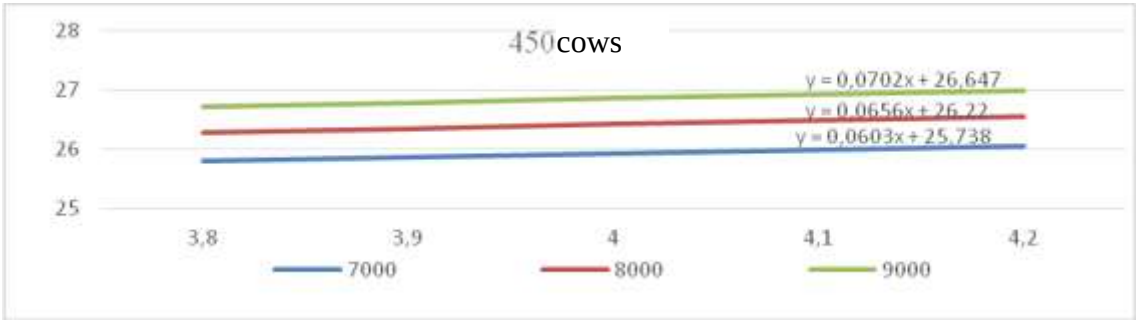

Fig. 2. **Dependence of the energy efficiency coefficient of products suitable for nutrition on the fat content in milk and productivity of cows.**

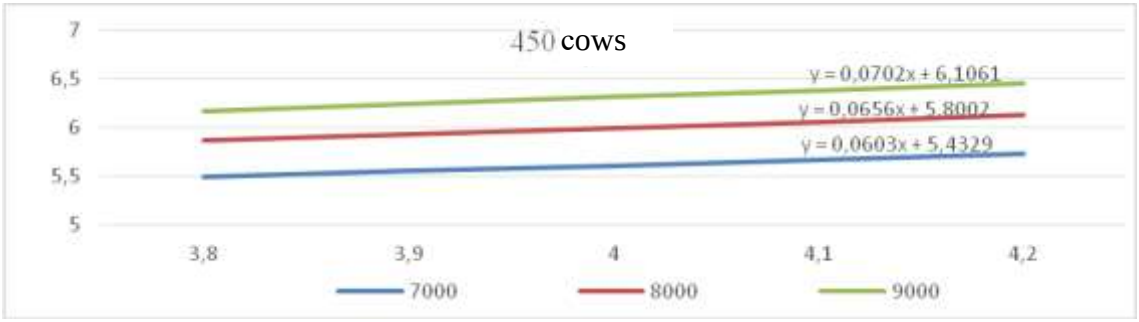

Fig. 3. **dependence of the energy efficiency coefficient of products suitable for nutrition on the fat content in milk and productivity of cows.**

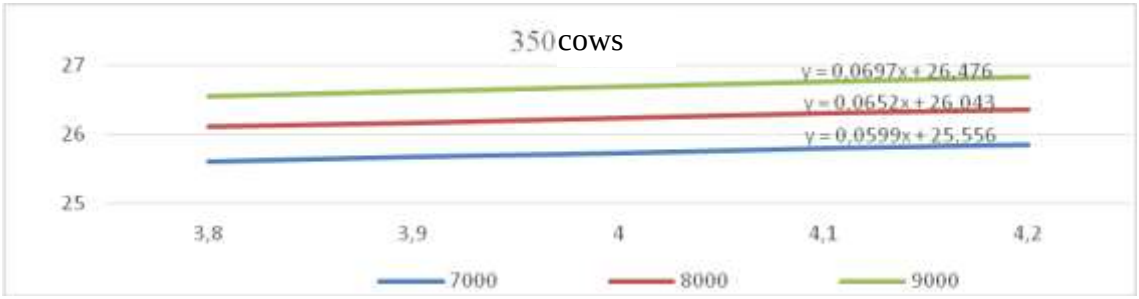

Fig. 4. **Dependence of the energy efficiency coefficient of total production on the fat content in milk and cow productivity.**

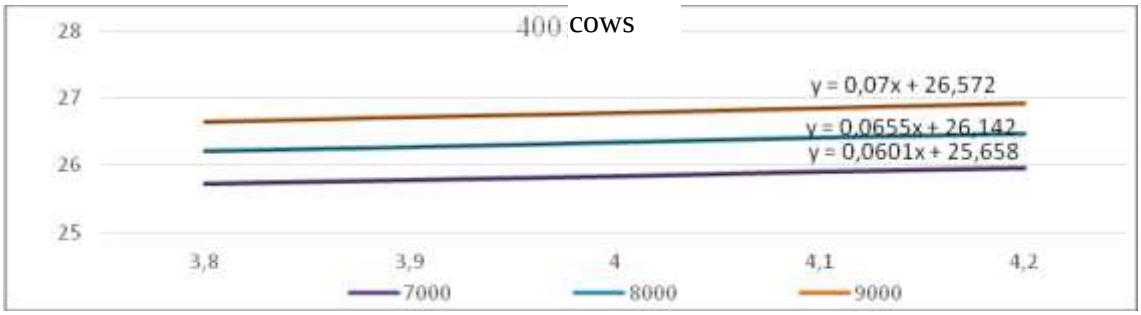

Fig. 5. **Dependence of the energy efficiency coefficient of total production on the fat content in milk and cow productivity.**

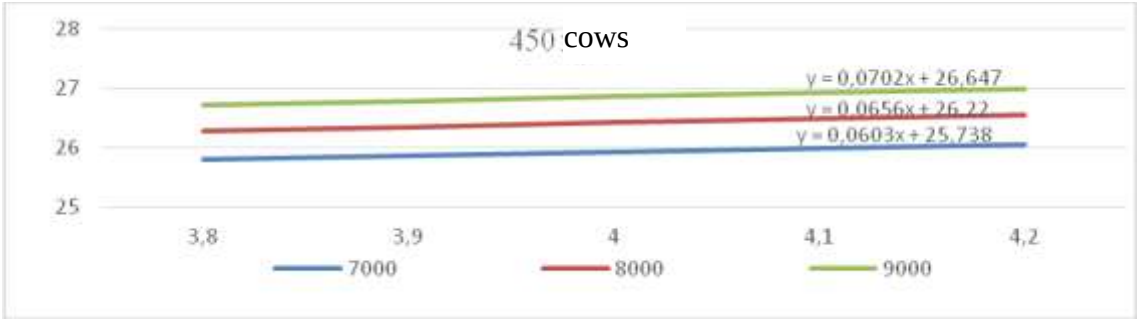

Fig. 6. **Dependence of the energy efficiency coefficient of total production on the fat content in milk and cow productivity.**

Under the same conditions, namely, for productivity from 7000 kg to 9000 kg per cow per year with an interval of growth of fat content in milk by 0.1% from 3.8% to 4.2%, regularities of changes in the energy content of products suitable for nutrition and the energy content of all products, taking into account the combined one, are established. The patterns of changes reflect the graphical dependencies in figures 7-12.

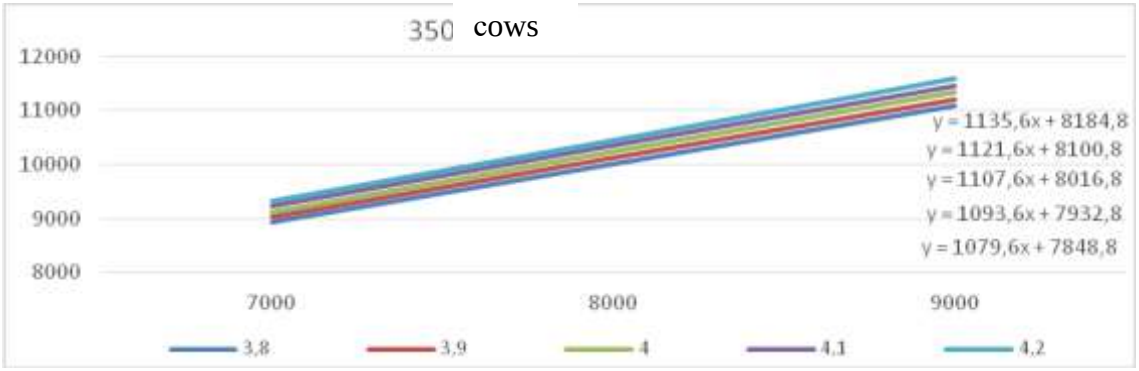

Fig. 7. **Dependence of the energy content of products suitable for nutrition on the fat content in milk and productivity of cows.**

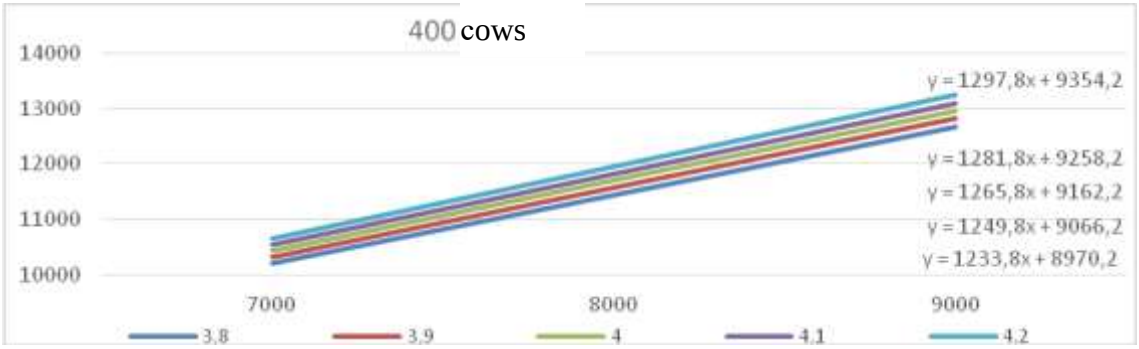

Fig. 8. **Dependence of the energy content of products suitable for nutrition on the fat content in milk and productivity of cows**.

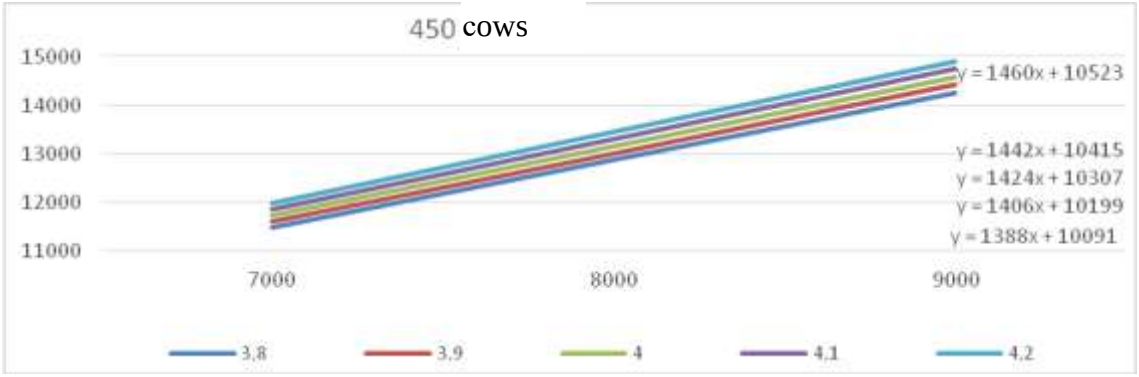

Fig. 9. **dependence of the energy content of products suitable for nutrition on the fat content in milk and productivity of cows.**

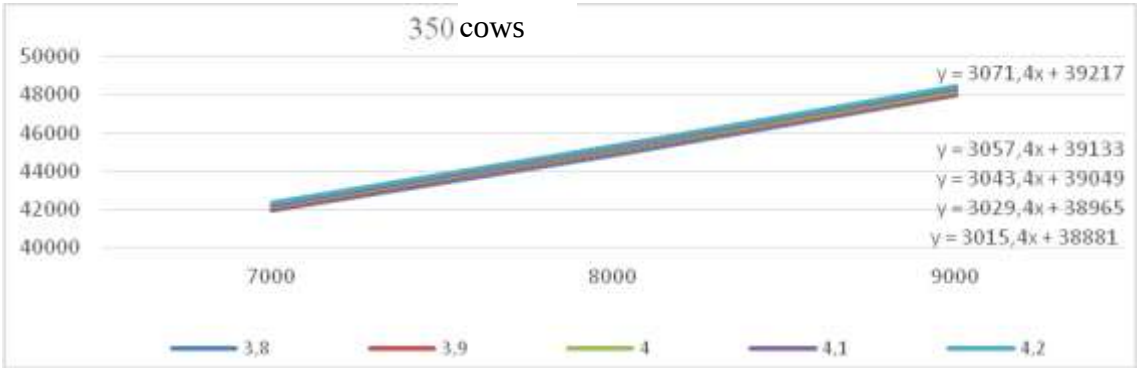

Fig. 10. **dependence of the energy content of all products, taking into account conjugated products, on the fat content in milk and cow productivity.**

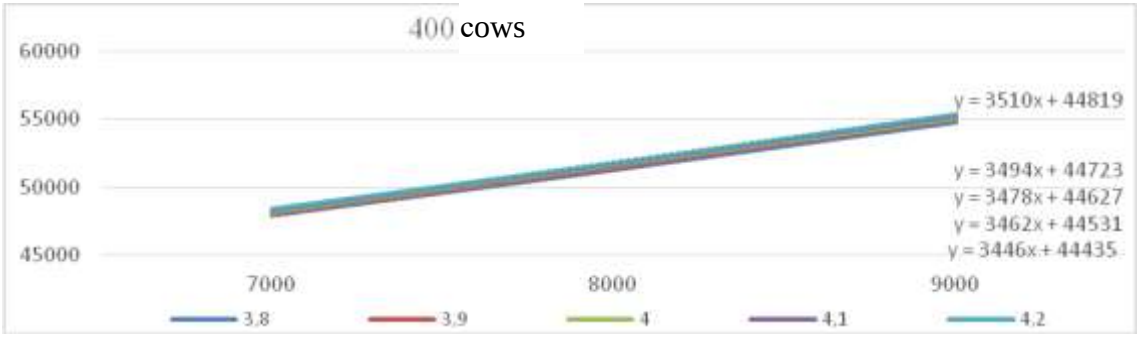

Fig. 11. **Dependence of the energy content of all products, taking into account conjugated products, on the fat content in milk and cow productivity.**

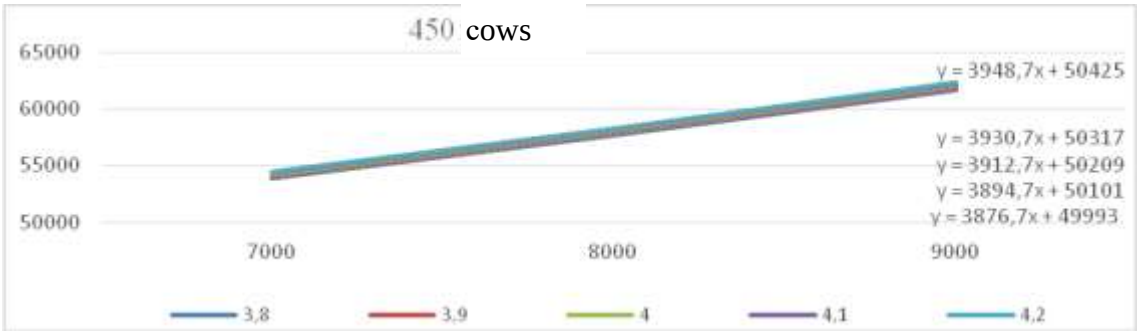

Fig. 12. **Dependence of the energy content of all products, taking into account conjugated products, on the fat content in milk and cow productivity.**

The established linear dependencies prove the general axiom that regardless of the fat content in milk, with an increase in productivity, there is an increase in both the energy content of products suitable for nutrition and the energy content of all products. At the same time, both an increase in the number of cows and their productivity affects the growth of absolute indicators. The result of productivity growth for every 1000 kg is an increase in this energy content by 1079-1135 GJ (350 cows with a plume), 1234-1298 GJ (400 cows), 1388-1460 GJ (450 cows) or by 5.2% in accordance with the quality of milk in terms of fat content. For the energy content indicator of all products, the corresponding increase is by 2914-2970 GJ; 3331-3395 GJ; 3747-3819 GJ or by 1.9 %. Based on 1 cow with a plume, the dependencies are shown in Table 2.

Table 2.

Energy content of products suitable for nutrition, and energy content of all products in accordance with the fat content in milk.

Fat content of milk (X), %	Energy content of products suitable for nutrition (Y), GJ per 1 cow with a plume	Energy content of all products including conjugated (Y), GJ per 1 cow with a plume
3,8	y = 3,0846x + 22,425	y = 8,6153x + 111,09
3,9	y = 3,1246x + 22,665	y = 8,6553x + 111,33
4,0	y = 3,1646x + 22,905	y = 8,6953x + 111,57
4,1	y = 3,2046x + 23,145	y = 8,7353x + 111,81
4,2	y = 3,2446x + 23,385	y = 8,7753x + 112,05

In the conditions of increasing the productivity of cows from 7000 kg of milk to 9000 kg of milk, the coefficients of energy efficiency of products suitable for nutrition and total products, respectively, the quality characteristics of milk change in the direction of improvement in the following dependence (Table. 3 and Table. 4).

Table 3.

Relationship between the energy efficiency ratio of food-friendly products (Y),%, and milk fat (X), %

Milk fat content (X), %	number of cows, heads		
	350	400	450
3,8	y = 0,3412x + 5,1236	y = 0,3414x + 5,1454	y = 0,3415x + 5,1620
3,9	y = 0,3461x + 5,1787	y = 0,3463x + 5,2007	y = 0,3465x + 5,2175
4,0	y = 0,3511x + 5,2337	y = 0,3513x + 5,2560	y = 0,3514x + 5,2730
4,1	y = 0,3560x + 5,2888	y = 0,3562x + 5,3113	y = 0,3564x + 5,3284
4,2	y = 0,3609x + 5,3439	y = 0,3612x + 5,3666	y = 0,3613x + 5,3839

Table 4.

Relationship between the energy efficiency ratio of total production (Y),%, and milk fat (X), %

Milk fat content (X), %	number of cows, heads		
	350	400	450
3,8	y = 0,4650x + 25,160	y = 0,4619x + 25,265	y = 0,4593x + 25,348
3,9	y = 0,4699x + 25,215	y = 0,4669x + 25,321	y = 0,4643x + 25,404
4,0	y = 0,4749x + 25,270	y = 0,4718x + 25,376	y = 0,4692x + 25,459
4,1	y = 0,4798x + 25,325	y = 0,4767x + 25,431	y = 0,4742x + 25,515
4,2	y = 0,4847x + 25,380	y = 0,4817x + 25,487	y = 0,4791x + 25,570

Thus, it is proved that both increasing productivity and improving the quality of milk has a positive effect on the energy efficiency of production.

Discussion. According to many scientists, the effective use of the resource potential of cattle breeding enterprises is an urgent problem today, and therefore the materials of our research are aimed at deepening solutions to this complex problem

because they coincide with common challenges. In this context, it should be taken into account that ensuring the necessary production indicators in the conditions of break-even production from an economic point of view is aimed at achieving the corresponding cost of production in the conditions of actual sales prices. Since the price does not fully (indirectly) describe the characteristics of energy costs of resources, more adequate, in our opinion, is the application of energy assessment and calculation of resource requirements through natural indicators of parameters and standards of production technology.

Our analysis and numerous studies have confirmed the facts that existing technologies do not always meet the requirements of our time, and the quality of milk or raw materials needs to be improved to a level that ensures high competitiveness.

Monitoring and generalization of technological and technical solutions of enterprises of medium production capacity allowed us to analyze the systems of keeping animals, the relationship between the degree of technical support for the production process of milk production, establish inhibitory or contributing factors of influence and determine the initial parameters when creating a simulation model.

Within the specified parameters of the multi-factor simulation model of medium-capacity enterprises, calculations are made and regularities of energy efficiency formation are established, which are disclosed in the presented materials.

The substantiated dependencies and established regularities make it possible, taking into account the qualitative characteristics of products (milk fat), to form the main technological elements of the cattle production system within the parameters of medium-sized enterprises (350-450 cows with a plume). Modeling of production using equations of dependence of its energy content on qualitative characteristics makes it possible to objectively assess the energy components of individual technological processes in the production of products by types of resources. This is of wide practical importance, since the energy efficiency of technological solutions directly correlates with the efficiency of the livestock production process.

Conclusions:

1. Monitoring and analysis of technological and technical solutions of enterprises of medium production capacity, which showed the best results in milk productivity in the conditions of various technologies of maintenance, milking systems, feeding cows, the intensity of young growth allowed to justify the initial parameters and standards of technological and technical solutions. This, in the conditions of regulated product quality and the use of the developed algorithm for modeling the energy efficiency levels of its production, makes it possible to create feasibility studies for pilot projects of enterprises of this type.

2. A correlation analysis of statistical data for Ukraine over the past two years is carried out. The strength of the impact on the annual productivity of cows of the degree of technical support or technological equipment of the production process of milk production (quantitative composition of tractors, trucks, machinery, aggregates, milking equipment) is estimated. Correlation coefficients indicate a moderate association between traits (0.3<Rxy,<0.5).

3. It was found that the energy content of products directly suitable for consumption with an increase in productivity from 7000 kg to 9000 kg increases from 9532 GJ to 11683 GJ (by 22.6 %) for 350 cows and from 11670 GJ to 14436 GJ (by 23.7 %) for 450 cows. The largest share in the structure of energy content of products suitable for nutrition, namely, the energy content of produced milk occupies 78.9–82.8 % (350 cows) and 82.9–86.1 % (450 cows) in accordance with productivity, which is the determining factor of both the coefficient of energy efficiency of products suitable for

nutrition and total products.

4. Increasing the capacity of the enterprise by increasing the number of cows requires additional costs of total energy, depending on their productivity level of 7000 kg; 8000 kg; 9000 kg at the level of 428.3 GJ/head; 462.8 GJ/head and 500.3 GJ/head, respectively. There is no significant difference in the structure of energy costs.

5. Within the parameters of the enterprise of one standard size of average capacity per 1 cow, the total energy costs for 7000 kg and 8000 kg are 443 and 478 GJ (350 cows), respectively; 441 and 476 GJ (400 cows) and 440 and 474 GJ (450 cows), that is, they are slightly reduced if the number of cows changes from 350 to 450 heads – by 0.7% if the milk yield increases to 9000 kg – reduction costs increased by 0.6 % – 515 GJ (350 cows) against 512 GJ (450 cows).

6. Increasing the productivity of cows from 7000 kg to 9000 kg requires additional total energy costs in the amount of 16.3–16.4% to the base level, regardless of the standard size, which corresponds to 0.036 GJ of total energy per 1 kg of added milk.

7. It is established that the coefficient of energy efficiency of products suitable for nutrition under conditions of increasing productivity of cows from 7000 kg to 9000 kg within each standard size improves from 5.45% to 6.14 % (350 cows), from 5.49% to 6.18 % (450 cows), but practically does not increase when it changes. The coefficient of energy efficiency of total products, respectively, the standard size and productivity level of cows is at the level of 25.6% -26.6% and 25.8–26.7%, that is, it also maintains a similar trend.

8. Regularities of the influence of changes in the quality characteristics of products on the energy consumption of their production are established. Thus, within the productivity range from 7,000 kg to 9,000 kg of milk per cow per year, an increase in the fat content in milk by 0.1% improves the energy efficiency coefficients by 0.06-0.07 %.

9. A systematic approach based on which an algorithm for calculating the main elements of competitiveness of an enterprise of average production capacity is created in the MS Excel environment, combining a margin assessment of its activities by types of energy consumption within the established technical and production indicators depending on changes in the energy efficiency of beef and milk production and its primary qualitative characteristic-fat.

10. Within the parameters of the simulation model, the assessment of existing technologies, taking into account the costs of total energy for the production of products in accordance with its energy content, allows us to determine the energy component of each type of resource and, based on their availability, form the most efficient production process in terms of energy efficiency and make operational decisions on its practical improvement.

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PLANT POLLEN AND ITS ROLE IN THE ECOSYSTEM: HONEY BEE – HUMAN (Review)

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The article provides a comprehensive review of the biological significance of pollen as a vital resource for honeybees. Its role in feeding larvae, maintaining the physiological activity of worker bees and ensuring high egg laying of the uterus is revealed. The nutritional and biochemical value of pollen, its nutritional characteristics, and the dependence of its qualitative composition on botanical origin and environmental conditions are considered in detail.

For honeybees, pollen is of key importance - it is a source of proteins, fats, minerals and vitamins necessary for larval development, immune defense and adult life. However, due to agrochemistry, reduction of honey and pollen fields, as well as climate change, the availability of high-quality pollen decreases, which weakens bee colonies and reduces the yield of entomophilic crops.

Pollen-bearing plants perform not only a fodder, but also an ecological function, contributing to the maintenance of pollinators, restoration of flora and sustainability of agricultural systems. Climate change and urbanization threaten their diversity, so the priority should be to restore flower biotopes and create favorable conditions for pollinators. Organic farming and urban planning that takes into account the needs of bees are the way to sustainable development.

The article provides a comprehensive analysis of the historical use of pollen (from ancient civilizations to modern science), while simultaneously reflecting its economic, biological and ecological significance.

Current scientific directions of pollen research are outlined, in particular in the field of apitherapy, pharmacology, food safety, biomonitoring of the environment, as well as prospects for using pollen as a functional ingredient in the food industry. The impact of agricultural factors, pesticides, urbanization, and climate change on the pollen base is considered. The role of pollen as an indicator of the environment, paleobotanic resource and a key factor in the stabilization of agroecosystems through the support of pollinator populations is highlighted.

Special attention is paid to the need to preserve and develop natural and cultivated pollen-bearing lands as the basis for the stable functioning of bee colonies and the preservation of biodiversity. The paper highlights the interdisciplinary nature of pollen research and justifies the need for further systematic research in this area.

Keywords: bees, plants, nectar-bearing, pollen-bearing, pollen, bee bread, climate change, urbanization.

ПИЛОК РОСЛИН ТА ЙОГО РОЛЬ У ЕКОСИСТЕМІ: МЕДОНОСНА БДЖОЛА – ЛЮДИНА (Оглядова)

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У статті здійснено комплексний огляд біологічного значення пилку як життєво важливого ресурсу для медоносних бджіл. Розкрито його роль у живленні личинок, підтриманні фізіологічної активності робочих бджіл та забезпеченні високої яйцекладки матки. Детально розглянуто харчову та біохімічну цінність пилку, особливості його поживність, залежність якісного складу від ботанічного походження та екологічних умов.

Для медоносних бджіл пилок має ключове значення - це джерело білків, жирів, мінералів і вітамінів, необхідних для розвитку личинок, імунного захисту та життєдіяльності дорослих особин. Однак через агрохімізацію, зменшення посівних угідь медоносів і пилконосів, а також зміну клімату доступність якісного пилку знижується, що послаблює бджолині сім'ї й зменшує врожайність ентомофільних культур.

Пилконосні рослини виконують не лише кормову, а й екологічну функцію, сприяючи підтриманню запилювачів, відновленню флори та стійкості агросистем. Зміна клімату та урбанізація загрожують їхньому різноманіттю, тому пріоритетом має стати відновлення квіткових біотопів і створення сприятливих умов для запилювачів. Органічне землеробство й міське планування, яке враховує потреби бджіл, - шлях до сталого розвитку.

В статті здійснено комплексний аналіз історичного використання пилку (з давніх цивілізацій до сучасної науки), одночасно відображено його економічне, біологічне та екологічне значення.

Окреслено актуальні наукові напрями дослідження пилку, зокрема у галузі апітерапії, фармакології, харчової безпеки, біомоніторингу стану довкілля, а також перспективи використання пилку як функціонального інгредієнта в харчовій промисловості. Розглянуто вплив агрофакторів, пестицидів, урбанізації та зміни клімату на пилкову базу. Виділено роль пилку як індикатора довкілля, палеоботанічного ресурсу та ключового фактору стабілізації агроекосистем через підтримку популяцій запилювачів.

Особливу увагу приділено необхідності збереження та розвитку природних і культурних пилконосних угідь як основи стабільного функціонування бджолиних сімей та збереження біорізноманіття. Стаття підкреслює міждисциплінарний характер вивчення пилку та обґрунтовує потребу в подальших системних дослідженнях у цій сфері.

Ключові слова: бджоли, рослини, нектаронос, пилконос, пилок, перга, зміна клімату, урбанізація.

Modernity is marked by dynamic changes that occur regardless of our perception or readiness for them. In such conditions, it is important not only to learn how to respond quickly to challenges, but also to actively act ahead of time. This statement is also quite relevant for beekeeping. This industry is increasingly acquiring a complex production direction, when apiaries produce not only long – known honey and wax, but also other bee products-bee pollen, propolis, royal jelly, bee venom.

Bees and flowering plants have evolved together over millions of years, forming complex interaction mechanisms. This is a classic example of symbiosis: plants provide bees with pollen and nectar as sources of energy and nutrients, and bees, in turn, provide the pollination process, without which the fruiting of most crops is impossible. By collecting pollen, bees bring invaluable benefits to many types of flowering plants, since almost 90% of them cannot exist without pollinating insects, one of the first places among which belongs to bees. Looking for food (pollen and nectar), bees visit the flowers of plants and transfer the stuck pollen to the stigmas of the pistils of other plants, thus carrying out cross-pollination. Disruption of this relationship due to environmental or man-made factors has global negative consequences for food security.

Pollen is not only a means of plant reproduction, but also one of the most important feeds in natural ecosystems. For bees, it plays the role of "animal protein" in the plant world. It is used for feeding larvae, stored in the form of bee bread. Thanks to bees transferring pollen grains from one flower to another, cross-pollination is provided, which is key to maintaining plant genetic diversity and productivity.

Reducing the area of natural biotopes and the predominant use of agrochemicals significantly limit bees' access to high-quality pollen. This creates risks for the physiological state and productivity of honeybees, which directly affects the yield of entomophilic crops and further food security.

Current issues of our time are the study of how much pollen is critical for maintaining brood, immunity and vital activity of adults, and how insufficient nutrition or monotony of pollen negatively affects the strength of the family, reduces the life expectancy of nursing bees and the oviposition of the uterus. The unique biochemical composition and healing properties of pollen justify the need for deeper scientific research.

The aim of the study is to analyze the biological significance of pollen in the life of the Bee Family, determine its role as a key source of nutrients for larvae, worker bees and Queens, and outline promising areas for further scientific research on the use of pollen in beekeeping, nutrition and medicine.

Research materials and methods. The analysis of scientific literature was carried out in the form of a systematic review study by searching for publications in the databases Scopus, Web of Science, Google Scholar, etc. The review included works in English published in recent years in accordance with certain criteria. The systematization of available scientific data was carried out in order to generalize modern knowledge about bee pollen as a food product, medicine, component of animal feed and a factor of influence on product quality, which will serve as the basis for the formation of its own research methodology in this direction in Ukrainian conditions, taking into account international experience.

Research results. Bee pollen is one of the oldest natural products used. In different historical epochs and civilizations, people valued it for its nutritional and healing value. Modern science only confirms the unique properties of pollen, which were used by ancient peoples. The history of pollen use demonstrates that this natural product has not lost its value from ancient times to the present day. It has been used as a nutrient and medicinal product in many cultures, and today science only confirms the unique

properties intuitively discovered by our ancestors. Only the depth of knowledge has changed: from intuitive application to scientifically proven properties.

Egyptian written sources mention the use of pollen as a component of medicinal products. The pharaohs used mixtures of pollen, honey, and milk as an elixir of strength and youth. In traditional Chinese medicine, pollen was considered as a means to strengthen the energy of "Qi", improve digestion and vitality. It was included in many phytocomplexes.

Hippocrates and Pliny The Elder mentioned the medicinal properties of pollen, especially for anemia, general weakness, and as a tonic.

In the Middle Ages, in Europe, it was used as an ingredient in medicinal ointments and teas for diseases of the skin, respiratory tract and general exhaustion. Pollen was believed to help restore strength after wars, epidemics, and famines, although there was no scientific justification at the time.

In the 50s and 70s of the twentieth century, active clinical studies of pollen began in Europe and the first dietary supplements based on them appeared. In modern medicine, pollen is used to maintain immunity, in the treatment of colds, anemia, gastrointestinal diseases, stress and depression (Li, X. M. et al., 2025; Anjum, S. I. et al., 2024; Alcalá-Orozco, M. et al., 2024; Khalifa, S. A. M. et al., 2021).

Bee pollen has many beneficial properties based on its multi-purpose potential, which is a new trend in the treatment of many complex diseases such as cancer and neurodegeneration (Kacemi, R. et al., 2024).

This unique product is included in masks, creams and tonics due to its antioxidant properties. It is widely used as a functional ingredient in the food industry as part of bars, mixtures for athletes, dietary products (na'aim, N. et al., 2022; Tirla, A. et al., 2023). Bee pollen is a natural product of beekeeping with great potential for use in medicine, and more recently in animal husbandry. Based on scientific studies, it was found that adding bee pollen in the amount of 1-20 g/kg to the diet improves the productivity, reproductive and immune status of animals. In particular, it was found that feeding different doses of bee skin to broiler chickens helps to reduce feed consumption and improve its conversion, thereby increasing their productivity and positively affecting blood parameters (Farag, S. A. et al., 2016). Studying the effect of bee skin on the biochemical parameters of the blood of broiler chickens, we obtained data on a significant decrease in blood glucose, cholesterol and calcium, as well as lower levels of triglycerides, but higher levels of sodium chloride, phosphorus and globulins in broiler chickens compared to the control that improves fattening of chickens (Klaric, I. et al., 2018). The effective effect of feeding Bee legs on the rate of physiological development of rabbits and their productivity was also established (Attia, Y. A. et al., 2011)

Its use as a feed additive can also become a practical nutrition strategy in animal husbandry (Abdelnour S. A. et al., 2019). The inclusion of pollen in food products such as bakery, confectionery and meat products, juices, improves the nutritional and functional properties of the final products (Kostić, A. et al., 2020).

Pollen grain has a complex three-layer structure. EXIN (outer layer) - thick and resistant to chemical, physical and biological effects. Thanks to sporopolenin, exina can persist in the soil for thousands of years, which makes it possible to use pollen analysis in paleobotany. Intexin (inner layer) is a thin and elastic shell that ensures the germination of the pollen tube. Cytoplasm-contains the nucleus, vesicles, energy structures (mitochondria), protein granules, enzymes and vitamins.

Grain sizes vary from 10 to 100 microns, depending on the plant species. The shape changes from rounded to elongated or triangular (Garga, B. et al., 2024). Pollen color is determined by pigments, in particular flavonoids and carotenoids, and can range

from white to dark yellow, red, or even purple (Thakur, M. et al., 2020). The stickiness and stickiness of the surface make it easier for pollen to adhere to the pollinator body. The Botanical origin of pollen is crucial for understanding its textural properties, such as hardness, stickiness, density, firmness, elasticity, cohesion, and chewability (Thakur, M. et al., 2020).

In its composition, pollen contains proteins that make up an average of 20-35% of the mass. The amino acids lysine, methionine, valine, threonine, and phenylalanine in pollen grains are the most important for larval development. Arginine and histidine-play a role in the synthesis of enzymes and hormones (Sommano, S. R. et al., 2020; Bryś, M. S. et al., 2024; Jeannerod, L. et al., 2020; Kostryco, M. et al., 2021).

The fat fraction of pollen (up to 13%) includes oleic, linoleic, and palmitic fatty acids (Čeksterytė, V. et al., 2023; Liolios, V. et al., 2022; Mayda, N. et al., 2020). The sterols that make up pollen grains, especially beta-sitosterol, are essential for the development of cell membranes in insects, and phospholipids provide nutrient transport.

Pollen contains glucose, fructose, sucrose, as well as fiber and hemicellulose. These compounds provide basic energy and support fermentation when stored as bee bread. Pollen also contains vitamins and more than 25 macro - and microelements that help strengthen vision and immunity, support the nervous system and Metabolism, have an antioxidant effect, participate in enzymatic processes and tissue growth (Sudha, R. et al., 2022; Barbieri, D. et al., 2020; Liolios, V. et al., 2019).

The nutritional value of pollen depends on the type of Plant, time of year, soil and climatic conditions (Li, Q. Q.et al., 2018). For example: dandelion, phacelia – rich in protein; sunflower has a predominant lipid composition; buckwheat, Acacia have a high concentration of antioxidants. The combined collection of pollen from different crops allows bees to form a balanced diet.

The honey bee (Apis mellifera) is one of the most important entomophilic pollinators, which plays a key role in agroecosystems. For normal development, growth and maintenance of vital functions, the bee family needs two main sources of nutrients: nectar as a source of energy and pollen – a source of protein, fat, vitamins and minerals. Pollen is of particular importance in the nutrition of larvae and adult nurse bees that ensure the cultivation of brood (Kim, H. et al., 2024).

Pollen for bee larvae is the main and only natural source of protein in the first 3 days of their development, when there is an active formation of tissues and organs. It is during this period that the larvae of all bee castes especially need high-quality protein nutrition, which is provided by bee bread. The larva consumes food in an amount exceeding its own mass by almost 1000 times in 5-6 days (Bryś, M. S. et al., 2021; Kratz, M. et al., 2022; Filipiak, M. 2019). Proteins, amino acids, fats, vitamins and trace elements contained in pollen contribute to intensive cell division, body weight growth and the formation of the immune system of the future bee. Pollen deficiency or poor quality during this critical period can negatively affect the usefulness of larval development, reduce the viability and productivity of adults in the future (Pang, C. et al., 2022; Austin, A. J. et al., 2021; Braglia, C. et al., 2025).

Pollen for Queen Bees is a critical component of nutrition needed to maintain a high level of egg laying. The uterus does not directly consume pollen, but it is the main source of protein for young nurse bees, which produce Royal Jelly-the only food for the uterus during its life. High-quality pollen with a sufficient content of amino acids, vitamins and minerals ensures the active functioning of the hypopharyngeal glands in nursing bees, which determines the intensity of feeding the uterus (Lan, J. et al., 2021; Corby-Harris, V. et al., 2018; Kratz, M. et al., 2024). As a result, the uterus is able to lay between 1,000 and 2,000 eggs daily (Clair, A. L. St. et al., 2022). Insufficient or poor-

quality pollen resource leads to a decrease in royal jelly synthesis, which can lead to a decrease in egg laying, weakening of the family and deterioration of its regenerative ability.

For worker bees, pollen is the main source of protein that determines their physiological development, functional activity, and life expectancy (Lajad, R. et al., 2025). On average, one bee consumes 3 to 4 grams of pollen during its lifetime. Its quality – in particular, the content of essential amino acids – directly affects the strength and viability of the family. protein starvation or monotonous pollen leads to inhibition of gland development, decreased immunity, shortening the life span of worker bees and deterioration of the ability to perform key functions in the hive.

In older bees performing field work, pollen performs a restorative and energetic function, supporting muscle activity, antioxidant protection, and overall endurance. During the period of intensive collection of nectar and pollen, it is especially important to provide a diverse and high-quality pollen base.

Flower pollen collected by a honey bee and glued together by the secretions of its salivary glands into multi-colored granules 1-3 mm in size is called bee pollen. It got its name due to the method of transporting pollen by the Bee to the hive. For the convenience of carrying pollen grains, the Bee "Combs" pollen directly on the flower or directly in flight with special foot brushes and folds it in the form of small lumps to "baskets" on the back pair of legs, while gluing individual pollen grains together with the secret of its salivary glands, enriching it with enzymes of its glands for the first time.

Pollen from flowering plants is an essential source of nutrients for honeybees, but its availability depends on the season, weather, and variety of flowers. To provide themselves with protein reserves during the entire period of life and, especially during periods of shortage, bees use a unique mechanism for preserving pollen in the form of Bee bread – a product of enzymatic fermentation, which is stored in honeycombs. Freshly picked pollen is hygroscopic, very sensitive to sunlight and after 48 hours. after collection, it begins to lose its consumer qualities. Pollen also contains microorganisms that begin to actively develop and also spoil it.

Bee bread is bee pollen that is mixed with nectar, saliva enzymes, and beneficial microorganisms. In order to quickly preserve pollen, bees immediately fly to the Hive and transfer it to wax cells, tamp it down, and pour a thin layer of honey. Under the influence of nectar, enzymes and enzymes of the pituitary glands, honey, pollen deprived of oxygen access is fermented and turned into bee bread. Thus, lactic acid fermentation takes place, which turns pollen into a stable nutrient product. During fermentation, the pH decreases (up to 4.0–4.2), which prevents the development of pathogenic microflora, increases the bioavailability of amino acids, and increases the content of vitamins (especially Groups B, C, and E). When growing brood (spring – early summer), the need for protein increases tenfold. During this critical period, bee bread provides larvae and young bees with the necessary substances for cell construction and milk production by nursing bees.

Due to its high content of phenolic compounds, enzymes, antioxidants, organic acids and enzymes, bee bread enhances the immunity of bees, helps reduce cases of diseases, especially during the period of family weakening (Oroian, M. et al., 2022). When the bee colony weakens or the number of larvae decreases, the addition of bee bread stimulates the uterus to lay eggs. For humans, bee bread has immunomodulatory, anti-inflammatory and antioxidant properties and is used in dietary supplements (Campos, M. G. et al., 2021).

Rational beekeeping is impossible without a high – quality and diverse food base that provides bees with the necessary nutrients-nectar and pollen. Honeybees are plants

that secrete nectar, a sugary liquid that serves as the basis for honey production. The sugar content of nectar is from 20 to 80%. Honey crops are the basis for the production of commercial honey, and also stimulate active oviposition of the uterus during the period of Intensive Family Development.

Pollen stalks are plants that secrete large amounts of pollen, which is necessary for feeding larvae, synthesizing proteins, and maintaining immunity. Often honeybees and pollen stalks are combined in one plant, but not always.

Pollen from different sources contains different amino acids and minerals, so the diversity of pollen stalks is critical for the formation of strong immunity of the bee family (Conti, I. et al., 2016). Rapeseed, sunflower, buckwheat are commercial pollen – bearing and honey-bearing crops sown taking into account the needs of apiaries. Corn is a weak nectar carrier, but a powerful pollen carrier. Wild honeybees, such as blackberries, raspberries, thistles, and thyme, provide continuous flowering throughout the summer. Medicinal herbs (mint, lemon balm, sage) enrich pollen with phytoncides.

To form a stable feed base, crops should be planned from mixed honeybees: for example, phacelia + Sainfoin + buckwheat. Crop rotation must be carried out with the inclusion of pollen stalks. Honeybee plants and pollen – bearing crops are the basis for the full development of the bee family, honey production and ensuring ecological balance. Their diversity, proper placement and preservation are the key to the stability of apiaries and the productivity of agroecosystems.

Seasonal supply of protein and carbohydrate feed to bees is a key factor in maintaining the strength and productivity of the bee family. there are three main active periods: spring, summer and autumn. Also important is the wintering period, when the reserves of honey and bee bread are replenished artificially by the beekeeper. Natural and cultivated honeybees and pollen stalks have different flowering periods, which affects the biorhythms of bees and the distribution of apiary work throughout the year. Planned cultivation of pollen-bearing crops not only stabilizes the feed base, but also increases the efficiency of agroecosystems. The distribution of flower resources over time is of strategic importance for the apiary. It is important to ensure continuous flowering – at least one source of pollen and nectar in each period, taking into account domestic plant varieties adapted to local conditions. It is necessary to sow mixtures of early, medium and late-flowering crops in each zone of the apiary and avoid treatment with agrochemicals during the flowering phase.

Pollination is the transfer of pollen from the anther of the stamen to the stigma of the pistil of the flower, which provides fertilization. In plants with cross-pollination, this process is almost entirely dependent on pollinators. Pollination is one of the most important ecosystem services performed by honeybees in interaction with flowering plants. This process has not only ecological, but also strategic food value. Most crops – from fruit trees to oilseeds and vegetables-need and benefit significantly from insect pollination.

Of all the bees that fly out of the hive, only about 50% of the bees bring pollen, these are pickers, of which about 25% collect only pollen and 25% – both pollen and nectar (Nery, D. et al., 2020). During periods of active brood rearing, up to 30% of collecting bees can be engaged in pollen collection. Pollen flight lasts an average of 20-30 minutes, after which the Bee rests and recovers energy. Scout bees find pollen-bearing plants using their vision, sense of smell, and ultraviolet vision. After returning to the Hive, The Bee performs a dance (mostly "wagging") that transmits information about the direction and distance to the pollen source (Corby-Harris, v. et al., 2018). The worker bee sits on a flower and uses its jaws, front and middle legs to collect pollen grains. Pollen mixes with the secret of the salivary glands and rolls into lumps (pollen legs). The legs

are placed in baskets on the hind legs – special structures with thick hair. The Bee delivers pollen to the honeycomb and transfers it to other workers. Pollen is rammed into cells, moistened with nectar and enzymes – the fermentation process begins (the formation of bee bread). In case of excessive heat or rain, pollen collection stops. Bees collect pollen most intensively in the morning to the middle of the day, when plants actively secrete it.

This process not only ensures the reproduction of plants, but also improves the quality of fruits: larger size, better taste, uniform maturation. Bees are versatile pollinators capable of serving both wild and cultivated entomophilic plants (Cooley, H. et al., 2021; Divekar, P. A. et al., 2024). Such cooperation has evolved over millions of years of evolution and is crucial for both biodiversity and the agricultural economy. According to the FAO, more than 70% of the world's crops improve yields due to bee pollination. For example, the yield of buckwheat increases by 1.5–2 times in the presence of bees. In horticulture, more than 30-60% of fruits are not tied without pollination. The profitability of pollination in many cases exceeds the profit from honey production itself (Khalifa, S. A. M. et al., 2021; Farina, W. M. et al., 2023; Hünicken, P. L. et al., 2022).

Climate change is one of the key threats to the conservation of floral diversity, in particular pollen-bearing plants, which play a crucial role in maintaining pollinator populations (Díaz-Calafat, J. et al., 2025; Neumann, P. et al., 2023; Zapata-Hernández, G. et al., 2024). The loss of such plants reduces the food supply for bees, wild pollinators and threatens the stability of agroecosystems.

Pollen-bearing plants are a fundamental element of the ecosystem network. However, every year, under the influence of global warming, the flowering period shifts, the distribution area decreases and there is a gradual depletion of the floral composition. Changes in the temperature regime lead to early or uneven flowering. Synchronization between the activity of bees and the possibility of collecting obnozhki is disrupted, which reduces the efficiency of pollination. Frequent droughts shorten the flowering period and pollen count. Heavy rains wash away pollen and prevent access to it. Many local pollen carriers are displaced by invasive species that are less nutritious or not at all pollen-bearing. High-altitude and northern species reduce their range, which reduces local biodiversity.

The situation in Ukraine regarding Honey and pollen crops is also complicated by the fact that the number of other animals has significantly decreased over the past decade. This negatively affected the number of crops of plants that met other animal species in the needs of feed, and bees – nectar and pollen. As practice shows, agriculture in Ukraine today is focused not on grain, feed and protein crops, but on food and industrial crops. In agricultural enterprises, there is a suboptimal structure of the feed wedge, unbalanced feed rations, poor feed quality, violation of technological conditions during the harvesting and harvesting of feed, low yield of forage crops, etc. Due attention is not paid to the primary seed production of fodder crops.

All this leads to a decrease in the volume of bee bread in the hives, a deterioration in the quality of pollen composition, a decrease in immunity and life expectancy of bees, a weakening of the spring start of the apiary due to the lack of early pollen carriers, a violation of the biological balance between wild and domestic pollinators – competition for limited resources.

Modern farming technologies involve the widespread use of fertilizers, pesticides and herbicides that directly or indirectly affect the quality and quantity of pollen formation in plants. Intensive farming involves the use of dozens of chemicals – fungicides, insecticides, desiccant growth regulators (pre-sowing plant dryers to accelerate maturation). Although these agents are designed to increase crop yields, they often have side effects on entomophilic plants and bees (Omelchun, Y. et al., 2023;

Migdał, P. et al., 2018). In particular, pesticides can reduce the level of pollen formation, alter the qualitative composition of pollen, and even have a toxic effect on collecting bees, which has far-reaching environmental and economic consequences (Omelchun, Y. A. et al., 2025). Some systemic substances (neonicotinoids) accumulate in nectar and pollen. They inhibit the enzymatic activity of the flower, which leads to a decrease in the amount of pollen or its sterility. Fungicides disrupt the microbiota of flowers, which is important for the formation of normal pollen and nectar.

Toxic pollen can cause poisoning of young bees feeding on larvae. The activity of the hypopharyngeal glands decreases – the production of royal jelly and feed for worker bees is disrupted. Pollen and nectar from treated plants and plantings can cause acute poisoning, when most flying bees die, as well as chronic ones. Due to the accumulation of sublethal doses of pesticides in Perga and Honey, an increase in the concentration of the latter in bee products due to a decrease in moisture during Nest ventilation, the family's immunity worsens, sensitivity to diseases increases, and the death of bees from chronic poisoning is observed. Pesticides in pollen can disrupt the orientation of bees in flight, which leads to the loss of working flying individuals. It was found that even at acceptable levels of pesticide residues in pollen (1-5 micrograms/kg), bees can experience behavioral changes, navigation disorders, and a decrease in life expectancy (Sadia, H. et al., 2024; Abay, Z. et al., 2023). In regions with high chemicalization of Agriculture, failures in Brood development and a decrease in winter survival are recorded 3-4 times more often.

The rapid expansion of urban areas is accompanied by the displacement of natural ecosystems, in particular flower beds, which are critical for pollinators (Guenat, S. et al., 2019). Urbanization causes fragmentation of the environment, loss of food resources for bees, and a decrease in the number of wild plant species. The increase in areas for construction, infrastructure, roads and industry is accompanied by the displacement of natural vegetation. Particularly vulnerable are the flower environments that provide a food base for honeybees, various species of solitary bees and bumblebees, butterflies, and many other pollinators. Their disappearance leads to the loss of ecosystem connections and threatens the functioning of even agricultural systems (Marshman, J. et al., 2019; Muñoz-Urias, A. et al., 2025).

Construction and asphalting destroy areas rich in pollen plants. Traditional biotopes (slopes, edges, coastal zones) where endemic species grew are being destroyed. Even if vegetation persists, its isolation from other ecosystems reduces the availability of pollen and nectar for insects. Urban parks and lawns mostly contain ornamental varieties that do not produce enough pollen or are sterile. The displacement of autochthonous species by exotics reduces the ecological value of green areas. A decrease in the number of forage plants leads to a decrease in the population of wild bees and butterflies (Neumann, A. E. et al., 2024). Urbanization creates thermal islands that disrupt the seasonality of flowering and the biorhythms of insects. Exposure to air pollution and noise changes pollinator behavior, reducing pollination efficiency (Guenat, S. et al., 2023; Genuchten, E. et al., 2023). Landscaping buildings with pollen species (lavender, sage, mint) helps create urban "islands of flowers". Planning continuous strips with honeybees between parks, squares and courtyards facilitates the movement of pollinators (Brasil, S. et al., 2023) public campaigns to create "Bee Gardens" promote biodiversity among citizens.

In the context of modern transformation of agricultural landscapes and reduction of wild flowering plants, it is necessary to introduce targeted methods for improving the feed base (Al-Ghamdi, A. A. et al., 2023). One of the most effective ways is to grow annual and perennial pollen-bearing crops. Taking into account the intensification of

Agriculture, the reduction of wild flora and the impact of climate change, sowing special honey-and pollen-bearing plants is becoming an obligatory element of modern apiary practice.

In the context of the general decline in the number of natural pollinators, there is a growing interest in ecological agriculture as an alternative model of agricultural production that contributes to the conservation of biodiversity (Wintermantel, D. et al., 2019). However, intensive farming, the destruction of wild flora and the widespread use of agrochemicals lead to a reduction in the population of bees, bumblebees, butterflies and other pollinators. One of the promising solutions is ecological (organic) farming, which minimizes interference in the environment and contributes to the preservation of entomofauna.

The main principles of ecological (organic) farming are the rejection of pesticides, herbicides and synthetic mineral fertilizers, maintaining soil fertility through crop rotations, green manure, compost, preserving natural flora in the form of wild flower strips, buffer zones (Ecological Farming: The Seven Principles of a Food System that has People at its Heart. Greenpeace International Netherlands, 2022). In farms with an organic approach, 30-50% more pollinator species are recorded compared to traditional ones. Crop productivity in the presence of a large number of pollinators increases by 10-20% even without the use of fertilizers.

Discussion. The analysis of information sources covers a wide range of issues related to the production and use of bee pollen, including its history, global production, diversity, nutritional and feed value for humans and animals.

Concluding the review of known sources on the peculiarities of the production and use of bee pollen as a priority food product, Medical means and component of feed additives in the conditions of climate change, modern farming technology, urbanization, it should be noted that these factors will continue to affect many areas in the entire chain of pollen production (bee pollen) and bee bread, and therefore the selection and expansion of areas of nectaronosiv and pollen carriers adapted to the influence of negative factors becomes particularly relevant.

Encouraging producers to resume cultivation of nectar and pollen carriers is based on the high potential of Ukraine in the form of acreage for these crops, which indicates its prospects. In the face of climate change and active urbanization, this is an important advantage. Equally important is the search for opportunities to grow annuals and perennials in the city, which will facilitate the movement of pollinators.

Compliance with important rules of organic production, introduction of targeted methods to improve the food supply, expansion of the areas of wild flowering plants will increase the number of bees, which in turn will ensure the pollination process, without which the fruiting of most crops is impossible. This will allow you to get enough pollen in a timely manner, which will contribute to obtaining high-quality food and preserving the health and productive longevity of people and animals.

Conclusions. The importance of plant pollen collected by bees (bee pollen) goes beyond beekeeping, covering the fields of Ecology, Biochemistry, Pharmacology, food safety, and agricultural science. However, despite numerous studies, a number of aspects remain insufficiently studied, which opens up broad prospects for scientists. The study of pollen is an extremely promising scientific field. Pollen is not only a source of protein for bees, but also a valuable natural product with a unique biochemical composition that can affect the physiological processes of both insects and the human body.

Thus, pollen remains a relevant object of research, which opens up wide opportunities for science and practical application in beekeeping and beyond.

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IMPROVED FEEDING STANDARDS FOR HIGHLY PRODUCTIVE COWS

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The article deals with the issues of rationing and organizing full-fledged feeding of highly productive dairy cows according to modern detailed standards, taking into account their physiological state and productivity level. In the improved feeding standards, new indicators of normalized nutrition of cows are taken into account, namely cleaved and non-cleaved protein in the rumen, digestible protein, neutral-detergent (NDC) and acid-detergent (ADC) fiber, essential amino acids, vitamins. On average, the NDC content is assumed to be at the level of 30-40% of the dry matter of the feed of the diet, and the ADC – at 15-20%. Optimization of the level of carbohydrate fractions increases the digestibility of dry matter, its consumption and milk yield of highly productive cows. The concentration of metabolic energy and biologically active substances of the diet feed was determined depending on the lactation phases, milk productivity and live weight of cows. It was found that the higher the productivity of cows, the higher the concentration of metabolic energy in one kilogram of dry matter of the feed of the diet. Annual rates of feed harvesting and consumption in dairy cattle breeding have been developed, which ensure intensive, highly profitable milk production. The main feature of these reasonable standards is that when assessing the nutritional value of feed and rationing feed feeding, a wide range of essential nutrition factors (21-30 indicators) is taken into account. This contributes to improving the efficiency of feed use, the level of transformation of feed nutrients into products and the realization of the genetic potential of dairy productivity of cows at the level of international standards. The use of energy-saving feed crops and high-quality feed provides an increase in the efficiency of land use in dairy cattle breeding and a significant increase in the milk productivity of cows from 5000 to 10000 kg and the profitability of milk production up to 40-50% in modern market conditions of management without state subsidies and investments.

Keywords: cow, feeding, feed, diet, productivity, lactation.

УДОСКОНАЛЕНІ НОРМИ ГОДІВЛІ ВИСОКОПРОДУКТИВНИХ КОРІВ

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В статті розглянуто питання щодо нормування та організації повноцінної годівлі високопродуктивних молочних корів за сучасними деталізованими нормами з врахуванням їх фізіологічного стану і рівня продуктивності. В удосконалених нормах годівлі враховано нові показники нормованого живлення корів, а саме розщеплюваний і нерозщеплюваний в рубці протеїн, засвоюваний протеїн, нейтрально-детергентна (НДК) і кислотно-детергентна (КДК) клітковина, незамінні амінокислоти, вітаміни. В середньому вміст НДК прийнято на рівні 30-40% від сухої речовини кормів раціону, а КДК – на 15-20%. Оптимізація рівня фракцій вуглеводів забезпечує підвищення перетравності сухої речовини, її споживання та надоїв високопродуктивних корів. Визначено концентрацію обмінної енергії та біологічно-активних речовин кормів раціону залежно від фаз лактації, молочної продуктивності та живої маси корів. Встановлено, що чим вища продуктивність корів, тим вища концентрація обмінної енергії в одному кілограмі сухої речовини кормів раціону. Розроблено річні норми заготівлі і витрати кормів у молочному скотарстві, які забезпечують інтенсивне високорентабельне виробництво молока. Головною особливістю вказаних обґрунтованих норм є те, що при оцінці поживності кормів і в нормуванні годівлі кормів враховується широкий комплекс незамінних факторів живлення (21-30 показників). Це сприяє підвищенню ефективності використання кормів, рівня трансформації поживних речовин корму в продукцію та реалізації генетичного потенціалу молочної продуктивності корів на рівні світових стандартів. Використання енергоощадних кормових культур і високоякісних кормів забезпечує підвищення ефективності використання земельних ресурсів в молочному скотарстві і суттєве зростання молочної продуктивності корів від 5000 до 10000 кг та рентабельності виробництва молока до 40-50% в сучасних ринкових умовах господарювання без державних дотацій і інвестицій.

Ключові слова: корова, годівля, корм, раціон, продуктивність, лактація.

Introduction. In recent years, dairy cattle breeding in economically developed countries has made a significant step forward both in terms of increasing cow productivity and in terms of improving the economic performance of high-quality milk production (Shkromada O. et al., 2019; Kramer K. & Bovenkerk B., 2024).). In many countries of the world, dairy systems are rapidly intensifying through the introduction of highly effective innovations (Nanka O. et al., 2018; Grout L. et al., 2020). Experts in the field of animal husbandry attribute the increase in the amount of milk produced by at least 70% to feeding highly productive cows where harmony was achieved between the normalized

diet and the physiological characteristics of animals (Henchion M. M. et al., 2022; Martins L. F. et al., 2022).

The high efficiency of dairy cattle breeding has become possible because European countries have completed the transition to New economically sound systems for the production and use of feed and the introduction of an improved system of full-fledged Animal Feeding (Erickson P. S. & Kalscheur K. F., 2020; Jackson A. et al., 2022; Grodkowski G. et al., 2023).

In most farms in Ukraine, the productivity of cows is 6000-7000 kg of milk per year. But the genetic potential of individual dairy herds significantly exceeds this indicator and can reach up to 8000-10000 kg.

Numerous studies have established that in the scientific organization of feeding highly productive cows, it is possible to manage the lactation activity of cows, which allows you to get high milk yields, preserve animal health at the lowest cost of feed and labor (Leduc A. et al., 2021; Vall E. et al., 2021; McAuliffe S. et al., 2022).

Full-fledged feeding of farm animals, which is based on scientifically based standards, is the key to realizing their genetic potential for productivity, maintaining health, normalizing reproductive capacity, as well as rational use of feed resources (Thanh L. P. & Suksombat W., 2015; Michalchenko S. A. et al., 2024).

The modern science of feeding farm animals has quite a lot of material in the issue of rationing individual elements of nutrition depending on the type, age, level and direction of productivity. These materials are based on the achievements of Experimental Physiology and biology in the field of digestion and metabolism, as well as on the results of scientific, economic and industrial experiments in animal feeding (Krizsan S. J. et al., 2014; Niu M. et al., 2014; Arndt C. et al., 2015).

Now the situation regarding the rationing of feeding in the world and domestic zootechnical science and practice has radically changed, which requires a significant revision of the traditional provisions on the organization of full-fledged Animal Feeding (Batistel F. et al., 2021; Ruban S. Y. & Danshyn V. O., 2024).

Recently, many countries with high-performance dairy and meat cattle have developed new feeding standards in which the protein nutritional value of feed and the need of animals for protein is assessed by Raw and broken down protein in the rumen, and when assessing the nutritional value of fiber, various forms of it are taken into account, in particular, the content of neutral-detergent fiber(NPC) and acid-detergent fiber (KDC) (Keum S-H. et al., 2022; Xiao D. & Meng T., 2024).

The Institute of animal husbandry of the National Academy of Sciences has developed an innovative product – a high-energy protein supplement TEP-mix based on protein (bypass-protein) and starch (bypass-starch) protected from cleavage in the pancreas. It was found that the use of an energy-protein supplement in the feeding diets of dairy cows provides an increase in protected protein and starch in the diet by 8-15% of their initial amount, which has a positive effect on increasing milk yield, and improves the economic efficiency of milk production (Sedyuk I. E. et al., 2019; Zolotarov A. P. et al., 2022; Mamenko O. et al., 2023).

According to the materials of experimental studies, the genetic potential of animals of newly created breeds, types and crosses, as well as imported livestock, cannot be realized without feeding according to the existing standards in Ukraine (Tsvigun A. T. et al. , 2021; Zolotarov A. et al., 2021).

Regarding the feeding standards of highly productive cows with a milk yield of 8-10 thousand kg of milk in different periods of the reproductive cycle, there is a significant amount of work (Kropyvka Yu. G. & Bomko V. S., 2021; Antonenko S. F. et al., 2022; Anwar A. E. A. et al., 2023). But there are many contradictions in them, especially with

regard to the amount of feed consumed and the concentration of energy and protein in the diet.

Taking into account the above, the general idea of previous studies conducted at the Institute of animal husbandry of the National Academy of Sciences was to improve the standards of feeding farm animals. For their implementation, the analysis of existing cattle feeding standards in the world, analysis of research materials in the direction of clarifying individual indicators of energy, protein and mineral value of feed and justifying the need to introduce new indicators to feeding standards, clarifying the needs of animals of different gender and age groups, the efficiency of using energy and protein depending on its energy-protein ratio, digestibility of nutrients was carried out. In order to compare various methodological approaches to substantiating the needs of animals for energy and biologically active substances, modern systems of energy and nutrient rationing were analyzed.

The aim of the research is to analyze the introduction of normalized full – fledged feeding of highly productive dairy cows.

Materials and methods. The research is based on the analysis of the results of long-term (1990-2015) experiments conducted by IT staff of the National Academy of Sciences on the basis of dairy farms in Polesie, forest-steppe and steppe of Ukraine and special literature on the problems of feeding highly productive dairy cattle using analytical, zootechnical, biochemical and economic research methods.

Research results. The intensification of animal husbandry and increased productivity require rationing of animal feeding, taking into account the physiological state and lactation periods. In the dry period of 45-60 days, two periods are determined from 1 to 30 and from 31 to 60 days, and during lactation – this is the distribution (from 101 to 200 days) and its attenuation (from 201 to 305 days). In each physiological period, the rate of feeding cows should be applied depending on the final goal (Table 1 and 2).

The available feeding standards for cows with a live weight of 600 kg and an annual milk yield of 8000 kg reflect the features of energy and nutrients consumed during different periods of lactation and dead wood. Depending on the physiological state of cows, the need for nutrients for life support, growth and development of the fetus during the dead period, milk production and growth (young cows) increases. For dead cows, live weight and milk productivity forecasting are taken into account.

The differential rate of feeding cows by the periods of the reproductive cycle is associated with changes in the direction of energy consumption.

During the first three months, the main costs are spent on maintaining milk metabolism and synthesis in conditions of reduced dry matter consumption. During the initial lactation period, the body's energy reserves are especially used for milk synthesis in conditions of reduced dry matter consumption, which cannot be compensated by the influence of feeding.

During the period of distribution of new-bodied cows, balanced feeding is introduced to study the productive potential. At the end of lactation, the need for feed for milk synthesis, nutrient Reserve and fetal growth is taken into account.

For highly productive cows, improved feeding standards have been developed that take into account the dynamics of live weight, energy and other nutrients by lactation months, taking into account the months of pregnancy and dry period.

The data shown in the table show that the norms of metabolic energy use during lactation change. It is known that the first period of lactation (up to 100 days) accounts for 40-45% of milk productivity, the second (101-200 days) 30-35% and the third period (201-305 days) 20-25%. According to this principle, the average daily milk yield by

lactation months is determined for cows with an annual milk yield of 5000-10000 kg of milk.

Table 1.

Tested feeding rations for cows with an annual milk yield of 8000 kg of milk 3.8-4.0% fat content, live weight of 600 kg (lactation period)

Indicator	Lactation period, months					
	1	2	3	4	5	6
Duration (days)	–	–	–	30	60	90
Live weight (kg)	573	560	555	558	561	564
Weight gain, plumb line (kg per day)	-0.9	-0.43	-0.17	+0.1	+0.1	+0.1
Daily milk yield, kg	32.0	37.3	34.7	32.0	29.3	26.7
Exchange energy, MJ	226	257	245	240	226	213
Dry matter, kg	21.2	23.9	23.0	23.4	22.3	21.2
Crude protein, g	3885	4392	4015	3590	3310	3150
Digestible protein, g	2195	2600	2430	2330	2150	1985
split, g	2642	2767	2731	2330	2250	2165
non-split, g	1243	1625	1284	1260	1160	1165
Raw fiber, g	3605	3140	3445	3830	4035	4195
neutral-detergent, %	35	40	40	35	35	35
acid-detergent, %	19	19	19	19	19	19
Starch, g	3410	4210	3860	3625	3270	2950
Sugar, g	2265	2800	2565	2410	2175	1960
Crude Fat, g	780	945	875	825	750	685
Table salt, g	140	165	155	150	140	130
Calcium, g	140	165	155	150	139	129
Phosphorus, g	100	119	111	107	99	92
Magnesium, g	34	37	36	36	35	33
Potassium, g	145	165	160	155	145	140
Sulfur, g	47	54	51	50	47	45
Iron, mg	1645	1910	1805	1750	1630	1525
Copper, mg	215	250	240	225	210	190
Zinc, mg	1375	1655	1535	1460	1340	1225
Cobalt, mg	16.4	19.5	18.2	17.7	16.4	15.1
Manganese, mg	1375	1655	1535	1460	1340	1225
Iodine, mg	18.6	22.5	20.8	19.8	18.1	16.5
Carotene, mg	945	1180	1100	1050	960	885
Vitamin D, Thousand IU	20.3	23.2	22.0	21.6	20.3	19.1
Vitamin E, mg	835	970	915	885	830	770
Lysine, g	115	121	115	110	109	104
Methionine, g	46	48	46	45	43	42
Tryptophan, g	69	73	70	67	65	62
OE concentration, MJ	10.66	10.75	10.65	10.25	10.13	10.05

Table 2.

Tested feeding rations for cows with an annual milk yield of 8000 kg of milk 3.8-4.0% fat content, live weight of 600 kg (lactation period, dead wood)

Indicator	Lactation period, months				Dead wood, months	
	7	8	9	10	1	2
Duration (days)	100	150	180	210	240	270
Live weight (kg)	567	570	580	600	627	654
Weight gain, plumb line (kg per day)	+0.1	+0.3	+0.33	+0.67	+0.9	+0.9
Daily milk yield, kg	24.0	21.3	18.7	10.7	–	–
Exchange energy, MJ	206	200	192	177	126	140
Dry matter, kg	20.7	20.2	19.7	18.5	13.0	14.4
Crude protein, g	2805	2740	2565	2215	1830	2030
Digestible protein, g	1825	1795	1675	1450	1200	1330
split, g	2240	2318	2232	2158	1775	1950
non-split, g	980	945	890	765	630	700
Raw fiber, g	4320	4700	4850	5500	2600	2880
neutral-detergent, %	35	30	30	30	30	30
acid-detergent, %	20	20	20	20	20	20
Starch, g	2645	2575	2290	1795	1315	1455
Sugar, g	1755	1670	1520	1190	1095	1205
Crude Fat, g	620	595	545	445	390	435
Table salt, g	120	118	111	99	67	74
Calcium, g	120	118	111	99	105	116
Phosphorus, g	85	83	78	69	101	112
Magnesium, g	32	32	32	31	22	24
Potassium, g	130	130	125	115	75	85
Sulfur, g	42	42	40	37	25	28
Iron, mg	1415	1405	1330	1200	760	810
Copper, mg	170	167	155	130	110	120
Zinc, mg	1115	1085	1005	845	545	600
Cobalt, mg	13.9	13.9	13.1	11.9	7.6	8.4
Manganese, mg	1115	1085	1005	845	545	600
Iodine, mg	15.0	14.5	13.4	11.1	7.6	8.4
Carotene, mg	810	785	730	620	595	660
Vitamin D, Thousand IU	18.0	18.0	17.2	15.9	12.0	13.3
Vitamin E, mg	720	710	675	610	430	475
Lysine, g	100	85	84	81	90	93
Methionine, g	40	39	37	36	42	44
Tryptophan, g	60	48	46	45	60	65
OE concentration, MJ	9.95	9.90	9.75	9.57	9.69	9.72

During the reproductive cycle, the live weight of cows changes and the full-aged cow before calving should be approximately the same as the live weight after calving. New-bodied cows, as a rule, in the first period of lactation are not able to consume enough feed to fully satisfy their energy and therefore their live weight decreases during milking. The decrease in live weight during milking is 25-40 kg of milk during lactation, 5000-

6000 kg – 35-60 kg, 7000-8000 kg – 55-85 kg, 9000 kg and more – 70-110 kg. In some highly productive cows, weight loss due to milk synthesis can reach 200 kg or more.

During the dry period, the need for energy is determined by the cost of maintaining and depositing energy in the development of the fetus. According to the results of many years of research, feeding cows during the last two months before calving should be organized so that the average daily increase does not exceed 0.6 – 0.8 kg per day, that is, it took place only due to an increase in weight (fetus and fetal membranes) and reproductive organs.

The necessary reserve of protein, fat, minerals and vitamins must be accumulated before launch. At the same time, the results of other studies and practices of dairy cattle breeding show that during the period of dead wood, a cow should increase its live weight by 50-60 kg, and the average daily increase should be 800-1000 G, or 8-12% by weight during the period of dead wood. In other specific cases, the planned increase is determined by the state of fatness of cows during the start-up period.

Feed for such dead cows should be of high quality. Unbalanced feeding, especially in terms of protein, carbohydrates, minerals and vitamins in the last period of pregnancy, negatively affects milk yield. Normalized feeding is carried out taking into account genetic conditions, the level of productivity and physiological state.

Depending on the projected productivity and fatness of pregnant cows, the quantity and quality of bulk feed, part of the concentrates in the diet should be 25-30% in terms of nutritional value. A special feature of feeding highly productive cows during the dry period is not normalized feed consumption. This is due to the physiological characteristics of cows, since the size of the fruit during this period reaches its maximum value, the capacity of the digestive stomach decreases. Therefore, animal feeding should be differentiated taking into account the pregnancy period: in the first decade of dry – standing about 80%, in the second up to 100% of the nutritional value of the diet, in the third - fourth-up to 120% and in the fifth reduced by bringing to the sixth decade up to 60-70%.

Immediately before calving, the daily feed intake rate does not exceed the maintenance level. During the dry period, cows should be released 1-2 times a day for a walk in pens, for at least 2-3 hours, or organize an active exercise.

Systematic exercise prevents udder edema before calving, eliminates weakening during calving and allows you to get strong and well-developed young animals.

After calving, cows have a discrepancy between productivity and feed consumption. During this period, they have a high need for energy, which is not met by the nutrients of the diet. Insufficient amount of nutrients and energy for the synthesis of large amounts of milk is covered from the body's Reserve. The average daily decrease in live weight of cows in the first 2-5 months of lactation should not exceed 0.6 - 1.0 kg per day, or during this period by 5-8% of the animal's weight.

Almost in the first 45-60 days after calving, highly productive cows should receive the main amount of concentrates until they are completely eaten and with a simultaneous increase in milk yield.

In order to provide cows with energy during the first lactation period, a concentrated type of feeding is used - 400-500 g of a mixture of concentrates enriched with macro - and microelements and vitamins A, D, E per 1 kg of milk or mixed feed according to a special recipe. At the same time, concentrates are fed in 3-4 dachas to ensure stomach function and prevent a decrease in the fat content of milk. Cows that receive 10 kg of concentrates or more per day are fed them 4 to 6 times a day.

When the fat content in milk is reached in the future, the increase in concentrate production stops and keeps this level unchanged during the second lactation period until

productivity decreases. Such feeding provides an optimal lactation curve, which is characterized by a different increase in the duration of fat retention, and then a gradual decrease in the third lactation period.

Studies have shown that a high level of feeding with a large amount of concentrates in the first lactation period satisfies the residual effect on milk yield in the second lactation period, which leads to an increase in productivity in general.

Concentrates stimulate appetite, prevent increased fat breakdown from the beginning of lactation, and prevent ketosis. In the second period of lactation, reserves in the body are restored, which, due to excessive feeding, can lead to negative consequences - obesity and a sharp decrease in milk yields. Therefore, animals must be encoded according to the norms in accordance with the amount of milk yield, live weight, fatness and the need for partial restoration of the body Reserve.

In the middle of lactation, the diet is basically the same as in the new – bodied period, only the amount of concentrates is reduced to 400 g per 1 kg of milk, in the third lactation period - up to 300 g and part of the bulk feed-hay, haylage and silage-is increased in the diet.

To obtain the predicted level of milk productivity, taking into account the grouping of daily milk yields by month, it is necessary to ensure the optimal ratio of basic feeds (coarse, juicy, concentrated), as well as mineral supplements and vitamins in the diet.

Tables 3 and 4 show the annual demand of cows of different productivity for energy and protein and the annual structure of feed for highly productive animals. The table shows that with an increase in the level of productivity from 5000 to 10000 kg of milk, the consumption of concentrates increases from 35 to 50%, while reducing the use of haylage, silage and green fodder at a constant specific weight of hay.

Table 3.

Annual feed requirement of cows (C)

Feed	Milk feed per cow per year (kg)					
	5000	**6000**	**7000**	**8000**	**9000**	**10000**
mixed grass hay	11.0	13.2	16.1	17.5	18.8	19.7
grass cutting	2.1	2.6	1.9	2.1	2.2	2.3
legume and cereal haylage	14.3	13.7	13.4	14.6	13.4	14.1
corn silage	22.2	23.3	26.1	24.3	26.1	27.3
legume and cereal haylage	26.9	36.9	51.7	61.6	72.3	82.0
green feed	76.5	84.7	83.0	77.1	64.5	53.1
mixed feed concentrate	17.5	23.4	27.6	32.0	37.6	41.0

The shown ratio of feed at high quality ensures the optimal concentration of energy and nutrients in the dry matter of rations, meets the need for feed in all elements of nutrition and will allow you to obtain a genetically determined level of productivity at the lowest feed costs for obtaining 1 kg of milk. When drawing up diets, it is necessary to use actual data on the chemical composition and nutritional value of feed. It is necessary to balance the diets of highly productive cows in terms of energy, protein, and other nutrients and biologically active substances with mixed feeds and premixes for winter and summer feeding.

Table 4.

The average annual requirement of cows for energy and digestible protein per cow with a milk fat content of 3.8-4.0%

Milk per cow per year (kg)	consumption per 1 kg of milk		required digestible protein (g)		required per year		
	required per year	MJOE	per 1 feed unit	per 1 MJ OE	feed units	MJOE	digested protein (kg)
5000	1.02	11.7	106	9.2	5100	58500	541
6000	1.00	11.5	110	9.6	6000	69000	600
7000	0.96	11.1	114	9.9	6720	77700	766
8000	0.91	10.5	118	10.2	7280	84000	859
9000	0.87	10.0	120	10.5	7830	90000	940
10000	0.82	9.4	120	10.5	8200	94000	984

Since the productivity of cows varies during lactation, the concentration of energy in dry matter will be different. For highly productive cows, it can be regulated by the method of differential distribution of high-energy and high-protein feeds and additives over lactation periods. Studies have established that differential feeding of high-energy and high-protein feeds reduces the consumption of concentrates in general during lactation, normalizes metabolism, improves reproduction indicators (reduces the insemination index and service period) and fully reveals the genetic potential of productivity.

The need for concentrated feed at the stages of lactation and dead wood for cows with a capacity of 5000-10000 kg of milk per year is shown in Table 5.

Table 5.

Cows need for concentrates

Indicator	Milk yield per cow per year (kg)					
	5000	6000	7000	8000	9000	10000
Feed consumption per 1 kg of milk (f. units.)	1.02	1.00	0.96	0.91	0.87	0.82
Required feed per year (k. units.)	5100	6000	6720	7280	7830	8200
Daily requirement (% of demand)	35	39	41	44	48	50
Dry period (kg)	150	180	210	240	270	270
lactation (kg)	1635	2160	2545	2965	3490	3830
on average, per 1 kg of milk	327	360	365	370	388	383
including lactation periods (g): 1-100 days	365	402	406	414	433	428
100-200	327	360	364	370	388	383
201-305	262	288	291	296	310	306

The technique of feeding highly productive cows depends on the conditions of keeping (tethered, loose), the composition of the diet and the use of individual feeds as part of multicomponent rations, in the form of a complete feed mixture based on grass, hay cutting, haylage, silage with the addition of crushed root crops and concentrates (Table 6).

Table 6.

Feed consumption structure

Milk yield per cow per year (kg)	percentage of nutritional value						
	hay	grass cutting	haylage	silage	root vegetables	green feed	concentrates
5000	11	3	10	8	7	26	35
6000	11	3	8	7	8	25	37
7000	12	2	7	7	10	21	41
8000	12	2	7	6	11	18	44
9000	12	2	6	6	12	14	48
10000	12	2	6	6	13	11	50

When feeding multicomponent diets to animals, concentrates are dosed before milking and calving. Juicy feed silage and root vegetables after milking. Coarse feed should be used at the end of feeding, grass cutting is recommended to be fed to cows mixed with concentrates.

Studies have shown that increasing the frequency of feeding feed mainly concentrates has a positive effect on productivity and on the state of animal health. Limiting the frequency of feeding concentrates leads to an increase in amylytic activity in the rumen by two or more times and a decrease in cellulolytic activity, while there is a different decrease in fiber digestibility. A mixture of cereals should be coarse ground, it is better to feed flattened grain.

Highly productive cows in the first period of lactation concentrates are recommended to be given up to six times a day in the middle of lactation – four times, in the third period of lactation - three.

In recent decades, individual rationing of concentrate delivery at the request of computer-controlled automatic feed stations has been widely developed in countries with developed animal husbandry. Further improvements will take place depending on the detailed needs of animals for energy and nutrients under various conditions of keeping and feeding, with a special focus on the quality and biosafety of products.

Discussion. Full-fledged balanced feeding, in which animals receive energy, protein, other organic and mineral substances with feed in accordance with their needs with a full physiological state and level of productivity, is a determining factor in the realization of the genetic potential of dairy cattle (McAuliffe S. et al., 2022; Bach A., 2023). The effectiveness of using new detailed feeding standards in practice is noted in the works of many researchers (Chase L. E. & Fortina R., 2023; Desta A. G., 2024; Liu N. et al., 2025). When testing these standards in a number of Main and zonal research institutions, their effectiveness was proved due to an increase in animal productivity and a reduction in feed costs by 8-12%. It was also found that with detailed rationing of feeding of highly productive cows, the digestion of dry matter is higher by 2.36%, organic matter – by 1.73%, crude protein – by 11.8% compared to cows of the control group, in which the diet was controlled according to six indicators. The main factor in drawing up a diet for any animal species is the amount of dry matter consumption of feed (Liang S.

et al., 2021). When the dry matter content increases to 35%, feed consumption increases. Consumption varies significantly depending on the type and quality of feed, feeding technology, and environmental conditions (Greenland M. S. et al., 2023). Feed consumption increases with an increase in live weight of animals and it usually occurs more slowly than an increase in live weight. There is also a difference in the amount of food consumed between animals of different breeds. Thus, dairy animals are able to consume more feed than meat cattle (Madilindi M. A. et al., 2022; Blake N. E. et al., 2023).

According to the recommendations of scientists, depending on the size of milk yields, the fiber content in the dry matter of diets should be in the range of 18-26%, most of them are coarse – fiber, since the content of milk fat is directly dependent on the quantity and quality of consumption of this digestive element (Parsons C. T. et al., 2021).

Important for increasing the milk productivity of cows is the protein nutritional value of the diet, which is estimated by the amount of raw and digestible protein, the ratio of hard - and easily soluble proteins, and their concentration in dry matter (Tebbe A. & Weiss B., 2020; Ayele J. et al., 2022).

To increase the intake of non-cleaved protein and amino acids in the duodenum, it is necessary to ensure that the dry matter content of the diet is up to 19% crude protein, in which 60% should be soluble protein and 40% insoluble. In order to improve the use of proteins and carbohydrates in the body of highly productive cows, it is necessary to feed feed as part of feed mixtures (Lee S. et al., 2021). The use of cow feeding technology using complete feed mixtures is zootechnically effective, since it contains coarse, juicy and concentrated feed, as well as mineral and vitamin supplements that have a positive effect on the animal body (Baber J. R. et al., 2021; Șanta A. et al., 2022).

At the same time, the issue of full-fledged feeding of lactating cows cannot be considered in conjunction with other external factors (Gross J. J., 2022). Among them, it is necessary to highlight the increased demand of cows for their provision with biologically active food components. It was found that feeding cows a complex mineral supplement consisting of cobalt chloride, copper sulfate, potassium iodide mixed with table salt and vitamins A, D at a dose of 100 and 30 IU, respectively, contributed to an increase in the cellulolytic activity of the rumen microflora by 3.5%, the concentration of light fatty acids by 10.5%, The digestible protein of the winter diet by 3.3%, and the summer diet by 3.9%, fiber, respectively, by 6.1 and 7.2%, fat – by 9.9 and 9.4%, organic matter – by 4.5 and 2.6%, which is accompanied by an increase in milk productivity by 8-10%. The positive effect of microelement additives on the chemical composition of milk (Akintan O. A. et al., 2025). The use of a supplement of insufficient macro - and microelements in the diet of cows helps to increase milk productivity, feed efficiency and improve their reproductive functions (Becker V. A. E. et al., 2022; Craig A. L. et al., 2022). Along with this, it is necessary to pay attention to the quality and safety of the feed used (Bogach M. et al., 2024).

Therefore, for the rational use of feed in the organization of feeding highly productive cows, it is always necessary to adhere to scientifically based standards, taking into account the genetic potential, the actual level of productivity, and the physiological state of cows. Failure to comply with the conditions of full feeding and keeping of cows leads to a decrease in milk productivity, infertility, and their culling, despite their productive qualities (Różańska-Zawieja J. et al., 2021).

Conclusions:

1. The feeding standards of highly productive cows adapted to the NRC meet the needs of animals in different periods of lactation and ensure the receipt of planned milk

yields under different maintenance technologies with a balanced diet for basic nutrients and biologically active substances.

2. The Modern and economic significance of the improved domestic standards for feeding highly productive farm animals is to reduce the cost of feed for the production of livestock products, increase the profitability of the industry, and preserve the environment, which will contribute to improving the well-being of the people of Ukraine.

3. the prospect of further research is to develop innovative, scientifically based technological approaches to breeding and keeping farm animals of various species, taking into account environmental and social factors.

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PRODUCTIVE PERFORMANCE AND HEMATOLOGICAL PROFILE OF DNIPRO MEAT BREED EWES DURING THE EARLY SUCKLING STAGE

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The research results on the metabolic processes in Dnipro Meat breed ewes at the initial stage of the suckling period depending on the number and sex of newborn lambs are presented. The ewes during lambing were divided into two groups of 10 animals each. The first group included ewes that gave birth to a single lamb, while the second group consisted of ewes with twin lambs.

At the beginning of the neonatal period, the rearing of newborn lambs is fully provided by the milk production of the ewes. The milk yield of ewes during the first 20 days of the suckling period, which nursed a single lamb, was at the level of 26.5 kg for ewe-lambs and 27.5 kg for ram-lambs, whereas for ewes with twins, the total milk yield amounted to 43.5 kg. As a result, the average daily milk yield during this period for ewes with single lambs was 1.33–1.38 kg, and for ewes with twins, it was 2.18 kg, which was higher by 58.0–63.9%.

Probable discrepancies in live weight indicators depending on the type of lamb birth have been identified. In single-born lambs, the predicted growth intensity was higher compared to twin-born lambs, with a difference of 34.5% among ram-lambs and 27.1% among ewe-lambs ($p<0.01$).

Among the key indicators of the chemical composition of milk in the experimental groups of ewes, the baseline values corresponded to the protein content – 5.84-5.82% – and lactose content, which was at the level of 4.77-4.78%. In the milk of ewes with single-born lambs, the fat content was 5.56% and was slightly higher compared to ewes with twins by 0.14 absolute percentage points.

It has been established that there are certain differences in the morphological composition of blood among the experimental ewes. More significant changes in red blood parameters are observed in ewes with twins, who not only have a higher number of erythrocytes – 9.1±0.27 T/L, compared to ewes with a single lamb – 8.7±0.17 T/L, but also a higher concentration of hemoglobin in them.

It has been determined that the blood of ewes with twin lambs contained a significantly lower number of leukocytes compared to ewes with single lambs — by 23.5%, which indicates a lower immunological reactivity of the organism, caused by a greater stress load on ewes with twin lambs.

The obtained data regarding the study of the morphological composition of ewe blood parameters during the most intense phase of the suckling period have practical significance for their application in the development of breeding measures aimed at forecasting their productivity.

Keywords: uterus, lambs, growth rate, milk yield, milk composition, blood.

ПРОДУКТИВНІСТЬ ТА ГЕМАТОЛОГІЧНИЙ ПРОФІЛЬ ВІВЦЕМАТОК ПРИДНІПРОВСЬКОЇ М'ЯСНОЇ ПОРОДИ НА РАННЬОМУ ЕТАПІ ПІДСИСНОГО ПЕРІОДУ

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Представлено результати досліджень за процесами метаболізму у вівцематок придніпровської м'ясної породи на початковій стадії підсисного періоду в залежності від кількості і статті новонароджених ягнят. Вівцематки в процесі ягніння були розподіленні на дві групи по 10 голів. До першої групи ввійшли тварини, які родили одне ягня, друга група складалася з маток з ягнятами-двійнями.

Початок неонатального періоду вирощування новонароджених ягнят повністю забезпечується молочністю маток. Молочність вівцематок за перші 20 діб підсисного періоду, які відгодовували одне ягня була на рівні 26,5 кг за ярочками і 27,5 кг – баранцями, тоді як з двійнятами сукупна молочність склала 43,5 кг. В результаті середньодобова молочність у цей період маток з ягнятами-одинаками склала 1,33-1,38 кг, а у маток з двійнями 2,18 кг, що було більше на 58,0-63,9 %.

Виявлено вірогідні розбіжності за показниками живої маси в залежності від типу народження ягнят. У ягнят-одинаків прогнозовано інтенсивність росту була вищою порівняно з ягнятами-двійнями, між баранцями вона становила 34,5 %, а ярочками – 27,1 % ($p<0,01$).

Серед визначальних показників хімічного складу молока дослідних груп маток базисній величині відповідав вміст білка – 5,84-5,82 % і лактози, вміст якої був на рівні 4,77-4,78 %. У молоці вівцематок з ягнятами-одинаками вміст жиру становив 5,56 % і виявився дещо вищим стосовно вівцематок з двійнями на 0,14 абс. відсотка.

З'ясовано, що у показниках морфологічного складу крові між піддослідними вівцематками відзначаються певні відмінності. Спостерігаються більш значні зміни в показниках червоної крові у вівцематок з двійнями, які мають не тільки вищу кількість еритроцитів – 9,1±0,27 Т/л, тоді як у маток з одним ягням – 8,7±0,17 Т/л, а й більш високу концентрацію в них гемоглобіну.

Встановлено, що в крові вівцематок з ягнятами двійнями була значно менша кількість лейкоцитів, відносно маток з одинаками – на 23,5%, це вказує на нижчу імунологічну реактивність організму, що обумовлено більшим стресовим навантаженням на тварин з ягнятами-двійнями.

Отриманні дані щодо вивчення морфологічного складу показників крові вівцематок у найбільш напружену фазу підсисного періоду мають прикладне значення для практичного їх застосування при розробці селекційних заходів спрямованих на прогнозування їх продуктивності.

Ключові слова: матки, ягнята, інтенсивність росту, молочність, склад молока, кров.

Introduction. Modern livestock farming imposes increasingly stringent requirements for assessing animal productivity. Therefore, an urgent task is to improve the meat productivity and reproductive qualities of sheep through reliable selection

methods. This requires the rational use of available resources and continuous monitoring of the productive and biological characteristics of newly created meat sheep genotypes, which make it possible to identify the most promising animals for breeding (Zharuk L. V., 2022; Mykytyuk V. V., 2023).

Due to the decline in sheep numbers in the country, there has arisen a need to increase the frequency of desirable genotypes in populations by identifying and widely using valuable breeding individuals. At the same time, most sheep breeds do not fully possess the necessary level of productivity, primarily due to mediocre fertility rates. To increase production volumes in the sheep industry, it is essential to maximize the genetic potential of the reproductive capacity of sheep of import-substituting intensive types (Polska P. I., 2020).

The key selection traits for successful sheep breeding are increasing the fecundity and milk production of ewes. It is the milk production of ewes that ensures the growth and development of newborn lambs during the first month of the neonatal period and subsequently contributes to the realization of the genetic potential of inherited precocity (Lesyk O. B., Pokhyvka M. V., 2020).

It is important to consider that deficiencies in nutrition and improper care of ewes during pregnancy significantly affect the overall development of the fetus — the duration of prenatal development, its weight, and viability (Rooke J. A. et al., 2008; Cukharlov V. O., 2010).

Ideally, ewes should give birth to a live lamb without complications, providing a reliable source of colostrum and milk within a stable maternal environment (Everett-Hincks, J. M. et al., 2004; Dwyer, C.M., 2007). The number of newborn lambs has a significant impact on the genetic evaluation of maternal ability to rear lambs successfully (Kim L. Bunter et al., 2017).

Moreover, lambs need to adapt to the external environment, being able to suckle within a relatively short period after birth to maintain the necessary energy levels and regulate their own body temperature (Everett-Hincks, J. M. et al., 2014; Bunter, K. L. et al., 2023).

Milk productivity, given an adequate level of ewe nutrition, is determined by the number of lambs born, the duration of productive use, live weight, and the level of provision with the necessary nutrients in the feeding ration (Asín, J. et al., 2021; Yakovchuk V. S., Zhulinska O. S., Ivanyna O. P., 2021).

In all sheep breeds, the milk productivity of ewes determines the growth and development of lambs, their health, viability, and survival rate. This factor becomes particularly significant for ewes that give birth to two or more lambs.

Research by Stapay P. V., Gavrylyak V. V., Stakhiv N. P., Paranyak N. M. (2016) established that the milk yield of ewes is closely correlated with fecundity. Thus, over 100 days of lactation, the milk productivity of ewes with one lamb amounted to 97.2 kg, with two lambs – 120.0 kg, with three lambs – 153.0 kg, and with four lambs – 169.1 kg.

On average, the chemical composition of sheep's milk in terms of the main indicators is as follows: total solids – 17.8%, fat – 7.4%, protein – 5.7%, lactose – 4.8%, and ash – 0.9% (Rooke J. A. et al., 2008; Stapay P. V., 2010; Thomas, D. L. & Haenlein, G. F. W., 2017).

Many aspects of this issue require a thorough understanding of the specifics of metabolic processes during the most critical periods of animal rearing. The basal metabolism in the body of ewes during all physiological periods depends on the intake of

nutrients and biologically active substances (Mykytyuk V. V. & Porotikova I. I., 2020; Yefremov et al., 2020; Asín et al., 2021).

The most accessible system for research, which reflects the entire complex of physiological and biochemical processes in the body of animals, is blood. Therefore, data on blood parameters make it possible to assess the direction of metabolic processes, the health status of animals, and, to a certain extent, the nature of productivity (Vovkotrub et al., 2021).

Assessing the milk productivity of ewes and the growth intensity of offspring through determining the relationship between hematological blood parameters and metabolic status during the suckling period is a relevant problem, as it allows for the formation of a scientifically substantiated opinion on the course of redox reactions in the body of sheep of newly created breeds.

Purpose of the study. The study was aimed at determining differences in productivity indicators in ewes of the Dnieper meat breed depending on the number and type of lambs born in the early period of neonatal rearing.

Materials and research methods. The experimental part of the research and the collection of necessary results were carried out during the lambing of ewes of the Prydniprovska meat breed at the sheep complex of the State Enterprise "Runo Research Farm" in Dnipropetrovsk region, as well as at the Department of Animal Feeding and Breeding Technology and the Research and Development Center for Biosafety and Environmental Control of Agro-Industrial Complex Resources of Dnipropetrovsk State Agrarian and Economic University (DSAEU).

During lambing, two experimental groups of sheep, each consisting of 10 ewes, were formed. The first group consisted of ewes with a single lamb, while the second group included ewes with twin lambs. In the course of the scientific research, zootechnical methods were applied to evaluate the studied productivity traits, which involved determining the live weight of lambs at birth and at 20 days of age, as well as calculating the average daily and total body weight gains.

The milk yield of the ewes was determined by multiplying the total weight gain of the lambs from birth to 20 days of age by a coefficient of 5, which assumes that an average of 5 kg of milk is consumed to produce 1 kg of lamb weight gain at this age (Ibatullin, I. I. & Zhukorsky, O.M., 2017).

On the third day after lambing, blood samples were taken from the ewes for laboratory analysis, as well as milk samples to determine its chemical composition.

The total number of erythrocytes and leukocytes, hemoglobin concentration, and hematocrit value were determined in blood using microcentrifugation according to the relevant methodologies (Levchenko et al., 2020). The indices of "red" blood – color index (CI), mean corpuscular hemoglobin (MCH), and mean corpuscular volume (MCV) – were calculated mathematically.

Milk samples were analyzed using an ultrasonic milk analyzer Ekomilk Total (Ultrasonic Milk Analyzer) (BULTEH2000 Ltd., Bulgaria).

For all types of analysis, a value of $p \leq 0.05$ was considered statistically significant. Statistical processing of the results was performed using the Statistica 10 software (StatSoft Inc., USA, 2011).

Experimental studies were conducted in accordance with the requirements of the Law of Ukraine No. 3447 – IV of 21.02.06 "On the Protection of Animals from Cruelty" and in accordance with the main principles of the "European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes"

(Strasbourg, 1986), the declaration "On Humane Treatment of Animals" (Helsinki, 2000), and the National Congress on Bioethics "General Ethical Principles of Animal Experimentation" (Kyiv, 2001).

Research results. The live weight of newborn lambs is an indicator of obtaining viable and well-developed offspring. Overall, the condition and live weight of newborn lambs, both singles and twins, corresponded to standard indicators but were at the minimum level.

Single-born male and female lambs did not significantly differ in live weight, which averaged 3.8±0.14 kg for ram lambs and 3.6±0.09 kg for ewe lambs. Among twins, no sexual differences in live weight at birth were observed between ram lambs and ewe lambs, and it was at the level of 2.6 kg (Table 1).

Table 1.

Intensity growth newborn young and milk yield of ewes (M±m, n=5)

Gender	Live weight, kg		Live weight gain		Average milk yield of ewes, kg (per lamb)
	newborns	20 days	20 days, kg	daily, g	
Singles					
Ram-lambs	3.8*±0.14	9.3±0.13	5.5±0.11	275.7*±1.29	1.38 ±0.12
Ewe-lambs	3.6*±0.09	8.9±0.10	5.3±0.12	265.9*±1.34	1.33 ±0.16
Twins					
Ram-lambs	2.6 ±0.09	6.9±0.10	4.3±0.10	215.2 ±1.28	1.09±0.14
Ewe-lambs	2.6±0.11	7.0±0.10	4.4±0.13	220.1 ±1.19	1.10±0.12

*Note. * – P<0.05 in compare to the group of ewes with singles*

To determine the milk productivity of ewes, the growth intensity of newborn lambs up to 20 days of age was studied. Significant differences in live weight indicators were found depending on the type of lamb birth.

The live weight of newborn single-born lambs was significantly higher ($p < 0.05$) compared to twin-born lambs, with an advantage of 46.2% for ram lambs and 38.5% for ewe lambs.

A higher growth intensity was observed in single-born lambs compared to twins during the first 20 days of rearing. Single-born ram lambs exceeded twins by 34.5%, and single-born ewe lambs by 27.1%, with these differences being statistically significant ($p < 0.05$).

Depending on gender, the difference between singles and twins was neither substantial nor predictable. Among single-born lambs, ram lambs had a 4.5% advantage, whereas among twins, a slight advantage (1.5%) was observed in ewe lambs.

The determination of average daily weight gains in the experimental young stock also confirmed the advantage in growth intensity of single-born ram lambs, which amounted to 275.7±1.29 g during this period. The average daily gain of ewe lambs was slightly lower – 265.9±1.34 g, while in twins, it was respectively 215.2±1.28 g and 220.1±1.19 g.

By calculation, the milk yield of ewes during the first 20 days of the suckling period was determined. Thus, in ewes that gave birth to a single lamb, depending on its sex, the milk yield was at the level of 26.5 kg for ewe lambs and 27.5 kg for ram lambs, whereas in those with twins, the average milk yield amounted to 43.5 kg. As a result, the average daily milk yield during this period in ewes with single lambs was 1.33-1.38 kg, while in ewes with twins, it reached 2.18 kg, which was 58.0-63.9% higher.

Using the Ecomilk device, the following indicators of the chemical composition of milk were obtained (Table 2).

Table 2.

Chemical composition of milk of ewes of the Dnieper meat breed, %

Indicators	Ewes with singles	Ewes with twins
Dry matter	17.12 ± 0.43	16.94 ± 0.51
Fat	5.56 ± 0.24	5.42 ± 0.18
Protein	5.84 ± 0.19	5.82 ± 0.23
Lactose	4.78 ± 0.21	4.77 ± 0.20
Non-fat milk solids (NFMS)	11.56 ± 0.37	11.52 ± 0.45
Ash	0.94 ± 0.26	0.93 ± 0.31
Calorie content of 1 kg, kcal	952.5	938.4

The study of the main indicators of the chemical composition of milk revealed the following. The protein content in the milk of ewes from both studied groups corresponded to the baseline value and amounted to 5.84-5.82%. Lactose in milk is the most stable component, with its content at the level of 4.77-4.78%. This is a very important factor, as milk sugar plays a significant role in maintaining constant pressure in the blood-milk system.

In the milk of ewes with single lambs, the fat content was 5.56%, which was slightly higher compared to ewes with twins by 0.14 absolute percent. It should be emphasized that a sufficiently low amount of milk fat at the beginning of lactation is quite a regular phenomenon, which is also indicated by the results obtained by other researchers (Stapay et al., 2016; Fotina, T. & Zazharska, N., 2016).

The content of dry matter in milk is related to its chemical composition, and in our case, its amount turned out to be somewhat higher in ewes with single lambs – 17.12%, whereas in ewes with twins – 16.94%. A similar ratio was observed for the solid non-fat residue of milk (NFMS). As a result, the milk of ewes with single lambs had a higher caloric value – 952.5 kcal, compared to 938.4 kcal in ewes with twin lambs.

The identified differences in milk yield and chemical composition of milk in the studied ewes, in our opinion, are associated with stress-related functional load during the lactation period on the animal's body, which is caused precisely by the larger number of lambs in the litter and the non-differentiated approach in feeding.

As is well known, blood plays an extremely important role in the animal's body. Blood enables the most vital property of living tissue – metabolism. Hormonal and enzymatic regulation is carried out through the blood, as well as the protective functions of the body.

Blood largely reflects not only the general structure of the organism and its constitutional features, but also its physiological state and the associated functioning of

vital processes. For the purpose of monitoring health status and tracking metabolic processes in ewes at the early stage of lactation, key morphological blood parameters were determined. The state of erythropoiesis in sheep was assessed based on the results of erythrocyte counts, hemoglobin content determination, and hematocrit values, on the basis of which red blood cell indices (Color Index – CI and Mean Corpuscular Hemoglobin – MCH) and the Mean Corpuscular Volume (MCV) were calculated.

Differences found in the morphological composition of blood among the experimental ewes indicate the presence of physiological changes or specific adaptive features of certain groups of animals to housing conditions, feeding, or the influence of experimental factors (Table 3).

Table 3.

Hematological indicators of ewes' blood, (M±m)

No. in order	Indicators	Ewes with singles	Ewes with twins
1	Hemoglobin, g/l.	119.1 ± 2.17	1 21.9 ± 1.97
2	Hematocrit, %	34.7± 0.91	36.3 ± 0.72
3	Erythrocytes, T/l.	8.7± 0.17	9.1 ± 0.27
4	Mean corpuscular volume (MCV), fl.	39.6 ± 0.68	39.9 ± 0.53
5	Mean corpuscular hemoglobin (MCH), pg	13.6 ± 0.24	13.1 ± 0.19
6	CI (color indicator), units	0.93± 0.07	0.89 ± 0.08
7	ESR (erythrocyte sedimentation rate), mm/hr	1.0 ± 0.0	1.0 ± 0.0
8	Platelets, G/l	373.5 ± 10.13	278.0 ± 9.92*
9	Leukocytes, G/l	13.1± 0.29	10.6 ± 0.23*
Leukocyte formula			
1 0	Basophils, %	0.0 ± 0.0	0.0 ± 0.0
11	Eosinophils, %	1.0 ± 0.3	0.5 ± 0.5
1 1	Rod-nucleated, %	0.0 ± 0.0	0.0 ± 0.0
1 2	Segmented nuclear, %	57.0 ± 4.5	52.5 ± 6.3
1 3	Lymphocytes, %	41.5 ± 3.8	45.0 ± 4.7
1 4	Monocytes, %	0.5 ± 0.5	2.0 ± 1.0

*Note: * – P<0.05 in compare to the group of ewes with singles.*

More significant changes in red blood cell parameters are observed in ewes carrying twins, which have not only a higher number of erythrocytes but also a higher hemoglobin concentration within them. The obtained data indicate that the blood of these ewes contains a greater number of erythrocytes – 9.1±0.27 T/L, with a volume of 39.9±0.53 fL, whereas in ewes with a single lamb, the number of these formed elements is lower – 8.7±0.17 T/L, although their volume is almost the same – 39.6±0.53 fL. No statistically significant difference in the number of erythrocytes between the experimental groups was found.

It is evident that this morphological differentiation of erythrocytes determines the nature of oxygen transportation to tissues and organs, which is reflected in their

hemoglobin content. The hemoglobin level in ewes carrying twins was 2.4% higher, which may indicate better tissue oxygenation.

The MCH (mean corpuscular hemoglobin) indicator in both groups of animals at the beginning of the study was within the reference range and did not differ significantly. In ewes with single lambs, the mean hemoglobin content per erythrocyte was 13.6±0.24 pg, while in ewes with twins, a decrease of this indicator by 3.8% was observed.

In healthy animals, the color index, which indicates the degree of hemoglobin saturation in erythrocytes, equals one or is close to it. The color index values in the blood of sheep from both experimental groups were within the minimum norm (0.9) and did not differ significantly. Despite certain differences in the red blood cell indices of the examined ewes, the erythrocyte sedimentation rate remained at the same level and was at 1 mm/h.

Leukocytes play an important role in the body, primarily performing a protective function in ensuring cellular immunity, as well as participating in the production of protective antibodies.

The number of leukocytes in the blood of sheep from both groups was within the reference range. However, laboratory test results showed that the blood of ewes with twin lambs had a significantly lower leukocyte count compared to ewes with single lambs – by 23.5%. This difference may indicate a lower immunological reactivity of the ewes, which could be associated with greater stress load on the bodies of animals with twin lambs.

The analysis of the leukocyte formula in the blood of ewes indicates that segmented neutrophils constituted the predominant proportion among leukocytes. In both groups of animals, their content exceeded the physiological norm. Specifically, in ewes that gave birth to a single lamb, the proportion of segmented neutrophils was 57.0%, while in ewes with twins, it was 52.5%.

Lymphocytes form the basis of the immune system, and their level in both groups of ewes was at the lower threshold, ranging from 41.5% to 45.0%, indicating a weakening of adaptive immunity.

It should be noted that in terms of percentage ratio, fluctuations in white blood cells in all examined animals did not go beyond the physiological norm, and no consistent differences were observed.

Discussion. At present, under challenging economic conditions, domestic animal husbandry is one of the priority sectors, with its objectives including the development of breeding improvement programs, especially for newly created breeds, through the rational use of their genetic resources (Iovenko, V. M., 2017; Zharuk, L. V., Koval, T. S., Krayeva, O. Ye., 2020).

One of the key factors in the effective management of sheep breeding, particularly meat production, is the improvement of sheep reproductive abilities by increasing fertility levels, as well as ensuring the survival and intensive growth of lambs from birth to weaning. This rearing period is primarily determined by the amount of milk that the ewe is capable of producing, i.e., her milk yield (Lesyk O. B., Pokhyvka M. V., Makoviichuk S. D., 2021; Nel C. et al., 2023).

The productive capabilities of ewes during the suckling period are determined not only by genotype but also by compliance with technological standards regarding the necessary welfare parameters and proper feeding.

The milk production of ewes is influenced by many factors, the most important of which are the number of lambs born, feeding in accordance with the needs for the required amount of nutrients and biologically active substances, as well as ensuring proper housing conditions (Dwyer, C.M., 2007; Yakovchuk V. S., Zhulinska O. S., Ivanyna O. P., 2021). Crossbreeding can also have a significant impact on the milk productivity of sheep (Černá et al., 2023).

Australian researchers have established that the survival of newborn lambs depends on the ease of lambing, which is influenced by live weight and the duration of the embryonic period (Everett-Hincks et al., 2014; Kleemann et al., 2023). With equal litter size and a similar birth-to-mature body weight ratio, more prolific genotypes exhibit better lamb viability and have a lower optimal birth weight (Gama, L. T. et al., 1991).

The genetic parameters of lamb birth weight influence the genetic evaluation of the ewes' ability to further raise lambs (Everett-Hincks et al., Kim et al., 2017).

According to the results of conducted studies, it was found that single-born lambs had significantly higher live weight and more intensive growth compared to twins—by 34.5% for rams and 27.1% for ewe lambs, with a statistically significant difference. Rams do not always grow faster than ewe lambs during the first month of the suckling period. Twin lambs usually lag in development due to competition for milk.

Similar results were obtained in studies conducted by Pomitun et al. (2016) during the investigation of the growth intensity of Precoce lambs during the first 20 days of the neonatal period. The authors established that the highest growth intensity was observed in single-born ewe lambs, whose average daily gains were 11.4% higher compared to single-born ram lambs and significantly higher by 30.6% and 37.8% than their twin-born peers.

The composition of milk in small ruminants depends on genotype, reproduction technology, balanced feeding, agro-climatic and socio-economic conditions, as well as farm management practices (Dettori M. L. et al., 2017; Skrepets K. V. et al., 2021; Li et al., 2022).

The results of the conducted research showed that there were no significant differences in the chemical composition of milk among ewes with different numbers of newborn lambs. In the studied groups, the content of fat, protein, and lactose in the milk did not differ significantly. The average fat-to-protein ratio in the milk of ewes with single-born lambs was 1:0.95, while in ewes with twin-born lambs it was 1:0.93. At the same time, it is worth noting that, according to most scientific sources, the typical fat-to-protein ratio in milk usually ranges from 1.3 to 1.4 (Moatsou, G., & Sakkas, L., 2019). This pattern is confirmed by the research of Pokhyl V. I. and Mykolaychuk L. P. (2020) on the qualitative characteristics of milk in Romanov sheep, where the fat and protein content ranges from 6.45–6.60% and 4.78–5.20%, respectively.

Sheep milk typically has high levels of milk fat, the amount of which is primarily determined by genotype. However, as numerous studies have shown, several paratypical factors significantly influence its content, and these are not limited solely to the level of complete feeding.

Fotina T. and Zazharska N. (2016) compared the quality and safety indicators of sheep and goat milk depending on the altitude of grazing in the valleys of Zakarpattia. According to their research, the highest fat content in sheep milk – 7.69% and in goat milk – 5.61% was observed at an altitude of 341 meters above sea level ($p<0.01$). At the same time, the protein content and milk density of these animals were the lowest. It was

found that at the highest grazing point (750 meters above sea level), the fat content in their milk decreased – in sheep to 3.27%, and in goats to 2.6%, while the indicators of solid non-fat residue and protein in goat milk were higher.

Blood is an important interior indicator of an animal that characterizes its internal environment, connects biochemical processes in different parts of the body into a single system, and thereby ensures the coordination of all organs and tissues. There is a close relationship between the biochemical parameters of milk and blood and the metabolic status of lactating animals. Andjelić, B. et al. (2022), studying changes in metabolite concentrations in blood and milk during lactation and the correlations between milk and blood, emphasize that milk has great potential for predicting blood metabolites and the metabolic status not only in cows but also in other animal species.

The study of hematological blood parameters allows for the analysis of the health status of animals, the intensity of metabolic processes, and the activity of the body's defense systems. Therefore, determining hematological indicators and their role as an integral marker of redox reactions in the bodies of sheep of newly developed breeds is a pressing need (Zharuk P. G., Astanovskaya-Maslyuk O. Y., Maslyuk A. M., 2020).

The research results revealed a trend toward increased red blood parameters in ewes with twin lambs, which may indicate a higher level of oxidative processes. This is because the greater the number of erythrocytes and the higher their hemoglobin concentration, the more intense the oxidative processes in the body. The regularity of this process is also supported by the findings of Korkh I.V., Boyko N.V. (2016), who studied the morphological composition and natural resistance status of the blood in rams of different genotypes.

In healthy animals, the color index, which reflects the degree of erythrocyte saturation with hemoglobin, is equal to or close to one. In hypochromic anemia, it is significantly lower, and in hyperchromic anemia, it is higher than one. In the blood of sheep from both groups, the color index remained within the minimum normal range and amounted to 0.89±0.08 in ewes with single lambs and 0.93±0.07 in those with twins.

The leukocyte composition of the blood is determined by the complex coordination of leukopoiesis and the rate of leukocyte destruction. At the same time, certain quantitative changes in leukocytes depend on their distribution in the body. Thanks to the redistribution mechanism, even minor physiological changes can alter the leukocyte count in the blood. A distinctive feature of such redistributive leukocyte reactions is their short duration and the absence of significant changes in the leukocyte formula.

Ewes with single lambs exhibited higher leukocyte counts. We interpret these findings as evidence of higher immunological reactivity in the body, which creates favorable conditions not only for the rapid growth of the offspring but also for their increased resistance to many infectious and parasitic diseases.

To assess changes in the ratio of erythrocytes to leukocytes, it is necessary to determine the cellular coefficient, which is calculated by dividing the number of erythrocytes by the number of leukocytes in 1 μL of blood. In most healthy animals, this coefficient is approximately 100 conventional units. However, according to research results, in ewes with single lambs, it was 66 and 86, which may indicate a reduced immune status due to the postpartum period and lactation in ewes.

These data may be useful for further analysis of the influence of the number of lambs born on the health and productivity of ewes.

Conclusions.

The obtained results indicate significant differences between the studied groups of ewes in terms of lamb growth intensity and milk yield, which depend on the number and sex of the newborn lambs. These differences are likely due to the level of stress load or metabolic adaptations of the animals' organisms.

Ewes that gave birth to a single lamb demonstrated more stable hematological parameters, while ewes with twins showed noticeable changes in these indicators, which is associated with increased physiological stress.

In summary, it can be stated that lambs of the newly created Dnipro meat breed are characterized by high growth energy during the first 20 days of the suckling period. This creates favorable conditions for implementing effective measures for the intensive rearing of young animals. Particular attention should be paid to ewes that give birth to twins, considering the increased needs of their bodies for recovery and ensuring the viability of their offspring.

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GENETIC IDENTIFICATION OF EARTHWORMS FROM THE FAMILY *LUMBRICIDAE*: *EISENIA FETIDA* AND *DENDROBAENA VENETA*

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The effectiveness of vermiculture using earthworms largely depends on the species. In Ukraine, the cultivation of the red California worm, commonly recognised as Eisenia fetida, is becoming increasingly popular. Although this name typically refers to this specific species, Dendrobaena veneta is sometimes included as well. While both species are utilised in vermiculture for industrial production, they are indeed different types of worms. The sale of brood stock, regardless of the name used, relies primarily on physical characteristics assessed through visual inspection. However, trying to identify earthworm species by their physical features alone is often a guessing game, since these creatures lack the intricate and distinctive structures found in other animals. Tracing the origins of products made from such earthworms becomes an even greater challenge. To reduce potential errors and prevent misuse, a genetic method has been developed to identify two specific earthworm species using single-nucleotide polymorphisms (SNPs) in the mitochondrial COI gene. Research was performed on four species of earthworms from the Lumbricidae family at the genetics laboratory of the Institute of Pig Breeding and AIP of the NAAS. Forward primers and reverse primers targeting the cytochrome c oxidase (COI) region were developed for the mitochondrial genome of E. fetida, D. veneta, and other representatives of the Lumbricidae family. In the forward primer sequences of E. fetida and D. veneta, one nucleotide substitution was observed in the reverse three. Despite this, specific PCR products were obtained using these primer pairs for the species E. fetida, E. andrei, D. veneta and Lumbricus terrestris. Nevertheless, specific PCR products were successfully obtained using these primer pairs for the species E. fetida, E. andrei, D. veneta, and L. terrestris. The size of the amplification products, which is 253 base pairs, matches the length predicted from the nucleotide sequence. An analysis of restriction fragments from amplified mitochondrial COI gene DNA samples of four species from the Lumbricidae family revealed three distinct sets of bands. As expected, the restriction fragments for E. fetida and E. andrei were identical. In contrast, the restriction fragments of D. veneta exhibited different characteristics, as predicted by bioinformatic analysis. Furthermore, it was confirmed that DNA from L. terrestris is suitable for use as a negative control. Therefore, the proposed method for genetic identification of the earthworm species E. fetida and D. veneta using PCR-RFLP may be useful for routine analyses.

Keywords: DNA, PCR-RFLP, SNP, *Eisenia andrei*, *Eisenia fetida*, *Dendrobaena veneta*, *COI*.

ГЕНЕТИЧНА ІДЕНТИФІКАЦІЯ ДОЩОВИХ ЧЕРВ'ЯКІВ РОДИНИ *LUMBRICIDAE*: *EISENIA FETIDA* ТА *DENDROBAENA VENETA*

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Ефективність вермикультури дощових черв'яків значно залежить від виду. В Україні набирає популярності вирощування дощових черв'яків відомих під назвою червоний каліфорнійський черв'як. Хоча під цією тривіальною назвою фахівці розуміють Eisenia fetida інколи до цього включають і Dendrobaena veneta. Звичайно це різні види черв'яків, хоча обидва використовуються в вермикультурі для промислового виробництва. Продаж материнського поголів'я під тією чи іншою назвою базується виключно на фізичних характеристиках, які досліджуються за допомогою візуального огляду. Однак спроба ідентифікувати види дощових черв'яків лише за їхніми фізичними ознаками часто є грою вгадування, оскільки цим істотам бракує складних та характерних структур, характерних для інших тварин. Відстеження походження продуктів, виготовлених з таких дощових черв'яків, стає ще більшим завданням. Щоб виключити потенційні помилки та зловживання, було розроблено генетичний метод ідентифікації двох видів дощових черв'яків заснований на визначені SNP мітохондріального гена COI. Дослідження чотирьох видів дощових черв'яків родини Lumbricidae виконані в лабораторії генетики Інституту свинарства і АПВ НААН. Для мітохондріального геному E. fetida, D. veneta та інших представників родини Lumbricidae було розроблено послідовності прямих та праймерів для області цитохром-с-оксидази (COI). У послідовностях прямих праймерів E. fetida та D. veneta спостерігалася одна нуклеотидна заміна у зворотних три. Незважаючи на це, з використанням цих пар праймерів для видів E. fetida, E. andrei, D. veneta та Lumbricus terrestris отримані специфічні ПЛР-продукти. Розмір продуктів ампліфікації 253 пар основ відповідає довжині, розрахованій за нуклеотидною послідовністю. Аналіз рестрикційних фрагментів з ампліфікованого мітохондріального гена COI зразків ДНК чотирьох видів родини Lumbricidae виявив три різні набори смуг. Як і очікувалося, рестрикційні фрагменти для E. fetida та E. andrei були ідентичними. Натомість, рестрикційні фрагменти D. veneta демонстрували різні характеристики, що було передбачено біоінформаційним аналізом. Крім того, було підтверджено, що ДНК з L. terrestris є придатною для використання як негативний контроль. Таким чином, запропонований спосіб генетичної ідентифікація видів дощових черв'яків E. fetida та D. veneta методом ПЛР-ПДРФ може бути корисним для рутинних аналізів.

Ключові слова: ДНК, ПЛР-ПДРФ, SNP, *Eisenia andrei, Eisenia fetida, Dendrobaena veneta, COI.*

Introduction. Organic waste management is a growing issue due to the unsustainable practices of its disposal. Sewage treatment plants are designed to treat wastewater to produce a safe effluent. However, one of the by-products, the sewage sludge which is disposed of in landfill or used as fertilizer in agricultural operation is high in pathogens. Sustainability can be achieved by Vermicomposting of organic matter which involves accelerated cycling of nutrients though a closed cycle whereby waste

products are put to productive end use. Vermicomposting and vermifiltration are natural waste management processes relying on the use of worms to convert organic wastes to stable soil enriching compounds. Domestic wastewater management can be accommodated through these processes in a sustainable manner. A considerable reduction in pathogens has been noticed in the end product to a level that it can be safely applied to land. This paper provides an overview of the system characteristics of management systems utilising vermiculture, to manage wastewater. The process can be used in a small scale for household waste treatment to rural or urban waste management (Bajsa O. et al., 2023).

The soil ecosystem is one of the most vital ecological systems on Earth, playing a crucial role in maintaining and regulating biogeochemical cycles. This is largely due to the presence of various organisms, including earthworms, microorganisms, and fungi, which function as reducers or sinks in these cycles. Additionally, the soil serves as a critical infrastructure for agricultural ecosystems, supporting many economically important crop production systems that rely on its fertility and nutrients (Dhakane R. & Shinde A. 2020).

Although earthworms are biologically and economically significant, the taxonomic status and evolutionary relationships of most *Lumbricidae* families continue to be debated. Furthermore, earthworms demonstrate considerable cryptic diversity, which adds complexity to this issue (Latif R. et al., 2020). In addition, there are hybrids, such as *E. fetida* and *E. andrei*, which require species-specific sequences of both the maternal mitochondrial *COI* gene and the maternal-paternal nuclear *28S* gene for identification (Jaskulak M. et al., 2022).

The importance of the correct identification of earthworm species lies in the differences in response to different chemical and physical factors. For example, vermicomposting is applied to different sewage sludges. *D. veneta* in experimental conditions shows much lower resistance. Their body weight and total number of circulating immune cells are reduced in the most polluted conditions. Eisenia sp. worms showed the highest ability to accumulate heavy metals (Suleiman H. et al, 2017).

Also, pharmaceuticals released into aquatic and soil environments can be taken up by plants and soil organisms, potentially leading to the formation of unknown metabolites that may adversely affect these organisms or contaminate the food chain. A study by Fučík J, et al. (2024) determined that the earthworms *E. fetida* and *Lactuca sativa* showed the highest intensities of metabolic reactions, followed closely by roots, and the leaves showed the lowest intensities. Common metabolic reactions observed included hydroxylation, decarboxylation, acetylation and glucosidation, with metabolites related to ketoprofen being the most abundant (Fučík J. et al., 2024).

Vermicompost, commonly referred to as bio humus, is a valuable organic fertiliser created during the decomposition of organic waste by earthworms, primarily *E. foetida* and *D. veneta*, along with other soil microorganisms. As it turned out, this organic fertiliser can also be used as a bio additive to pig feed. Fomichenko M., (2025) found that the introduction of vermicompost obtained using *E. foetida* into the diet of weaned piglets had a positive effect on their growth energy and survival. In terms of live weight, weaned piglets exceeded control counterparts at the age of 60 days by 13, 11 and 6.96%, and at 90 days by 14.2 and 11.52%, respectively (Fomichenko M. 2025).

Finally, earthworms are attracting increasing attention as potential next-generation protein production systems, especially for biopharmaceuticals and animal proteins. For example, Akazawa S.I. et al. (2021) reported the development of the earthworms *E. fetida* and *E. andrei* for the production of a new generation of animal protein. They developed a transfection method for *E. fetida* and *E. andrei* using

microinjection and electroporation systems. The maximum survival and transfection efficiency were 79.2% and 29.2% for *E. fetida*, and 95.8% and 50.0% for *E. andrei*, respectively. As a result, human erythropoietin was detected in the transformed earthworm fragments by enzyme-linked immunosorbent assay. These results contribute to the development of a potentially novel animal protein production system based on earthworms (Akazawa S.I. et al. 2021). An analysis of the publications allows us to conclude that a key characteristic of vermiculture products is the species of earthworm used. There is a clear need for straightforward and dependable methods to identify earthworms, which we aimed to address in this study.

Thus, this study aims to develop a PCA-RFLP method for identifying the earthworm species *E. fetida* and *D. veneta*. This will involve a bioinformatic analysis establishing specific molecular genetic characteristics by determining the single-nucleotide polymorphisms in the mitochondrial COI gene. Additionally, we aim to assess the effectiveness of this method for the genetic identification of these earthworm species using control DNA samples.

Materials and methods. Bioinformatic analysis of six species of the genus *Eisenia*, namely – *E. andrei* (KM823569), *E. fetida* (MT271119), *E. nordenskioldi pallida* (KU708411), *E. nordenskioldi* (JX531495), *E. nordenskioldi* (JX531494) and *E. japonica* (AB542698), as well as species of four other families – *D. veneta* (KM823561), *Aporrectodea caliginosa* (KX400650), *Hormogaster huescana* (HQ621980), *Haplotaxida sp.* (HM400434) were performed by aligning nucleotide sequences using the BLAST program: Basic Local Alignment Search Tool (Altschul S.F. et al., 1990). The primer sequences specific to *D. veneta* and *E. fetida* were designed using the Primer-BLAST program (Ye J., et al. 2012). The primers EISF: GGTGGATTTGGAAACTGACT and EISR: CTAAAATTGAGGAGGCACCTG were synthesised (Metabion International AG, Germany). The search for restriction enzymes for SNP analysis was performed using the GenScript Biotech Corporation online resource (GenScript Biotech Corporation).

Control DNA samples of *E. fetida* and *E. andrei* were obtained from Dr. Jörg Römbke at ECT Oekotoxikologie in Flörsheim am Main, Germany, and Professor Barbara Plytycz from the Department of Evolutionary Immunobiology at the Institute of Zoology, Jagiellonian University, Kraków, Poland. Live samples of *D. veneta* and *E. fetida* were sourced from the entrepreneur N.L. Fomichenko, Zaporizhia, Ukraine. The common earthworm (*L. terrestris*) served as a negative control, with samples collected in Poltava, Ukraine (GPS coordinates 49.631625, 34.549721).

Before isolating DNA from live worms, they were euthanised by freezing at -20°C for 3 to 4 hours. DNA was extracted from the worm tissue using the DNA-sorb-B nucleic acid isolation kit following the manufacturer's instructions (InterLabServis-Ukraina, LTD).

DNA amplification was performed on a programmable thermostat (Biometra GmbH), with annealing of primers under conditions (t = 60°C). Restriction digestion of PCR products was performed using *Tas*I endonuclease (Thermo Scientific™) under the manufacturer's conditions.

The restriction digestion products were separated by electrophoresis on an 8% polyacrylamide gel in 1×TBE buffer, using pUC19/*Msp*I DNA (Thermo Scientific™) as a molecular weight marker. The gel was stained with ethidium bromide solution (10 mg/cm^3). The results were documented using the MicroDOC Gel Documentation System (Cleaver Scientific).

Research results. Forward primer sequences were developed for the cytochrome c oxidase (*COI*) region of the mitochondrial genome for the species *E. fetida*, *D. veneta*,

and other members of the family *Lumbricidae*. A single nucleotide substitution was observed in the forward primer sequences of *E. fetida* and *D. veneta*. Additionally, the forward primer sequences for *E. fetida* and *E. andrei* were found to be identical (Tab. 1).

Table 1.

Sequence of forward primers for *Eisenia fetida, Dendrobaena veneta* and other members of the family *Lumbricidae*

An earthworm species	Nucleotide accession from NCBI Datasets	Forward primer sequences
Eisenia fetida	MT271119	GGTGGATTTGGAAACTGACT
Dendrobaena veneta	KM823561	* GGAGGATTTGGAAACTGACT
Eisenia andrei	KM823569	GGTGGATTTGGAAACTGACT
Lumbricus terrestris	PV871429	* * GGCGGGTTTGGAAACTGACT
Eisenia nordenskioldi pallida	KU708411	* * GGGGGTTTTGGAAACTGACT
Eisenia japonica	AB542698	* * * GGGGGGTTTGGAAATTGACT
Hormogaster huescana	HQ621980	* * * GGGGGATTTGGAAATTGATT
Aporrectodea caliginosa	KX400650	* * * * GGCGGCTTCGGAAATTGACT

Note. Nucleotide mismatches with the Eisenia fetida sequence (MT271119) are indicated with an asterisk.

Three nucleotide substitutions were identified in the reverse primer sequences of *E. fetida* and *D. veneta*. The forward primer sequences of *E. fetida* and *E. andrei* were identical, similar to the forward primers (Tab. 2).

Table 2.

Sequence of forward primers for *Eisenia fetida, Dendrobaena veneta* and other members of the family *Lumbricidae*

An earthworm species	Nucleotide accession from NCBI Datasets	Reverse primer sequences
Eisenia fetida	MT271119	CAGGTGCCTCCTCAATTTTAG
Dendrobaena veneta	KM823561	* * * CAGGGGCCTCATCAATCTTAG
Eisenia andrei	KM823569	CAGGTGCCTCCTCAATTTTAG
Lumbricus terrestris	PV871429	* * * * CAGGTGCATCCTCTATTCTGG
Eisenia nordenskioldi pallida	KU708411	* * * * ** * CTGGAGCTTCATCAATCCTTG
Eisenia japonica	AB542698	* * * * * * CTGGAGCCTCATCTATTCTTG
Hormogaster huescana	HQ621980	* * * CAGGAGCCTCATCTATTTTAG
Aporrectodea caliginosa	KX400650	* * * * * ** * CTGGAGCTTCATCTATCCTTG

Note. The sequence of the reverse primers is provided for the plus strand of DNA; nucleotide mismatches with the Eisenia fetida (MT271119) sequence are indicated with an asterisk.

Amplification of a fragment of the mitochondrial cytochrome c oxidase subunit I (*COI*) gene from DNA samples of four species within the *Lumbricidae* family resulted in PCR products measuring 253 base pairs in size. The size of the amplified products matches the calculated size derived from the nucleotide sequence. This finding indicates that the developed primer pair is effective for studying at least four species of earthworms in this family (Fig. 1).

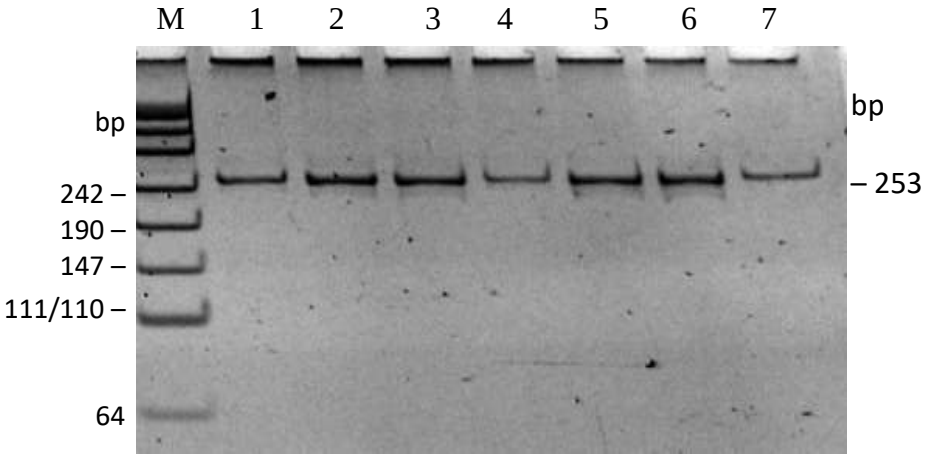

Fig. 1. ***Amplification products of a 253 bp fragment of the mitochondrial COI gene: M – pUC19/MspI DNA marker; 1,2,3,4 – DNA from Eisenia fetida; 5 – DNA of Lambricus terrestris 6 – DNA from Dendrobaena veneta; 7 – DNA of Eisenia andrei.***

An analysis of the restriction fragments of the amplified mitochondrial COI gene of DNA samples of four species from the *Lumbricidae* family revealed three distinct band sets. As anticipated, the *Tas*I restriction fragments for *E. fetida* and *E. andrei* were identical. In contrast, the *Tas*I restriction fragments for *D. veneta* displayed a clear and distinct identity, confirming the expected made through bioinformatic analysis. The *Tas*I restriction fragments of DNA from *E. fetida* and *E. andrei* measured 144, 101, and 8 bp. The sizes of the restriction fragments obtained correspond precisely to those calculated from the nucleotide sequence (Fig. 2).

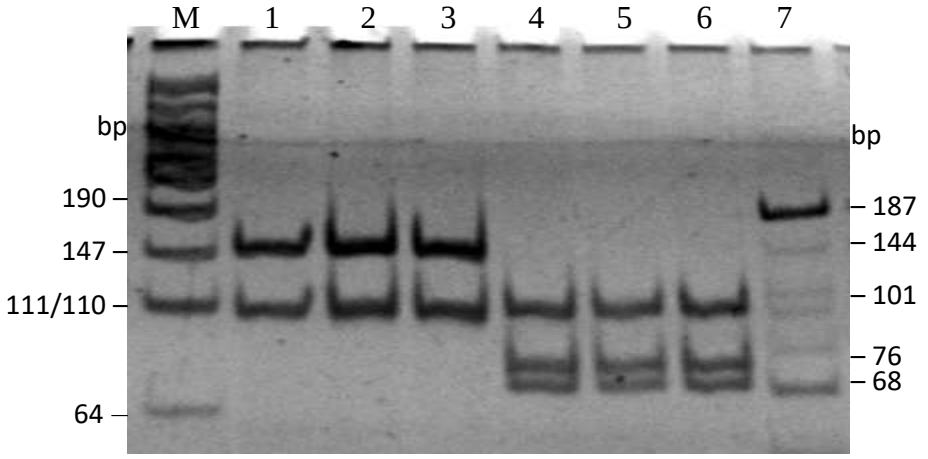

Fig. 2. ***Tas1 electrophoresis of restriction DNA fragments of earthworms of the Lumbricidae family: M – pUC19/MspI DNA marker; 1,2, – DNA Eisenia fetida; 3 – DNA Eisenia andrei; 4,5,6 – DNA Dendrobaena veneta; 7 – DNA Lambricus terrestris***.

The *Tas*I restriction fragments of *D. veneta* DNA measured 101, 76, 68, and 8 bp in size. However, the observed fragment sizes did not completely align with the expected

sizes based on the nucleotide sequence KM823561. According to the calculations derived from the nucleotide sequence KM823561, with have expected one fragment of 101 base pairs and two fragments of 76 bp.

The difference from what was expected is the incorporation of the reverse primer EISR: CAGGTGCCTCCTCAATTTTAG into the PCR product (the sequence is provided for the plus strand of DNA). This insertion creates an artificial *Tas*I (AATT) recognition site in the *D. veneta* DNA PCR product, resulting in the formation of restriction fragments of 76 and 8 base pairs.

L. terrestris DNA is confirmed as a suitable negative control. The application of an 8% polyacrylamide gel permits effective separation of TasI restriction fragments via vertical electrophoresis.

Discussion. Both *E. fetida* and *D. veneta* are epigean (surface) worms. These species live in organic-rich places such as manure piles, compost pits, and decaying plants. However, *D. veneta* is capable of penetrating deeper into the soil.

D. veneta, also known as *Eisenia hortensis*, is a species of earthworm in the family *Lumbricidae*. Daniele Rosa (1857-1944), the renowned Italian invertebrate zoologist celebrated for his pioneering studies of oligochaetes, was the first to describe *D. veneta* (Rosa, 1886). While the Latin word "veneta" conjures images of sea blue or blue-green, the name pays homage to its discovery site, Campo di Marte in Venice. Rosa described its colouration as matching that of *E. fetida*: a ruddy hue streaked with yellow bands between the segments, making these two species frequent sources of confusion. However, *D. veneta* stands apart with its broader setae, which glow clearly under blue light, and a clitellum that is typically pale and whitish, unlike the more ruddy clitellum of *E. fetida*. (Blakemore R.J. et al., 2022).

Composting earthworms of the genus *Eisenia* play an important role in soil ecosystems. However, the taxonomic classification of this genus, especially the sibling species *E. fetida* and *E. andrei*, is complicated due to their morphological similarity. C. Csuzdi et al. (2022) assessed the utility of the complete mitochondrial genome (mitogenome) for identification and differentiation of the two species. The complete mitogenomes of *E. andrei* and *E. fetida* were 15,714 and 16,560 bp, respectively. They contained 37 genes, comprising 13 protein-coding genes (PCGs), two rRNA genes, 22 tRNA genes, and a putative non-coding region, as observed in other earthworms. Sequence comparisons based on the complete nucleotide sequences, excluding the non-coding region, showed 85.8% similarity, whereas the predicted amino acid sequences of the 13 PCGs were 92.7% similar between the two species. The extended sequence showed significant differences between the two species and other known earthworm species, suggesting its potential as a feasible molecular marker for species identification (Csuzdi C. et al., 2022).

Nucleotide sequences, in particular a fragment of the mitochondrial *COI* gene, have been used for species identification of earthworms. This sequence is also involved in DNA barcoding, a common method of species identification. The practicality and reliability of this method were assessed by cross-validation organised by an international group of scientists, the Eisenia Barcoding Initiative (EBI), from four public institutions and two private laboratories. Coded samples of *E. fetida* and *E. andrei* were provided to 28 ecotoxicology laboratories from 15 countries on four continents. Five laboratories in Belgium, Canada, Germany and Spain tested the blank samples by DNA barcoding. The results of this cross-validation were submitted to the OECD and ISO for standardisation of DNA barcoding. This study also revealed nucleotide sequences of *Eisenia fetida* 1 and *Eisenia fetida 2*, which were assigned to different cryptic species (Römbke J. et al., 2016).

A simultaneous hermaphrodite is an organism that possesses both male and female reproductive organs, allowing it to produce both types of gametes: sperm and eggs. While self-fertilisation is possible, it is not the primary method of reproduction. In many species, isolated virgin earthworms tend to produce very few viable offspring or may even result in sterile cocoons.

To investigate the existence of hybridisation between *E. fetida* and *E. andrei*, Plytycz B. et al. (2018) crossed virgin individuals of both species in the laboratory. A hybrid offspring was identified using two methods: first, they were recognised by species-specific haploid mitochondrial DNA sequences of maternal origin, specifically the COI gene. Second, hybrids were identified using diploid nuclear DNA sequences from the 28s rRNA gene of maternal and paternal origins. The results obtained show that the *E. andrei* and *E. fetida* species are easily cultivated under laboratory conditions, making them ideal models in biomedicine and ecotoxicology. Fertile hybrids of the species *E. andrei* and *E. fetida* were discovered during this study, highlighting their potential for investigating the molecular basis of interspecific barriers, introgression mechanisms, and speciation (Plytycz B. et al., 2018) Experimental confirmation of the existence of fertile hybrids *E. andrei* and *E. fetida* revealed the insufficient suitability of standard methods for the differentiation of these species. For this purpose, another method of genetic identification was proposed.

Another method of genetic identification is the use of microsatellite markers. Thus M. Jaskulak et al. (2022) used Illumina technology (Nano 2×250 v2 - MiSeq) and a *de novo* assembly strategy. A total of 4,258 microsatellites were identified in the genomic DNA of the earthworm species *E. fetida* and *E. andrei*. The utilisation of microsatellite markers was essential for analysing genetic diversity and studying the population genetics of these species, particularly due to the presence of interspecific hybrids (Jaskulak M. et al., 2022)

Currently, molecular methods are preferred for accurately classifying earthworm species. However S. Andleeb et al. (2021) note that these methods can be labour-intensive and costly. To address this issue, a model has been proposed that uses digital images and machine learning to identify earthworm species. In all evaluation conditions, this model exhibited the highest performance, validating its use for studying earthworm taxonomy (Andleeb S. et al., 2021).

The most important reason for the lack of a nationwide and standardized survey of soil organisms in Germany is probably the laborious and expensive identification of soil invertebrates. To address this problem, S. Jänsch et al. (2025) sampled earthworms and soil at 25 sites. The animals were identified morphologically and by metabarcoding of community DNA (comDNA) and environmental DNA (eDNA). A comparison of the results showed that comDNA detected more species (on average 3.6) than eDNA (3.0) and morphological identification (2.8). In contrast, eDNA, on average, detected a similar number of species as morphological identification. However, some species seem to have a different probability of being detected by eDNA than others, depending on their abundance, behavior, biology or body size. All three identification methods can distinguish between sites with different species composition, and the degree of separation can vary depending on the identification method. The relative fraction of eDNA reads shows potential as a surrogate for relative abundance/biomass for endogeic but not for anecetic species. The overall goal of the MetaSOL project (from which this contribution emerged) was to develop guidelines for effective and routinely implemented monitoring of soil fauna. The results showed that genetic identification methods are suitable for earthworms. S. Jänsch et al. (2025) emphasize that before genetic identification methods can be implemented in official practice, key prerequisite issues, such as comprehensive,

well-curated and quality-controlled DNA databases and standardization of methods, need to be addressed.

In summary, it is important to acknowledge the points discussed. Although there are various methods for identifying earthworms, the PCR-RFLP method can be advantageous for laboratories that utilise it.

Conclusions.

1. The studies allowed us to utilise the PCR-RFLP method by selecting the optimal pair of primers and restriction enzymes for the genetic identification of the earthworm species *E. fetida* and *D. veneta*;

2. An artificial *Tas*I recognition site is created in the PCR product of *D. veneta* DNA by incorporating the reverse primer EISR into the PCR product: CAGGTGCCTCCTCAATTTTAG (sequence presented on the plus strand of DNA);

3. *Lambricus terrestris* DNA can serve as a negative control in genetic studies due to its notable differences in nucleotide sequences compared to *E. fetida* and *D. veneta*;

4. The genetic differentiation of *E. fetida* and *E. andrei* requires more complex analysis for several reasons. First, there is considerable genetic similarity between these species. Second, earthworms exhibit high cryptic diversity. For example, *E. fetida* 1 and *E. fetida* 2 have been assigned to different cryptic species. Finally, interspecific hybrids of *E. fetida* and *E. andrei* exist.

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USE OF CRUSHED FLAX SEEDS AS A PREBIOTIC WHEN FEEDING DAIRY COWS DURING THE FULL LACTATION CYCLE

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Increased consumption of dry matter in diets by highly productive cows leads to a high level of energy per unit of dry weight and the introduction of 45-50% of concentrated feed into the feed mixture. As a result, scar digestion is modified, lactic acid synthesis by scar microorganisms increases, which creates conditions for the development of an acute inflammatory process in typical scar acidosis.

The main method of preventing this disorder is the constant use of alkaline additives and buffer mixtures in the diet, which allow you to maintain the optimal pH.

The cationic structure of these systems, when constantly used, has an irritating effect on the small and large intestines of cows, which leads to a weakening of digestion and the development of a diarrheal effect of varying severity. This leads to a decrease in the digestibility of feed nutrients and, as a result, a decrease in the level of milk yield with a loss of milk quality indicators.

Restoration of normal digestion in ruminants in such conditions is possible with the additional introduction of specific probiotic drugs into the diet, of which there are not many, and most of them are ineffective.

Therefore, it is more reliable and expedient to use not pro -, but prebiotics, which form a protective effect against diarrhea based on the activation of animals ' own intestinal microflora by changing the activity of the villi surface. In addition, the prebiotic effect is achieved by using individual astringents that reduce villi irritation.

However, such special additives are characterized by an increased cost, so it is advisable to search for normal feed components of the diet that have pronounced prebiotic properties and justify their effectiveness in feeding cows.

In a long-term experiment on dairy cows, the effect of correcting the feeding of highly productive animals using crushed flax seeds was studied, which was used as a functional feed ingredient with a prebiotic effect.

Keywords: prebiotic, crushed flax seeds, feed additive, dairy cows, feeding ration.

ВИКОРИСТАННЯ ПОДРІБНЕНОГО НАСІННЯ ЛЬОНУ В ЯКОСТІ ПРЕБІОТИКА ПРИ ГОДІВЛІ ДІЙНИХ КОРІВ ПРОТЯГОМ ПОВНОГО ЛАКТАЦІЙНОГО ЦИКЛУ

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Підвищене споживання сухої речовини раціонів високопродуктивними коровами зумовлює високий рівень енергії в одиниці сухої маси та введення в кормову суміш 45-50% концентрованих кормів. В результаті модифікується рубцеве травлення, зростає синтез молочної кислоти мікроорганізмами рубця, що створює умови у розвиток гострого запального процесу у типовому рубцевому ацидозі.

Основним методом профілактики зазначеного порушення є постійне застосування у складі раціону лужних добавок і буферних сумішей, що дозволяють утримувати оптимум pH.

Катіонна структура зазначених систем при постійному застосуванні діє дратівливо на тонкий і товстий кишечник корів, що обертається послабленням травлення та розвитком діарейного ефекту різного ступеня тяжкості. Це призводить до зниження перетравності поживних речовин корму і, як наслідок, зменшення рівня надою із втратою показників якості молока.

Відновлення нормального травлення у жуйних у таких умовах можливе при додатковому введенні в раціон специфічних пробіотичних препаратів, яких не багато, і більшість з них малоефективна.

Тому надійніше і доцільніше застосовувати не про -, а пребіотики, які формують захисний ефект від діарей на основі активації власної мікрофлори кишечника тварин шляхом зміни активності поверхні ворсинок. Крім того, пребіотичний ефект досягається використанням окремих в'яжучих речовин, що знижують подразнення ворсинок.

Однак такі спеціальні добавки відрізняються підвищеною вартістю, тому доцільно здійснити пошук нормальних кормових компонентів раціону, що мають виражені пребіотичні властивості і обґрунтувати їх ефективність у годівлі корів.

У тривалому досліді на дійних коровах вивчали вплив корекції годівлі високопродуктивних тварин за допомогою подрібненого насіння льону яке використовувалось в якості функціонального кормового інгредієнта з пребіотичною дією.

Ключові слова: пребіотик, подрібнене насіння льону, кормова добавка, дійні корови, раціон годівлі.

Introduction. Feeding highly productive cows requires a mandatory increase in dry matter intake to the maximum in any segment of the cow's lactation cycle. In addition, when cows are milked above 30 kg per day, the energy concentration in the dry matter of

the diet of such animals should be 11.0 - 11.3 MJ per 1 kg. It is possible to ensure such a high level of energy concentration per unit of dry mass only if at least 45-50% of concentrated feed with a large part of their corn grain composition is introduced into the feed mixture of cows .

With a high level of concentrated feed in the diet, scar digestion is modified, which dramatically increases the synthesis of lactic acid by Rumen microorganisms. As a result, the pH of the scar content falls below 6.0. Acidification of the scar contents creates conditions for the development of an acute inflammatory process, which is typical of scar acidosis.

Failure to take timely measures to normalize the acidity of the scar contents (PH 6.2-6.7) leads to the destruction of the absorbent surface of the scar wall and the entry of large amounts of acids into the blood. Metabolic acidosis occurs, which develops into lactation acidosis (Khorrami, B., 2021, Hossain, E. 2020, Galbat, S. A. 2020).

As a result of the development of lactation acidosis, the acidity of fresh milk rises to 19.5-21.0 tons, its thermal stability decreases, and problems arise with fermentation of dairy raw materials during the preparation of fermented dairy products. As a rule, milk with high acidity is rejected, causing huge damage to production.

The main method of preventing acidosis of cows is the constant use of alkaline additives (baking soda, magnesium oxide) and buffer mixtures with a large buffer capacity, which allow you to maintain the optimal pH for up to 6-8 hours.

All known buffer additives used in dairy cattle breeding are made on the basis of a special mixture of oxides and salts of magnesium and potassium. sodium.

The level of introduction of such buffer additives into the diet of cows sometimes has to be raised to 150-300g per head per day.

Almost always, the cationic structure of these buffer systems irritates the small and large intestines of cows. Therefore, the constant use of buffer additives often leads to a weakening of digestion and the development of a diarrheal effect of varying severity in cows. If this effect lasts for a long time, then the severity of the process increases. This leads to a decrease in the digestibility of feed nutrients and, as a result, a decrease in the level of milk yield with a loss of milk quality indicators.

Restoration of normal digestion in ruminants in such conditions is possible with the additional introduction of probiotic drugs into the diet.

However, for dairy cows, there are not many specific probiotic drugs on the market, and most of them are ineffective.

Therefore, it is more reliable and expedient to use not pro -, but prebiotics, which form a protective effect against diarrhea based on the activation of animals ' own intestinal microflora by changing the activity of the villi surface (Uyeno, Y. 2015, Wang, Y. 2021,Hernández Sánchez, D. 2022). In addition, the prebiotic effect is achieved by using individual astringents that reduce villi irritation (Yuan, C. 2023, 2024).

However, special prebiotic supplements are characterized by an increased cost, and their use does not always pay off with additional milk products (Zhang, Y. 2021)

Therefore, it is advisable to search for normal feed components of the diet that have pronounced prebiotic properties and justify their effectiveness in feeding cows (Jonova, S. 2021, Sun, N. 2021).

Research material and methodology. The experiment was conducted in the conditions of sooo "Petrodolinskoe" of the Odessa District of the Odessa region from July 1, 2023 to March 30, 2024 on one technological group of dairy cows of the Holstein breed.

A group of dairy cows was recruited within 12 days. It included 89 cows 10 days after calving.

The experiment was conducted using the Group period method. To this end, the study was divided into three stages. For each of them, a separate diet was compiled, balanced by a wide range of indicators. At the same time, the nutritional value of the experimental and control diets did not differ from each other.

At the first stage, the effect of introducing an experimental supplement on the productivity and physiological parameters of the animals during the phase of increasing milk yield was studied. To do this, after 10 days of the equalization period and the end of colostrum production by cows, they were transferred to a control diet. After 20 days of feeding the control diet, 150 g of crushed flaxseed was added to the cows ' feed instead of a sufficient amount of crushed sunflower seeds 40 days before the end of the Phase of increasing milking capacity .

Then, from 100 to 120 days of lactation (the second control period), the cows were fed a control diet without flax seed additives. On the 121st day of lactation, the animals were transferred to the second experimental diet with the inclusion of 200 g of flax per head per day. The billing period was extended by 20 days, but the experimental diet was maintained until the end of the second lactation phase (200 days).

In the final, third phase of lactation, cows were transferred to the third control diet without the study supplement, and animal observations continued for the next 20 days. After that, flax seeds were added to the diet again in the amount of 250 g per head instead of sunflower seeds.

In the third experimental period, the observation of cows lasted for 20 days, but after the end of the experimental feeding, it was preserved until the beginning of cow offspring.

During the experiment, it was studied:

- in fact, cow milk yields by lactation days are individual for each head during the control and experimental periods;
- the fat and protein content of milk is individual for each cow;
- daily ruminant status of cows in groups according to computer diagnostic tools;
- actual feed consumption by group according to the information on the amount of feed indicated on the feed feed table through the mixer, and taking into account the residues on the feed feed table the next day before the phase of increasing milking capacity of a new portion of the diet;
- some biochemical parameters of cow blood at the end of each period of the experiment.

Total protein (refractometrically), protein fractions (albumins, globulins) – according to all and McCord, Reserve alkalinity – according to I. P. Kondrakhin, creatinine – according to the Jaffe color reaction, ASAT and alt - dinitrophenylhydrozine method according to Reitman-Frenkel, total bilirubin – according to the Endrassik diazoreaction-the Cleghorn-Grof method, calcium – according to Devaard, phosphorus from vanado - is pulsed molybdate reagent.

Research results. Taking into account the actual range of feed on the farm and the possibility of purchasing feed additives and veterinary drugs, as well as the actual productivity of cows for pre - lactation, we have formed and optimized the feeding rations of cows for three phases of lactation-distribution, maximum milk production and the last third of lactation.

The results of optimizing rations during the Phase of increasing milking capacity are shown in Table 1.

Table 1.

Feeding rations for cows at the Phase of increasing milking capacity (10-60 days of lactation)

Indicators	Units. measurements	Preliminary period of the Phase of increasing milking capacity (10-30 days of lactation)	Experimental period at the Phase of increasing milking capacity (30-60 days of lactation)
Wheat	kg	1,0	1,0
Corn	kg	2,8	2,8
Wheat bran	kg	2,0	2,0
Peas	kg	0,5	0,5
Sunflower seeds with husk	kg	0,5	0,35
Soy cake	kg	2,5	2,5
Sunflower meal. SP 36%	kg	0,8	0,8
Rapeseed meal	kg	1,5	1,5
Kitchen salt	kg	0,11	0,11
Monocalcium Phosphate	kg	0,1	0,1
Limestone flour	kg	0,11	0,11
Baking soda	kg	0,1	0,1
Protected fat	kg	0,2	0,2
Magnesium oxide	kg	0,05	0,05
Buffer"Kremix"	kg	0,15	0,15
Haylage	kg	8	8
Corn silage	kg	18	18
Legume hay/green	kg	0,8	0,8
Winter wheat straw	kg	0,8	0,8
Premix	kg	0,2	0,2
Ground flaxseed		-	0,15
The diet contains:			
OE CATTLE	MJ	264,6	263,2
Dry matter	kg	22,98	22,98
% CP concentrates	%	46,0	46,0
Crude protein	g	3618,0	3692,0
Prot. PEREV. cattle	g	2508,0	2519,0
RP	g	2338,0	2331,0
NRP	g	1271,0	1298,0
Raw fat	g	1499,0	1499,0
Raw fiber	g	4733,0	4702,0
CDC	g	4190,0	4178,0
NDC	g	8203,0	8022,0
Sugar	g	1102,0	1101,0
Starch	g	4559,0	4557,0
Ca	g	151,4	151,2
P	g	119,0	118,8

The diets were balanced in all main nutritional indicators and corresponded to the planned daily milk yield of cows by lactation phases.

Additives were introduced into the diet to normalize the acid-alkaline balance in the body and prevent acidification of scar contents (drinking soda, magnesium oxide and a special buffer produced by Kremix).

20 days after the start of feeding the diet of the previous period, crushed flax seeds were additionally introduced into its composition at a dose of 150 g per head instead of an adequate amount of sunflower seeds. As a result, the feeding ration remained balanced only at the level of the control period, but began to have the form shown in Table 1.

The experimental diet was continued to be fed until the end of the Phase of increasing milking capacity (60 days), after which the animals were transferred to the feeding characteristic of the maximum lactation according to Table 2 (second control period) without including flax seeds.

Such a diet continued to be fed until the lactation period of 120 days, and after that the cows were again transferred to experimental feeding, which differs from the control one in that crushed flax seeds were introduced into its composition.

As a result, the composition and nutritional value of the experimental diet for the second phase of lactation acquired the form shown in Table 2.

Table 2.

Feeding rations of cows of the control and experimental periods at the stage of maximum milk yield (60-200 days of lactation) for dairy cows 600 kg of milk yield 30 liters maximum milk production

Indicators	Unit of Measurement	Control Period	Experimental period
Wheat	kg	1,5	1,5
Corn	kg	2,5	2,5
Wheat bran	kg	2,0	2,0
Peas	kg	0,8	0,8
Sunflower seeds with husk	kg	0,5	0,3
Soy cake	kg	2,2	2,2
Sunflower meal. SP 36%	kg	0,9	0,9
Rapeseed meal	kg	1,5	1,5
Kitchen salt	kg	0,11	0,11
Monocalcium Phosphate	kg	0,1	0,1
Limestone flour	kg	0,11	0,11
Baking soda	kg	0,1	0,1
Protected fat	kg	0,2	0,2
Magnesium oxide	kg	0,05	0,05
Buffer"Kremix"	kg	0,15	0,15
Haylage	kg	9	9
Corn silage	kg	17	17
Legume hay/green	kg	0,8	0,8
Winter wheat straw	kg	0,9	0,9
Premix	kg	0,2	0,2
Ground flaxseed		-	0,2

Continuation of Table 2.

The diet contains:			
OE CATTLE	MJ	258,1	259,3
Dry matter	kg	23,15	23,15
% CP concentrates	%	50,10	50,10
Crude protein	g	3561,0	3591,0
Prot. PEREV. cattle	g	2479,0	2492,0
RP	g	2338,0	2321,0
NRP	g	1255,0	1293,0
Raw fat	g	1444,0	1439,0
Raw fiber	g	4791,0	4793,0
CDC	g	4332,0	4337,0
NDC	g	7,893	7,901
Sugar	g	1032,0	1032,0
Starch	g	4522,0	4521,0
Ca	g	155,4	155,2
P	g	117,0	117,0

After 80 days of the experimental period of the second phase of lactation, the cows were transferred to the last phase and the diet presented in Table 3 was set.

After 20 days of the control period (lactation period 220 days), the cows were transferred to an experimental diet, which was fed before cow drying off period.

The composition of the experimental diet of the last phase of lactation is presented in Table 3.

Table 3.

Feeding rations of cows of control and experimental periods at the stage of the last third of lactation (200-300 days of lactation)for dairy cows 600 kg of milk yields 26 liters

Indicators	Unit of Measurement	Control period at the stage (200-220 days of lactation)	Experimental period at the stage (220-300 days of lactation)
Wheat	kg	1,0	1,0
Barley	kg	1,0	1,0
Corn	kg	1,0	1,0
Wheat bran	kg	2,0	2,0
Sunflower seeds with husk	kg	0,3	0,05
Soy meal SP 44%	kg	2	2
Rapeseed meal	kg	1	1
Kitchen salt	kg	0,15	0,15
Monocalcium Phosphate	kg	0,1	0,1
Limestone flour	kg	1,3	1,3
Protected fat	kg	0,1	0,1
Ryegrass haylage	kg	6	6
Corn silage	kg	20	20
Ryegrass hay	kg	1,5	1,5
Winter wheat straw	kg	2	2

Continuation of Table 3

Premix	kg	0,2	0,2
Ground flaxseed		-	0,25
The diet contains:			
OE CATTLE	MJ	252,1	252,7
Dry matter	kg	23,04	23,04
% CP concentrates	%	36,9	36,9
Crude protein	g	3661,0	3668,0
Prot. PEREV. cattle	g	2479,0	2481,0
RP	g	2338,0	2327,0
NRP	g	1255,0	1262,0
Raw fat	g	1444,0	1443,0
Raw fiber	g	4601,0	4621,0
CDC	g	4332	4338,0
NDC	g	7,893	7,895
Sugar	g	1032,0	1032,0
Starch	g	4522,0	4522,0
Ca	g	155,4	155,3
P	g	117,0	117,3

The results of zootechnical studies are shown in Table 4.

Table 4.

Results of zootechnical studies in the experiment on the phases of the physiological cycle of lactation

№	Indicators	Experiment period		In % be control
		control	experiment	
	Phase of increasing milking capacity of a cow (10-60 days of lactation)			
1	milk yield in 20 days, kg per head /	32,3÷0,24	33,1±0,29	102,4
2	percentage of fat in milk	3,77±0,08	3,76±0,09	99,73
3	percentage of protein in milk	3,21±0,09	3,22±0,06	100,3
4	feed consumption, OE per 1 kg of n	8,19	7,95	97,06
5	rumination, min.	503±11,3	527±12,8	104,77
6	frequency of visually visible diarrhe	3	1	33,34
	Maximum milk yield phase (60-200 days of lactation)			
1	milk yield in 20 days, kg per head /	31,2±0,31	32,3±027	103,5
2	percentage of fat in milk	3,82±0,10	3,80±0,09	99,47
3	percentage of protein in milk	3,22±0,07	3,24±0,08	100,6
4	feed consumption, OE per 1 kg of n	8,27	8,03	97,07
5	rumination, min.	498±12,21	518±11,33	104,01
6	frequency of visually visible diarrhe	5	2	40,0
	Phase of preparation to cow drying off (200-300 days of lactation)			
1	milk yield in 20 days, kg per head /	25,5±0,39	26,8±0,33	105,1
2	percentage of fat in milk	3,88±0,12	3,89±0,14	100,2
3	percentage of protein in milk	3,21±0,1	3,23±0,09	100,6
4	feed consumption, OE per 1 kg of n	9,88	9,43	95,44
5	rumination, min.	494±13,2	507±12,4	102,6
6.	frequency of visually visible diarrhe	6	1	16,67

Table 4 shows that the introduction of flax seeds into the diet of cows in selected doses without changes in the overall nutritional value of the diet affected their productivity at all stages of the experiment. At the phase of increasing milking capacity, flax supplementation stimulated milk yield growth by 2.4%, in the maximum milk yield phase - by 3.55%, and in the lactation attenuation phase - by 5.1%. At the same time, fluctuations in the percentage of fat and protein in milk at different stages of observations were not significant.

Analysis of the data in Table 4 shows the effect of the introduction of an experimental dietary supplement on the optimization of digestion. Under the influence of the additive, an increase in the duration of rumination by 2.6-4.77% was recorded in all three stages of the experiment. In addition, visual observations of cows allowed us to establish a significant decrease in the frequency of diarrheal effects under the influence of dietary changes during the experimental periods of the experiment.

Changes in the nature of digestion under the influence of the introduction of flaxseed into the diet affected some indicators of blood biochemistry (Table 5).

The data in Table 5 show that the change in cow feeding caused a positive reaction in the blood composition of the animals.

Table 5.

Some indicators of blood serum biochemistry by lactation phases at the end of the control and experimental periods of the experiment

№	Indicators	Experiment period	
		control	experiment
	Phase of increasing milking capacity of a cow (10-60 days of lactation)		
1	Total Protein, g/%	73,5±1,17	74,77±2,23
2	Albumins, g/%	35,2±2,21	37,2±2,17
3	y-globulins, g/%	28,4±3,05	29,9±2,76
4.	Reserve alkalinity OB % CO_2	47,7±2,99	49,2±3,07
5	Creatinine, mmol / l	88,9±3,54	90,2±3,67
6	ASAT, Mo / l	39,2±5,33	37,1±3,29
7	Alt, Mo / l	106,5±2,99	100,3±4,55
8	Bilirubin, mmol / l	5,49±0,77	5,01±0,49
9	Calcium, mmol / l	2,55±0,11	2,56±0,12
10	Phosphorus, mmol / l	0,77±0,06	0,79±0,09
	Maximum milk yield phase (60-200 days of lactation)		
1	Total Protein, g/%	79,22±2,23	81,37±2,98
2	Albumins, g/%	39,18±2,06	39,91±2,54
3	y-globulins, g/%	29,67 ±3,12	32,8±2,90
4	Reserve alkalinity OB % CO_2	51,37±3,87	53,8±2,02
5	Creatinine, mmol / l	92,2±3,93	96,5±4,45
6	ASAT, Mo / l	39,44±6,34	37,9±2,99
7	Alt, Mo / l	113,31±5,21	102,11 ±4,23
8	Bilirubin, mmol / l	5,38±1,24	4,78±0,55
9	Calcium, mmol / l	2,59±0,19	2,87±0,21
10	Phosphorus, mmol / l	0,88±0,09	0,92±0,13

Continuation of Table 3

	Phase of preparation to cow drying off (200-300 days of lactation)		
1	Total Protein, g/%	79,5±1,56	77,01±2,92
2	Albumins, g/%	40,13±2,29	41,75±2,45
3	y-globulins, g/%	29,55±3,34	31,79±3,06
4	Reserve alkalinity OB % CO_2	48,11±3,03	50,24±1,61
5	Creatinine, mmol / l	81,54±2,23	88,92±3,01
6	ASAT, Mo / l	40,12±6,08	35,44±2,57
7	Alt, Mo / l	108,11±2,03	99,12±3,02*
8	Bilirubin, mmol / l	5,89±0,43	4,52±0,31*
9	Calcium, mmol / l	2,67±0,19	3,36±0,22*
10	Phosphorus, mmol / l	0,79±0,09	0,84±0,11

*Note. * P<0.05*

During all three stages of the experiment, a tendency to increase total protein, albumins, and gamma globulins was recorded. Under the influence of the additive used, there is an increase in the Reserve alkalinity of the Reserve alkalinity of the blood and a decrease in the concentration of bilirubin. Flax supplementation caused a decrease in the activity of liver enzymes. Moreover, this decrease in the last stage of the experiment was significant against the control.

Indirectly, the supplement used caused an increase in the concentration of calcium and a tendency to increase the concentration of phosphorus in the blood.

The results of the zootechnical effect in relation to the indicators of blood biochemistry allow us to state that the use of crushed flax seed supplements should be considered as an effective prebiotic supplement that normalizes digestion in the gastrointestinal tract of cows.

This supplement had little effect on the nature of scar digestion, but at the same time significantly changed the nature of the processes of nutrient absorption in the small intestine and the normalization of biocenosis in the small and large intestines. This can be confirmed by the multiple reduction in the frequency of diarrhea in highly productive cows in the experiment.

Discussion. The aim of our study was to find out whether the effect of crushed flax seeds can be considered as an effective prebiotic agent. Ghedini, C.P. 2021, argues for the effect of such probiotics due to lignans, which are rich in plant substances.

It is known that flax contains astringents of the glycosidic series, which retain their activity throughout the entire gastrointestinal tract of the cow. This reduces the degree of intestinal maceration by chyme residues, which creates the expected antidiarrheal effect (Warnasooriya, V. B. 2023,. Huang, G.,2021).

In addition, flax carbohydrates and its phenolic compounds are a beneficial environment for the development of lactic acid of the small and large intestines and bifidoflora of the large intestine. Because of this, microbial coenosis can be optimized, which will positively affect the immune characteristics of the gastric intestinal tract (Melgar, A. 2025).

Reducing irritation of the intestinal villi, most likely, provided an increase in the degree of absorption of energy, protein and minerals, which affected the positive dynamics of blood biochemistry indicators. For this reason, the dairy productivity of cows increased.

Our data are consistent with numerous European studies that have shown a positive effect of flax seeds on the normalization of digestion, increased milk productivity

and improved blood biochemistry indicators.(Zhang, Y. 2021, Singh, S. 2021, Johnson, A.2023).

Flax seeds contain a significant concentration of mucus or gum, which is mainly found in the outer layer of the seed coat and is known for its many health benefits, such as slowing down digestion, lowering serum cholesterol, and improving glycemic control (Lee, M. 2023).

Adding flaxseed to the diet of dairy cows can effectively increase the levels of omega-3 polyunsaturated fatty acids (n-3 PUFAs) in raw milk, which in turn leads to changes in volatile organic compounds (Huang, G.2022).

Conclusions:

1. Crushed flax seeds can be considered as an effective prebiotic to normalize the cow's digestion during the lactation period.

2. Under the influence of an experimental supplement at a dose of 150-250g at different stages of the cow's lactation cycle, it is possible to increase milk productivity by 2.4-5.1%, reduce feed costs by 3.93-4.56% per 1 liter of milk, increase the duration of scar rumination and reduce the diarrheal effect in animals to a minimum.

3. Prebiotic supplement in the form of crushed flax seeds provides a positive dynamics of individual blood parameters: the total protein, albumins and gamma globulins in the blood serum increase, the alkaline Reserve increases, the activity of ASAT and alt enzymes decreases, the accumulation of bilirubin in the blood decreases, and the concentration in calcium and phosphorus increases.

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DETERMINATION OF THE BREEDING VALUE OF STUDRAMS, TAKING INTO ACCOUNT THE INFLUENCE OF THE LEVEL OF FEEDING ON THE MANIFESTATION OF PRODUCTIVITY IN THEIR OFFSPRING

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The article presents the results of studies that were performed on the livestock of gimmers *-14 months of age of the Kharkiv intra-breed type of the precos breed. In total, 516* gimmers *heads were individually registered for Origin and productivity. Among them-409 heads of offspring of 5* studrams, *the breeding value of which was determined by comparing the productivity indicators of the Daughters of individual sheep with the indicators of their peers, and-with the average indicators for the herd. All offspring obtained from* studrams *from artificial insemination of sheep in three adjacent years were evaluated. At the same time, their cultivation took place at different levels of annual feed consumption. Statistical processing, correlation-regression, and variance analysis were performed in the SPSS-22 software environment.*

Studies have shown that with an increase in feed consumption by 4-6% per year, there is a likely increase in the average live weight for the herd from 6.7 to 11.6%, – by 15.1-16.1%, wool length – by 6.4–16.0 %. ($p<0.001$ in all cases), but this had a different effect on the disclosure of the potential of breeding traits in the offspring of individual sheep. So, if the genotype of studram *No. 1823 turned out to be stable in terms of transmitting its hereditary qualities to offspring in changing conditions of providing them with food, then the genotype of* studram *No. 1625 and, especially, No. 1579 turned out to be plastic. In this regard, the indicators of rank correlation ($R \pm mr$) of their score on the quality of offspring in adjacent years significantly differed and ranged from 0.600±0.462 to 0.900±0.252. in general, the indicators of feed consumption in the cultivation of offspring had reliable positive, average correlation (r) with the live weight of 0.439, clipping and wool length, respectively, 0.487 and 0.505. it is shown that the influence of genotypes of* studrams *(η^2) for live weight, woolclip and coat length in their daughters was 3.0, respectively; 4.5 and 8.3% (in all cases $p < 0.001$), while the influence of the annual feed consumption factor was significantly greater, 17.9; 26.4 and 26.2%, respectively. The interaction of two factors (the genotype of the Ram X feed consumption) in relation to the impact on the living mass of* gimmers *was significantly lower, and amounted to 2.8 %, but remained probable, $p< 0.05$. to predict the parameters of individual characteristics of offspring productivity, appropriate mathematical models are*

proposed that take into account the complex influence of the genotype of the Ram and the level of feed consumption on them.

Keywords: studram, genotype, prediction model, offspring, feeding level, impact strength.

ВИЗНАЧЕННЯ ПЛЕМІННОЇ ЦІННОСТІ БАРАНІВ-ПЛІДНИКІВ З УРАХУВАННЯМ ВПЛИВУ РІВНЯ ГОДІВЛІ НА ПРОЯВ ПРОДУКТИВНОСТІ У ЇХНІХ ПОТОМКІВ

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У статті наведено результати досліджень, що були виконані на поголів'ї ярок -14-місячного віку харківського внутрішньопородного типу породи прекос. Всього в індивідуальному обліку походження і продуктивності перебувало 516 голів ярок. В їх числі - 409 голів потомків 5 баранів-плідників, племінну цінність яких визначали методом порівняння показників продуктивності доньок окремих баранів з показниками ровесниць, та – з середніми показниками по стаду. Оцінці підлягали усі потомки, одержані від баранів плідників від штучного осіменіння вівцематок у три суміжні роки. При цьому їх вирощування відбувалося за різних рівнів річних витрат кормів. Статистичну обробку, кореляційно-регресійний та дисперсійний аналіз здійснювали в програмному середовищі SPSS-22.

Дослідженнями встановлено, що за збільшення витрат кормів на 4-6 % за рік відзначається вірогідне підвищення середньої живої маси по стаду від 6,7 до 11,6 %, настрига вовни – на 15,1-16,1 %, довжини вовни – на 6,4–16,0 %. ($p<0,001$ в усіх випадках), але це по різному позначалося на розкритті потенціалу селекційних ознак у потомків окремих баранів. Так, якщо генотип барана № 1823 виявився стійким щодо передачі своїх спадкових якостей потомкам в мінливих умовах забезпечення їх кормами, то генотип барана № 1625 та, особливо, № 1579 виявився пластичним. У зв'язку з цим, показники рангової кореляції ($r \pm m_r$) бальної їх оцінки за якістю потомства у суміжні роки істотно різнилися та складали від 0,600±0,462 до 0,900±0,252. В цілому ж показники витрат кормів при вирощуванні потомків мали достовірні додатні, середнього рівня кореляційні зв'язки (r) з живою масою 0,439, настригом та довжиною вовни відповідно 0,487 і 0,505. Показано, що вплив генотипів баранів-плідників (η^2) на живу масу, настриг та довжину вовни у їхніх доньок складав відповідно 3,0; 4,5 та 8,3 % (в усіх випадках $p < 0,001$), тоді як вплив фактора річних витрат кормів мав значно більшу силу, відповідно 17,9; 26,4 та 26,2 %. Взаємодія двох факторів (генотип плідника х витрати кормів) щодо впливу на живу масу ярок виявилая значно нижчою, та склала 2,8 %, але залишалася вірогідною, $p< 0,05$. Для прогнозування параметрів окремих ознак продуктивності потомків запропоновані відповідні математичні

моделі, що враховують комплексний вплив на них генотипу плідника та рівня витрат кормів.

Ключові слова: баран-плідник, генотип, модель прогнозування, потомок, рівень годівлі, сила впливу.

Introduction. In the conditions of constant growth of current costs, and recently the instability of providing livestock feed due to the influence of sharp climate fluctuations, an important problem for the development of sheep breeding is the development of production systems that are resistant to this impact. One of its important components is the development of effective methods for creating genotypes of animals with increased resistance to extreme climate changes and the ability to convert feed resources, if they are deficient, into products. That is, under these conditions, the importance of breeding sheep genotypes increases, on the one hand, with a lower sensitivity to the impact of environmental factors on their body, and on the other – with a lower impact on the environment.

In this regard, according to McLaren A., Brotherstone S., Lambe N.R. et al. (2015), to assess the degree of interaction in the genotype – environment system and their consideration in production systems, an important task is to identify and quantify the effects of environmental factors and, based on them, study the relationships with certain breeding and adaptive characteristics of animals.

Nel C.L., Werf J. H. J., Rauw W.R., Cloete S.W.P. (2023) also emphasize the importance of solving the above problem and note that in relation to the sheep industry, it is less studied in contrast to pig or dairy cattle breeding, which develops through intensive production systems.

Among the mechanisms for reducing the influence of environmental factors on the state of production systems in the field of animal husbandry, a number of authors see the genetic selection of individuals who are most able to counteract this influence (Knap P.W.,2005; Rauw W.M., and Gomez-Raya L., 2015; Berghof T.V.L., Poppe M. and Mulder H.A., 2019).

At the same time, Falconer D.S.(1990) notes that antagonistic selection (selection of plus-options in a "bad" environment and vice versa of minus-options in a "good" environment reduces susceptibility to its influence, while synergistic selection (+ , or - viriants in a better or worse environment, respectively) increases this sensitivity.

Vdovychenko Yu.V., Kudryk N.A., Polska P.I. et al. (2018) the main methodological prerequisite for an objective assessment of studrams by genotype is considered, first of all, sufficient and full-fledged feeding and appropriate conditions for keeping their offspring in ontogenesis. In other words, it is necessary to provide maximum conditions for the implementation of synergistic selection. This is a methodological approach, comparing it with the above conclusion of Falconer D.S., can provide high-performance animals as a result of selection, but with a high sensitivity to environmental factors.

According to Jong G., Bijma P. (2002), the presence of a variance in the interaction between the animal genotype and the environment is the basis for selecting the level of sensitivity of the genotype to environmental diversity. Therefore, all known models of quantitative selection use the presence of covariance between phenotype and fitness. At the same time, genotypes that show high variability of phenotypes under changing environmental conditions are classified by these researchers as "plastic", while those that show low variability are classified as "stable" or "stable".

Colditz I.G. and B.C.Hine (2016) characterizes resistance as the ability of an animal organism to maintain productivity in a wide range of environmental conditions,

primarily without compromising reproduction functions, as well as health. in their opinion, the test indicator for assessing the stability of an organism can be the rate of Return of its variable indicators to their original (normal) state. The phenotypic stability of sheep and cattle at such critical technological moments as weaning young animals from their mothers is determined by them for further genotypic selection of individuals more resistant to this technological stress.

Rather M.A., Shanaz S., Ganai N.A. et al. (2020) examined the effect of the year of assessment and genotype of the studrams on the main indicators of young Development – live weight at birth, at 6 and 12 months of age, as well as the age of the first lamb and the period between lambs in daughters. Using a mixed least squares model and maximum likelihood, they revealed significant variability of traits over a significant period of their evaluation, and also established a highly likely influence of the studrams genotype on their manifestation in offspring. Unlike the above, Santos-Silva J., Mendes I.A, Bessa R.J.B. (2002) in an experiment on lambs weaned from sheep, it was found that the genotype of the father had little effect on the main indicators of meat productivity and quality of Lamb compared to the applied feeding system and live weight at slaughter. Research By Wang W., Zhang X., Wei H. et al. (2024) also prove the reliable effect of feeding lambs with concentrated feed in the pasture system of their fattening on some quality characteristics of the resulting Lamb.

Mallick P.K., Pourouchottamane R., Rajapandi S. et al. (2017) also note that in addition to the feeding factor, other non-genetic factors play an important role in realizing the genetic growth potential of Bharat merino lambs in India. At the same time, the analysis of variance proved that the year, gender and season of birth are reliably sources of variability in the live weight indicators of young animals in different periods of its development up to one year of age. Due to the positive correlations they found between live weight at 6 months of age and other age periods, this indicator is recommended to be used as a selection criterion for achieving progress in this breed of sheep in terms of live weight.

Research By S. Kramarenko, Luhovyi S., Balan D. et al. (2020) also attest to the significant impact of the year of lambing, breed, sheep genotype, maternal age, birth type, and sex of lambs on their birth weight and weaning from their mothers. According to their data, the influence of the Ram genotype on these characteristics of offspring ranges from 2.5 to 9.0 %.

Abebe A., Banarjee S., Goshmie S. et al. (2020) indicate that the effect of the sex factor of lambs was likely only in relation to the live weight of newborn lambs and was not associated with this indicator at weaning lambs and at 6 and 12 months of age. The influence of factors of the age of sheep and the type of birth of lambs was also not significant. At the same time, the season and year of birth significantly affected growth indicators in all age periods. In this regard, the breeding value of animals was significantly cut off by the years of their evaluation.

Along with this, Tortereau F., Marie-Etancelin C., Weisbecker J.-L. (2020). et al. it is noted that in conditions when feed costs are among the largest in the structure of total production costs in the field of sheep breeding, studrams are increasingly inclined to produce animals that consume less feed and at the same time retain high growth energy and meat productivity. They also note that the feed efficiency indicator is inherited by sheep in this area of productivity and, according to them, may not be genetically related to other characteristics of productivity. In addition, the researchers separately emphasize that sheep with a high conversion of feed into products is characterized by a lower level of methane emissions due to intestinal fermentation of feed. Therefore, they are

recommended to select studrams according to the criterion of the effectiveness of the use of feed by their offspring.

Confirming the great importance of indicators of the effectiveness of sheep feed use for the modern development of sheep breeding, Trapina I., Kairisa D. and Paramonova N. (2023) still note that the performance indicators of each Ram's offspring are very variable. Therefore, in their opinion, no marker accurately explains the variability of feeding performance indicators to be used in breeding programs aimed at improving them. In this regard, it is proposed to search for relationships between phenotypic effects and genotypic effects, which is located at the DNA level, on the effectiveness of sheep feed use in relation to Latvian dark-headed sheep.

Regarding the function of animal reproduction, Joshi P. (2022) among the factors that significantly affect the body's response to changes in environmental conditions, the level of feeding, photoperiod, behavioral responses and hierarchical status, as well as the genotype of animals are identified. At the same time, the level of energy supply to the body is more influential on the reproductive function of females than males.

Nel C.L., Werf J. H. J., Rauw W.R., Cloete S.W.P. (2023) pointing out certain difficulties in measuring the strength of environmental factors on certain indicators of the state of the animal body (health, physical fitness, product quality), they emphasize the need to combine existing methods for evaluating and selecting the best animal genotypes with the possibilities of genomic selection. A similar conclusion is reached and

Biriukova O., Polupan Yu., Melnyk Yu., et al. (2024), investigating the effect of the bug assessment method on improving individual characteristics of dairy cattle productivity. In addition, they note that the forecast of breeding value based on the results of genomic assessment is often overestimated, which indicates the need to adjust it by evaluating studrams for the quality of offspring using traditional methods.

Vashchenko P. A., Zhukorskyi O. M., Saenko A. M. et al. (2023) in the process of searching for links between the manifestation of productivity and the genotype of animals, as well as the nature of interaction with the environment, indicate its presence in individuals carrying the MC4R gene, which encodes the melanocortin receptor associated with the regulation of appetite and energy balance in the body with live weight and spy thickness in pigs of different ages. At the same time, they revealed a different degree of influence of the feeding factor and genotype on live weight due to the age of young animals. If at the age of 4 months the influence of only the type of feeding was reliable on this indicator, then at the age of 6 months the likely influence of the interaction of feeding factors and genotype was recorded. Under conditions of limited feeding, young pigs with AG alleles of this gene had the lowest live weight and had a thicker fat layer compared to peers with the GG genotype.

Currently, there are separate data on non-genomic inheritance of certain traits in animals in the literature sources. So, the Gross N study., Taylor T., Crenshaw T., Khatib H. (2020) reveal the genetic mechanisms of the influence of feeding rations of sheep of the polypay breed during prepubertal period on puberty and the development of offspring obtained from them. They proved that the diet of studrams is able to alter DNA methylation in influential genomic regions (genes associated with sexual development DAZAP1, CHD7, TAB1, MTMR2, CELSR1, MGAT1 and live weight DUOX2, DUOXA2) in sheep gametes, which caused differences in live weight and age of puberty in their offspring. See Also Tillquist N.M., Reed S.A., Reiter A.S et al. (2024) report that deficiencies in the feeding of pregnant females can negatively affect the reduction in the number of offspring born, its growth and metabolic processes. These negative consequences can also manifest themselves in the next generation. Research By Tillquist N.M., Kawaida M.Y., Reiter A.S. et al. (2025) also prove that limited (60%) and increased

(140% of NRC norms) feeding of suyagny sheep caused a slight decrease in the concentration of immunoglobulins (IG) in their colostrum and milk, and also manifested in their first-generation offspring as a decrease in the intensity of IG sorption. In the second generation, the established feature did not appear.

Taking into account the urgency of solving the problem of creating highly productive sheep genotypes resistant to the influence of negative environmental factors, as well as taking into account the complex nature of interaction between them, we set out to study the influence of a quantitative level of feeding, genotypes of sheep-parents and the complex effect of these factors on the manifestation of the main indicators of productivity in offspring and assess the degree of stability of sheep genotypes based on the reaction of their offspring to the influence of this factor.

Materials and methods of research. The study was performed on a number of sheep of the Kharkiv intra-breed type of the prekos breed of the breeding plant "Dpdg "Gontarovka" of Livestock farming Institute of National Academy of Agrarian Sciences of Ukraine. According to the quality of offspring, 5 main studrams of the "elite" class were evaluated, which were used in this herd for artificial insemination of sheep for three adjacent years. Sheep for insemination were randomly assigned to individual studrams, taking into account the quantity and quality of sperm received daily from them. And inseminated with fresh sperm in accordance with the requirements of the "instructions for artificial insemination of sheep and goats" (2002). Feed costs in the corresponding years of cultivation of the offspring obtained from them differed significantly and amounted, according to the official accounting statements of the farm (form 50-SG) in the first year – 4.55; the second – 4.73 and 5.02 centners of feed units per head per year. At the same time, the maintenance staff and technology of keeping sheep were stable.

The assessment of animals was carried out by expert and instrumental methods in accordance with the main provisions of the "Methodology for assessing breeding value and genetic changes in sheep populations of various areas of productivity" (2018) and the current sow 01.22.37-525: 2006 " studrams. Methods for evaluating your own productivity and genotype". All daughters of studrams were evaluated for a complex of the most important breeding traits at the age of 14 months.

Statistical processing of results, correlation-regression and variance analysis were performed in the "general linear model" software environment of the SPSS-22 statistical analysis package for PCs.

Research results. Studies have established that with an increase in the level of feeding when raising the offspring of the evaluated studrams, there is a corresponding increase in their productivity (table. 1). If we take as a basis for comparison the first year of the assessment, which accounted for the lowest level of feeding, then in the following year such productivity indicators as live weight, woolclip and its length increased on average for the gimmers herd by 6.7; 16.1 and 16.0 % ($p<0.001$ in all cases). The difference in the same characteristics between animals in the second and third years of evaluation was also highly likely and amounted to 11.6, 15.1 and 6.4%, respectively ($p<0.001$). Changes in the level of feeding also had a positive effect on most other signs – the assessment of the pattern of fiber Convolution and the assessment of hair overgrowth of the back and belly in gimmers. Indicators for assessing head overgrowth and coat thickness were more stable.

Due to an increase in the level of feeding, the reaction of genotypes of descendants of studram No. 1579 was the greatest in terms of changes in live weight and woolclip.

Table 1

Changes in productivity indicators for the herd and in the Daughters of individual studrams **by the years of their assessments**

Number of ram	Daug-hters, heads	Indicators for evaluating daughters by a set of characteristics (M±m)								
		heads hairiness, points	length wool, sm	waviness, points	fineness, microns	constitu-tion asses-sment, points	wool hairiness of the sheep's, points		live weight, kg	wool-sclip, kg
							back	belly		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
First year of evaluation										
1579	42	2,12±0,13	11,76±0,26	4,33±0,11	23,95±0,13	4,49±0,06	3,94±0,08	3,98±0,08	47,07±1,58	4,26±0,16
1625	23	1,74±0,17	11,43±0,28	4,17±0,16	23,91±0,11	4,58±0,09	4,07±0,10	3,93±0,09	53,74±1,57	4,36±0,23
1823	18	2,39±0,12	12,19±0,37	4,28±0,18	24,06±0,13	4,53±0,10	4,03±0,11	4,28±0,11	51,39±1,19	4,60±0,22
9510	17	2,00±0,17	11,47±0,37	3,94±0,13	23,88±0,15	4,44±0,09	3,79±0,10	3,79±0,09	53,94±1,28	4,04±0,21
4464	38	2,11±0,09	10,59±0,28	3,63±0,12	23,95±0,10	4,63±0,06	4,04±0,07	3,84±0,07	54,50±0,91	3,98±0,15
Others (2 heads)	9	1,78±0,22	12,17±0,55	4,00±0,29	24,11±0,11	4,67±0,14	3,94±0,15	3,89±0,18	53,11±1,89	4,40±0,43
Herd	147	2,05±0,06	11,45±0,14	4,05±0,06	23,96±0,05	4,55±0,03	3,98±0,04	3,95±0,04	51,73±0,66	4,23±0,08
Second year of evaluation										
1579	22	1,95±0,19	14,09±0,30	4,05±0,18	23,91±0,29	4,43±0,07	3,93±0,12	4,30±0,10	55,24±1,71	5,35±0,19
1625	37	1,70±0,14	12,84±0,27	4,27±0,14	23,62±0,21	4,49±0,07	4,12±0,07	4,22±0,07	55,10±1,26	4,68±0,13
1823	63	2,17±0,08	13,63±0,21	4,35±0,09	23,90±0,10	4,52±0,06	4,00±0,10	4,28±0,06	55,44±1,13	5,02±0,10
9510	19	2,26±0,13	12,66±0,36	4,05±0,20	23,32±0,23	4,37±0,11	3,84±0,11	4,08±0,09	53,94±1,51	4,51±0,25
4464	31	2,23±0,13	13,13±0,28	4,13±0,14	23,71±0,22	4,42±0,08	3,98±0,10	4,08±0,09	55,60±1,72	4,84±0,18
Others (5 heads)	33	2,09±0,13	13,03±0,22	4,24±0,15	23,55±0,17	4,41±0,08	3,79±0,09	3,89±0,08	55,33±1,40	4,98±0,18
Herd	205	2,08±0,05	13,28±0,11	4,23±0,06	23,71±0,08	4,46±0,03	3,97±0,04	4,6±0,03	55,20±0,59	4,91±0,06

Continuation of Table 1

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Third year of evaluation										
1579	17	2,09±0,23	14,44±0,57	4,47±0,19	23,71±0,18	4,44±0,07	4,05±0,11	3,88±0,10	63,29±1,44	5,77±0,26
1625	30	1,83±0,15	15,13±0,40	4,37±0,16	24,07±0,16	4,55±0,06	4,22±0,08	4,22±0,09	61,33±1,29	5,52±0,19
1823	17	2,29±0,19	15,41±0,76	4,71±0,14	24,06±0,06	4,65±0,07	4,32±0,10	4,41±0,12	62,00±1,57	6,38±0,33
9510	14	1,43±0,31	14,46±0,30	4,64±0,17	23,71±0,19	4,54±0,10	4,07±0,12	3,89±0,11	60,51±2,02	5,35±0,29
4464	21	2,48±0,11	12,67±0,51	4,10±0,17	23,90±0,19	4,45±0,08	4,33±0,09	4,36±0,10	62,48±1,60	5,56±0,22
Others (4 heads)	68	2,10±0,10	13,70±0,31	4,22±0,09	24,12±0,12	4,57±0,04	4,29±0,05	4,21±0,06	61,25±0,77	5,59±0,13
Herd	167	2,06±0,07	14,14±0,20	4,34±0,06	24,00±0,07	4,54±0,03	4,25±0,03	4,19±0,04	61,60±0,51	5,65±0,09
Total estimate for three years										
1579	81	2,06±0,09	12,96±0,24	4,28±0,08	23,89±0,11	4,46±0,03	3,96±0,06	4,03±0,05	52,69±1,21[2]	4,87±0,13
1625	90	1,76±0,09[1]	13,24±0,24	4,28±0,09	23,84±0,11	4,53±0,04	4,13±0,04	4,14±0,05	56,82±0,84	4,88±0,11
1823	98	2,23±0,07	13,67±0,22[1-3]	4,40±0,07	23,97±0,07	4,56±0,04	4,07±0,05	4,30±0,05	55,83±0,86	5,18±0,11[2,3]
9510	50	1,94±0,12	12,76±0,26	4,18±0,11	23,62±0,12	4,44±0,06	3,89±0,06	3,93±0,06	55,78±0,99	4,59±0,16[3]
4464	90	2,23±0,07	11,95±0,23[1]	3,91±0,08	23,86±0,10	4,52±0,04	4,09±0,05	4,04±0,05	56,74±0,86	4,65±0,12
Others (11 heads)	107	2,17±0,09	12,79±0,22	4,16±0,10	23,75±0,11	4,46±0,50	3,99±0,07	4,04±0,07	57,39±1,04	5,09±0,14
Herd	516	2,07±0,03	13,04±0,10	4,21±0,03	23,87±0,04	4,51±0,02	4,06±0,02	4,11±0,02	56,29±0,38	4,95±0,05

Note: for woolclip between No. 1823 and No. 4464 (3 - p<0.05) and No. 9510 (2-p<0.01) and between No. 9510 and The Herd average (p<0.05);
By live weight - between No. 1579 and No. 1625 and No. 4464 and The Herd average (2 p<0.01 in all cases);
By coat length-between No. 1823 and No. 4464 (1-p<0.001), No. 9510 (2-p<0.01) and No. 1579 (3 - p<0.05) and No. 4464 compared to the Herd average (1-p<0.001)
By heads hairiness -No. 1625 and No. 1823 and No. 4464 and against the Herd average (1-p<0.001).

According to these signs, there was an increase of almost 1.34 times. Approximately the same increase in the length of wool in the Daughters of Ram No. 1625, while in terms of woolclip and live weight – only in the range of 14-25%. Against the background of high feed costs, the realized potential of only wool productivity in the descendants of sheep No. 1823, No. 4464 increased by 39.1 and 39.6%, respectively, while the increase in other characteristics was in the range of only 14-26 %. These data indicate that an increase in total feed costs has different effects on unlocking the potential of certain breeding traits in the offspring of individual sheep. To a greater extent, this applies to wool cuts, to a lesser extent – to live weight. This feature is probably due to the belonging of sheep of the precos breed to the combined meat-wool direction of productivity, in which live weight is a breeding feature, which is realized in priority under different environmental conditions, while wool productivity for the formation of which the body spends more feed nutrients, requires an increase in the overall level of feeding.

In general, for three adjacent years of evaluation, the descendants of studram No. 1579 were 7.3% lower in live weight than the peers of the best Studram No. 1625 in terms of development of this trait ($p<0.01$). The live weight of the Daughters of this studram was also significantly lower compared to the indicators of the offspring of studram No. 4464 and from the average indicator for the herd, respectively, by 7.1% and 6.4 % ($p<0.01$ in both cases). In terms of hair cutting, the Daughters of sheep No. 9510 and 4464 were inferior to the offspring of the best in the development of this trait of Ram No. 1823 by 11.3 % ($p<0.01$) and 10.2 % ($p<0.05$), and the Daughters of Ram No. 9510 were also inferior to the Herd average by 7.3 % ($p<0.05$).

The difference between the" best "and" worst " in terms of coat length of gimmer daughters of rams No. 1823 and 4464 was 1.7 cm (or 12.6% for $p<0.001$). Daughters of sheep No. 9510 and 1579 were also inferior to offspring of sheep No. 1823 by 6.7 % ($p<0.01$) and 5.2 % ($p<0.05$), respectively. Also significantly "worse" against the indicator of the average length of wool in the herd were gimmers, the father of which was ram No. 4464 (by 8.4 %, at $p<0.001$).

Among other signs, attention is drawn to the lowest assessment of head overgrowth in the descendants of ram No. 1625. they were significantly inferior to their peers – the descendants of sheep No. 1823 and No. 4464 and the average value for the herd ($p<0.001$). Significantly better in the herd, and in comparison with the same age-descendants of Ram No. 9510 were the Daughters of Ram No. 1823 according to the assessment of belly overgrowth and wool convolutions ($p<0.001$).

Taking into account the significant number of breeding traits that were taken into account when evaluating the offspring obtained from sheep and the differences indicated above between individual groups of gimmers, we ranked each group of offspring by the value of these traits. The sum of points obtained in this case on all grounds allowed us to make a generalized assessment of each Ram. Results (Table. 2) show that in most respects the descendants of Ram No. 1823 had the highest ranks. At the same time, this is typical not only for a generalized three-year assessment of all offspring, but also for the results of assessment in individual years of their cultivation. That is, the genotype of the offspring of this ram can be considered to a certain extent more stable in terms of the effect of the feeding level factor on the phenotypic manifestation of productive signs. At the same time, the stability, but the lowest ranks for the years of evaluation of offspring and generally for three years was noted Ram No. 9510. this indicates its status as a "degrader" for most indicators of productivity of offspring. Daughters of Ram's No. 1579 and No. 1625 were relatively better compared to peers of other studrams at a lower level of feeding, while gimmers, whose father is Ram No. 4464, significantly increased the total rank score for improving feeding conditions during their cultivation (Table. 3).

Table 2

Results of ranking the average values of offspring indicators by years of evaluation of studrams

Number of Ram	Year of evaluation	Rank of descendants by attributes									
		heads hairiness, points	length wool, sm	waviness, points	fineness, microns	constitution assessment, points	wool hairiness of the sheep's, points		live weight, kg	wool-sclip, kg	total points for all attributes
							back	belly			
1579	1	2	3	1	3	5	4	2	6	4	30
	2	5	1	5	6	3	4	1	4	1	30
	3	4	4	3	1	6	6	6	1	2	33
	Σ	3	3	2	5	4	5	4	6	4	36
1625	1	6	5	3	2	3	1	3	3	3	29
	2	6	5	2	3	2	1	3	5	5	32
	3	5	2	4	4	3	3	3	4	5	33
	Σ	5	2	2	3	2	1	2	2	3	22
1823	1	1	1	2	4	4	3	1	5	1	22
	2	3	2	1	5	1	2	2	2	2	20
	3	2	1	1	3	1	2	1	3	1	15
	Σ	1	1	1	6	1	3	1	4	1	16
9510	1	4	4	5	1	6	5	6	2	5	38
	2	1	6	5	1	6	5	4	6	6	40
	3	6	3	2	1	4	5	5	6	6	38
	Σ	4	5	3	1	5	6	5	5	6	40
4464	1	3	6	6	3	2	2	5	1	6	34
	2	2	3	4	4	4	3	4	1	4	29
	3	1	6	6	2	5	1	2	2	4	29
	Σ	1	6	5	4	3	2	3	3	5	32
Others	1	5	2	4	5	1	4	4	4	2	31
	2	4	4	3	2	5	6	5	3	3	35
	3	3	5	5	5	2	4	4	5	3	33
	Σ	2	4	4	1	4	4	3	1	2	25

Table 3.

Sum of points and ranks of Studrams by indicators of evaluation of their daughters in adjacent years

Number of Ram	Results by years of offspring evaluation							
	first year		second year		third year		together for 3 year	
	total points	rank	sum of points	rank	sum of points	rank	sum of points	rank
1579	30	3	30	3	33	3	36	4
1625	29	2	32	4	33	3	22	2
1823	22	1	20	1	15	1	16	1
9510	38	5	40	5	38	4	40	5
4464	34	4	29	2	29	2	32	3
Others	31	-	35	-	33	-	25	

The above-mentioned features of productivity in the offspring of sheep by the years of their rearing under the influence of both the genotypes used in the selection of sheep and environmental factors caused from 60 to 90% of the coincidences of evaluation ranks (table. 4). At the same time, the highest rank correlation was found in studrams between the second and third years of their offspring's assessment (with a higher level of feeding compared to the first year).

Table 4.

Coefficients of rank correlations of sheep ratings (n=5) based on the productivity indicators of their daughters raised in years with different feeding levels

Indicators	Value of rank repeatability coefficients by year of assessment					
	1-2	1-3	2-3	1- total*	2- total*	3- total*
$(r \pm m_r)$	0,600± 0,462	0,700± 0,412	0,900± 0,252[3]	0,900± 0,252[3]	0,700± 0,412	0,600± 0,462
(tr_s)	1,30	1,70	3,57	3,57	1,70	1,30

*Note: [3] – probably, p<0,05; * overall score for 3 years*

It is characteristic that the highest rank relationship was between the overall (cumulative) assessment of offspring and the first year. That is, the worst level of feeding when growing spring crops most affected the generalized indicator of the rank assessment of sheep - studrams.

Obviously, this state of connections is due to the different number of offspring over the years in which they were raised and evaluated. So, despite the fact that over three adjacent years, most sheep (with the exception of Ram No. 9510) received and evaluated from 81 to 98 heads of daughters, their ratio for individual years was different. More than 52% of all offspring of Ram No. 1579 were raised in the first year, while more than 64% of Daughters of Ram No. 1823 were raised in the second year, and 42% of offspring of Ram No. 4464 were raised in the third year of evaluation. Consequently, the different proportion of daughters whose rearing occurred in years with low or high feeding levels accordingly affected the objectivity of the generalizing assessment for three years.

In this regard, using the "general linear model" procedure of the SPSS-22 statistical analysis package, we developed models for predicting the expected indicators

of woolclip, wool length and live weight of sheep based on estimates of the factors "studram" and "feed consumption". This made it possible to take into account the influence of the feeding level factor on the overall assessment of Rams - on the quality of offspring. The parameters of the developed model for wool cuts due to the influence of factors of the Ram's genotype and the level of feeding of its offspring are shown in Table 5.

Table 5.

Model for predicting the expected clipping of sheep wool (kg) based on estimates of the factors "Studram" and "feed consumption"

Factor characteristics	Value of factor characteristics	Fixed effect / regression coefficient		Level significance
		B	standard error	
	Free member	-10,510	1,323	0,000
Ram	№ 1579	0,455	0,176	0,010
	№ 1625	0,193	0,172	0,263
	№ 1823	0,600	0,170	0,000
	№ 4464	0,150	0,172	0,386
	№ 9510	0	-	-
Feed consumption/ year		3,178	0,277	0,000

This model satisfactorily (R^2 = 0.272; R^2 adj = 0.263) and reliably (p < 0.001) describes the main patterns that occur between the estimates of studrams and feed costs, on the one hand, and sheep woolclip , on the other.

It was also found that the feeding level factor was more influential on woolclip than the Ram genotype. Although in both cases, this effect was likely and amounted to η^2 = 4.5 % (p = 0.001) and η^2 = 24.6 % (p < 0.001), respectively.

In general, the woolclip in 14-month-old gimmers had a positive average strength, a significant correlation with the level of feed consumption during their cultivation (r =+ 0.487; p < 0.001).

Taking into account the developed model, the average indicators of clipping in the Daughters of individual sheep were adjusted for the influence of the feeding factor. The calculation results are shown in Table 6.

Table 6.

Adjusted for the impact of the feeding level of woolclips the Daughters of different sheep

Number of ram	woolclips of daughters, kg		95% difference confidence interval, kg	
	mathematical mean (m)	standard error (m)	lower limit	upper limit
1579	5,007	0,109	4,793	5,222
1625	4,746	0,104	4,542	4,949
1823	5,153	0,099	4,959	5,347
4464	4,702	0,103	4,500	4,905
9510	4,553	0,138	4,281	4,824

By comparing the obtained adjusted values (Table. 7) and the average values of wool cuts shown in Table 3 revealed certain unlikely differences. In Ram's daughters No. 1579 and No. 1625, the difference between these values was 2.8% each. Moreover, in the descendants of the first ram, the adjusted indicator increased, and in the second – it was lower against pre-determined values. In the Daughters of other sheep, a similar difference was not significant, and ranged from 0.6 to 1.1% in the direction of increase.

Table 7.

Differences between estimates of adjusted average woolclip **values the Daughters of different sheep**

Ram No. - 1 (B1)	Ram No. - 2 (B2)	Difference between the strings of the Daughters of individual Studram, kg		Difference significance level	95% difference confidence interval, kg	
		average difference B1-B2	standard error	lower limit	lower limit	upper limit
1579	1625	0,262	0,151	0,084	-0,036	0,559
	1823	-0,145	0,147	0,324	-0,435	0,144
	4464	0,305*	0,150	0,042	0,011	0,599
	9510	0,455*	0,176	0,010	0,109	0,801
1625	1823	-0,407*	0,143	0,005	-0,688	-0,126
	4464	0,044	0,146	0,766	-0,244	0,331
	9510	0,193	0,172	0,263	-0,146	0,532
1823	4464	0,451*	0,143	0,002	0,170	0,731
	9510	0,600*	0,170	0,000	0,267	0,934
4464	9510	0,150	0,172	0,386	-0,189	0,488

It was found that the descendants of Ram No. 1823 in terms of wool cutting from 0.145 to 0.600 G exceeded their peers received from other studrams. At the same time, the advantage over the Daughters of Rams No. 9510; 4464 was likely. Adjusted values of strings in comparison with similar data in Table. 3 Increased the reliability values of the difference. In addition, due to taking into account the influence of the feeding factor, a significant advantage of Ram daughters No. 1823 over their peers, whose father is Ram No. 1625, was revealed.

The parameters of the developed model regarding the length of the coat due to the influence of factors of the breeder's genotype and the level of feeding of his offspring are shown in Table 8.

This model satisfactorily (R^2 = 0.317; R^2 adj = 0.309) and reliably ($p < 0.001$) describes the main patterns that occur between sheep parent estimates and feed costs, on the one hand, and sheep wool length, on the other.

It was also found that the factor of feed consumption during the cultivation of spring crops significantly, at the level of η^2 = 26.2 % ($p < 0.001$), affected the formation of their wool length indicator. In terms of strength, it turned out to be almost similar to the indicator of the effect on clipping. As for the influence of the sheep genotype, it on the length of hair in daughters, compared to the haircut, increased and amounted to η^2 = 8.3% and was also likely ($p < 0.001$). Compared to wool cutting, the correlation between wool length and feed costs during spring cultivation increased and amounted to r = +0.505 and turned out to be likely ($p < 0.001$).

Table 8.

Model for predicting the expected wool length (sm) of sheep based on estimates of the factors "Studram" and "feed consumption"

Factor characteristics	Vvalue of factor characteristics	Fixed effect / regression coefficient		Level significance
		B	standard error	
	Free member	-17,118	2,511	0,000
Ram	№ 1579	0,527	0,334	0,116
	№ 1625	0,292	0,327	0,374
	№ 1823	0,931	0,322	0,004
	№ 4464	-0,632	0,327	0,054
	№ 9510	0		
Feed consumption		6,290	0,526	0,000

Taking into account the developed model, the average coat length in the Daughters of individual sheep was adjusted for the influence of the feeding factor. The calculation results are shown in Table 9.

Table 9.

Coat length indicators adjusted for the influence of feeding levels the Daughters of different sheep

Studram	daughter's wool length		95% confidence interval, sm	
	mathematical mean (M)	standard error (m)	lower limit	upper limit
№ 1579	13,22	0,207	12,813	13,628
№ 1625	12,99	0,197	12,599	13,372
№ 1823	13,63	0,187	13,256	13,993
№ 4464	12,06	0,196	11,677	12,446
№ 9510	12,69	0,262	12,178	13,209

The adjusted values of wool length indicators for groups of Daughters of individual studrams were within 95% confidence intervals of reliable probability. At the same time, they changed in the offspring of RAM No. 1579 and No. 1625 due to the correction for the influence of the feeding level factor against the average data in Table. 3 by about 2%. As in the case of wool cutting, the offspring of the first Ram changed in the direction of growth, and the second – a decrease. In the remaining groups of offspring, changes were only in the range of 0.3-0.9 %.

When comparing the average adjusted values of wool length indicators in the Daughters of individual sheep, it was found (Table. 10) that the outsiders are the descendants of RAM No. 4464, who were inferior to their peers received from other studrams.

At the same time, the difference ranged from 5.2% to 13.0% and turned out to be significant with the Daughters of studrams No. 1823; 1579 and 1625 ($p < 0.001$), and with the Daughters of studrams No. 9510 – at the trend level.

Table 10.

Differences between estimates of adjusted average coat length values in Daughters of different sheep parents

Ram-father No. 1 (B1)	Ram-father no. 2 (B2)	difference between the length of hair in Daughters of sheep-parents, CM		significance level lower limit	95% confidence interval, sm	
		average difference B1-B2	standard error difference		lower limit	upper limit
1579	1625	0,235	0,287	0,413	-0,329	0,800
	1823	-0,404	0,280	0,149	-0,954	0,146
	4464	1,159*	0,284	0,000	0,600	1,717
	9510	0,527	0,334	0,116	-0,131	1,184
1625	1823	-0,639	0,271	0,019	-1,172	-0,106
	4464	0,923*	0,278	0,001	0,377	1,470
	9510	0,292	0,327	0,374	-0,352	0,935
1823	4464	1,563*	0,271	0,000	1,030	2,095
	9510	0,931*	0,322	0,004	0,298	1,564
4464	9510	-0,632	0,327	0,054	-1,275	0,012

The parameters of the developed model for predicting the live weight of due to the influence of factors of the Ram genotype, feeding level, as well as their interaction are shown in Table 11.

Table 11.

Model for predicting live weight in Daughters of different sheep based on estimates of the influence of factors "Studram", "feed consumption" and "Studram" × feed consumption"

Factor characteristics	value of factor characteristics	fixed effect / regression coefficient		Signifi-cance level
		B	standard error	
	Free member	-13,169	28,408	0,643
Ram	№ 1579	-98,700	36,131	0,007
	№ 1625	-11,822	35,592	0,740
	№ 1823	-38,219	38,739	0,324
	№ 4464	-9,424	35,530	0,791
	№ 9510	0		
Feed consumption		14,515	5,976	0,016
Ram × feed consumption	№ 1579 × feed consumption	20,517	7,633	0,007
	№ 1625 × feed consumption	2,600	7,470	0,728
	№ 1823 × feed consumption	8,071	8,153	0,323
	№ 4464 × feed consumption	2,287	7,491	0,760
	№ 9510 × feed consumption	0	-	-

This model satisfactorily (R^2 = 0.232; R^2 adj = 0.215) and reliably (p < 0.001) describes the main relationships that occur between the estimates of sheep parents and feed costs, on the one hand, and the live weight of sheep, on the other.

At the same time, the factor of feed consumption, as well as the clipping and length of wool, had a predominant effect on the manifestation of live weight in 14-month-old gimmers. Its value was η^2 = 17.9%; and it was probable (p< 0.001). The influence of the sheep genotype and the interaction of factors "Studram" x "feed consumption" on the studied trait was approximately the same (respectively, η^2 = 3.0% and η^2 = 2.8 %) and was likely (p <0.05 in both cases).

Table 12.

Indicators of marginal average live weight values of Daughters of different sheep, adjusted for feed consumption

Studram	live weight of gimmers, kg		95% confidence interval	
	mathematical mean (M)	standard error (m)	lower limit	upper limit
№ 1579	54,16	0,890	52,412	55,913
№ 1625	56,12	0,844	54,465	57,782
№ 1823	55,66	0,790	54,102	57,209
№ 4464	57,04	0,827	55,413	58,665
№ 9510	55,62	1,106	53,448	57,798

The indicators of live weight values adjusted for feed consumption underwent the greatest changes (an increase against the given average values in Table. 3) only in the descendants of RAM No. 1579 – by 2.8 %. In the remaining groups of gimmers, these changes ranged from only 0.2 to 1.2%, mainly in the downward direction. As a result of the adjustment, the Daughters of Ram No. 1625 lost their priority position, and their difference of 3.6% with their peers, descendants of Ram No. 1579 became unlikely. The absence of a statistically likely difference in live weight, as well as in hair cutting and coat length revealed in this way can be considered natural, since these two studrams are complete siblings (born as part of same-sex twins).

But it was established that the largest in terms of live weight were the Daughters of Ram No. 4464. they exceeded their peers, whose parents were other sheep by 1.6-5.3 %. However, this advantage was only likely for the descendants of Ram No. 1579 (p<0.05). This feature of the descendants of Studram No. 4464 is natural, since it belonged to the merinolandschaf breed, the leading genetically determined feature of which is a large living weight.

It was also found that the correlation between the live weight of young sheep and feed costs during their rearing period is positive and average, r = 0.439; p < 0.001.

Discussion. Analyzing the scientific reports of many researchers given in the introductory part of the article, it should be noted that the level of feeding of farm animals of various species is considered by them among the most powerful paratypical factors affecting the implementation of genetically determined productivity indicators in animals. The methodological approaches we have chosen to solve the problem fully agree with the conclusions of McLaren A., Brotherstone S., Lambe N.R. et al. (2015), on the need for clear identification of environmental factors and quantitative assessment of their impact on animal productivity. As such a factor, we determined a quantitative indicator of the average annual feed consumption for the year in which young sheep were raised. As for productivity indicators, we have identified a wide range of characteristics, among which

the most important are live weight, clipping and coat length. In most studies, the above problem is considered mainly in relation to determining the impact on the live weight indicators of young sheep in different age periods (Mallick P.K., Pourouchottamane R., Rajapandi S. et al. (2017); Rather M.A., Shanaz S., Ganai N.A. et al. (2020); Abebe A., Banarjee S., Goshmie S. et al. (2020); Wang W., Zhang X., Wei H. et al. (2024)). Our research shows that the overall level of annual feed consumption is a more influential factor in the formation of the main breeding trait of spring precos breeds at the age of 14 months than the genotype of their parent sheep. The effect of feeding levels on the manifestation of live weight, clipping, and coat length in animals was likely and ranged from 17.9% to 26.2 % ($p<0.001$ for all traits). The share of influence of the father Ram genotype on the same indicators of offspring was significantly lower, and amounted to 3.0 % (live weight), 4.5 % (woolclip) and 8.3 % (wool length), respectively. The advantage of feeding factor influence over genotype influence determined by US is consistent with the scientific results of Santos-Silva J., Mendes I.A, Bessa R.J.B (2002). At the same time, although the influence of the factor of the genotype of the Studram was lower, it was also vigorid, which is consistent with the results of studies by Kramarenko S., Luhovyi S., Balan D. et al. (2020), Rather M.A., Shanaz S., Ganai N.A. et al. (2020), regarding the live weight of lambs in different age periods of their rearing. The probable effect of the interaction of feeding factors and genotype on the living mass of gimmers is also revealed by US, which is consistent with the results of Vashchenko P. A., Zhukorskyi O. M., Saenko A. M. et al. (2023), who, using the example of young pigs, note that such an impact is manifested at an older age of animals.

Significant variability in the results of evaluating studrams based on the performance indicators of their offspring, which was noted in their Rather m studies.A., Shanaz S., Ganai N.A. et al. (2020) and Trapina I., Kairisa D. and Paramonova N. (2023) is also confirmed by the low indicators of rank correlation of scores of offspring of individual sheep raised in years with different feeding levels. At the same time, adjusting the results of this assessment for the influence of the feeding factor allows us to identify both individual studrams whose genotype is stable against the influence of this factor, and studrams whose genotype is plastic. Studrams with genotypes that are resistant to the influence of feeding factors, through selection and widespread use, will contribute to the formation of a herd with less sensitivity to the influence of this factor and can be objects for further evaluation and identification of genes that are associated with the effectiveness of feed use, or with stress resistance to the influence of reduced feeding levels in sheep.

Conclusions.

1. An increase in the average annual feed consumption in the range of 4-6% per year provides a likely increase in the live weight of gimmers at the age of 14 months from 6.7 to 11.6 %, woolclip – by 15.1-16.1 %, wool length – by 6.4 – 16.0%. ($p<0.001$ in all cases), but it has a different effect on the disclosure of the potential of individual breeding traits in the offspring of individual sheep.

2. The different number of offspring obtained and evaluated from individual Studram, the rearing of which occurred in years with different annual feed costs, negatively affected the indicators of rank correlation ($r \pm mr$) of their estimates. It ranged from 0.600±0.462 to 0.900±0.252 and was the highest in terms of the complex of signs of productivity of offspring whose cultivation in adjacent years occurred at an increased level of feeding.

3. It is established that the indicators of average annual feed consumption in the cultivation and evaluation of offspring have a positive, average correlation (r) with the main features of their productivity: live weight 0.439, clipping and wool length, respectively, 0.487 and 0.505 (reliable for all signs).

4. It is proved that the influence of genotypes of Studram (η^2) on the formation of live weight, clipping and wool length in their daughters was 3.0, 4.5 and 8.3%, respectively (in all cases $p < 0.001$), while the factor of annual feed consumption had a significantly greater impact force, respectively 17.9, 26.4 and 26.2% and was also highly likely. The interaction of these two factors (genotype x feed consumption) was significantly lower in its influence – 2.8 %, but remained probable, $p< 0.05$.

5. In order to predict the parameters of individual characteristics of offspring productivity, it is recommended to use appropriate mathematical models that take into account the complex influence of the Ram genotype and the level of feed consumption on them. The results obtained indicate that the genotype of Ram No. 1823 is stable in terms of transmitting its hereditary qualities to offspring in changing conditions of providing them with food, while the genotype of Ram No. 1625 and especially No. 1579 is plastic.

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THE EFFECT OF USING GRAIN SILAGE FEED FROM DIFFERENT CROPS ON THE MILK PRODUCTIVITY OF COWS

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The article presents the results of studies of milk productivity indicators of Ukrainian Black-and-White dairy cows when corn silage was replaced in their diets with grain silage from a vetch-oat mixture or winter triticale. Cows in the first (control) group received the basic diet. In the diets of the animals in the second (control) and third (experimental) groups, 50% (by nutritional value) of the corn silage was replaced with grain silage made from green mass of vetch-oat mixture or winter triticale.

It was found that replacing corn silage with grain silage from winter triticale in the feed mixture of the experimental group, with a slight decrease in starch content, contributed to an increase in crude protein content by 93 g or 3.4%, digestible protein by 26 g or 1.2%, non-digestible protein by 68 g or 10.7%, digestible protein by 102 g or 11.6%, sugar by 391 g or 66.8%, and fat by 28 g or 4.5%.

Replacing 50% of corn silage in the feed mixture for cows with winter triticale grain silage contributed to an increase in their average daily milk yield by 2.23 liters or 13.1% ($p \leq 0.05$) and the amount of milk obtained during the experiment (on average per head) by 541 liters. Due to the slightly higher fat and protein content in the milk of the experimental group animals by 0.09% and 0.04% compared to the first control group, feeding grain silage from winter triticale had a positive effect on the amount of milk fat and protein obtained from milk. In particular, the animals in the experimental group had an advantage in this indicator by 25.6 kg and 19.0 kg, or by 15.7% ($p \leq 0.01$) and 14.6% ($p \leq 0.05$).

Feeding grain silage from both vetch-oat mixture and winter triticale contributed to an increase in milk fat content (by 0.09%) and milk protein content by 0.01% and 0.04%. The difference in the mass fractions of dry matter and dry skim milk residue in milk, compared to the animals in the first group, was 0.08% and 0.2% and 0.08% and 0.1% in favor of the animals in the second and third groups.

Keywords: cows, milk productivity, milk quality, grain silage, winter triticale.

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ВПЛИВ ВИКОРИСТАННЯ ЗЕРНОСІНАЖІВ ІЗ РІЗНИХ КУЛЬТУР НА ПОКАЗНИКИ МОЛОЧНОЇ ПРОДУКТИВНОСТІ КОРІВ

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У статті наведено результати досліджень показників молочної продуктивності корів української чорно-рябої молочної породи при заміні у складі їх раціонів кукурудзяного силосу на зерносінажі з вико-вівсяної сумішки або з озимого тритикале. Корови першої (контрольної) групи одержували основний раціон. У раціонах тварин другої (контрольної) та третьої (дослідної) груп 50 % (за поживністю) кукурудзяного силосу заміняли зерносінажем, виготовленим із зеленої маси вико-вівсяної сумішки або із озимого тритикале.

Встановлено, що заміна у складі кормосумішки тварин дослідної групи кукурудзяного силосу на зерносінаж з озимого тритикале, за незначного зменшення вмісту крохмалю, сприяла підвищенню вмісту сирого протеїну на 93 г або 3,4 %, протеїну здатного до розщеплення на 26 г або 1,2 %, протеїну нездатного до розщеплення на 68 г або 10,7 %, перетравного протеїну на 102 г або 11,6 %, цукру на 391 г або 66,8 % та жиру на 28 г або 4,5 %.

Заміна у складі кормових сумішок корів 50 % кукурудзяного силосу на зерносінаж з озимого тритикале сприяла збільшенню їх середньодобових надоїв, на 2,23 л або 13,1 % ($p \leq 0,05$) та кількості молока отриманого за період досліду (в середньому на 1 голову), на 541 л. Завдяки дещо більшому вмісту жиру та білка у молоці тварин дослідної групи на 0,09% і 0,04 % порівняно з першою контрольною, згодовування зерносінажу з озимого тритикале мало позитивний вплив на показник кількості молочного жиру та білка отриманих з молоком. Зокрема, тварини дослідної групи мали перевагу за цим показником на 25,6 кг і 19,0 кг або на 15,7 % ($p \leq 0,01$) і 14,6 % ($p \leq 0,05$).

Згодовування зерносінажів як з вико-вівсяної сумішки, так і з озимого тритикале, сприяло підвищенню жирномолочності (на 0,09 %) і вмісту білка в молоці на 0,01 % і 0,04 %. Розбіжність за масовими частками сухої речовини і сухого знежиреного молочного залишку в молоці, порівняно з тваринами першої групи, становила 0,08 % і 0,2 % та 0,08 % і 0,1 % на користь тварин другої та третьої груп.

Ключові слова: *корови, молочна продуктивність, якість молока, зерносінаж, озиме тритикале.*

Introduction. Corn is considered a traditional crop for use in intensive feed production technology. However, in recent years, global warming has led to extremely unstable yields of both corn and other traditional crops, which has a negative impact on silage production (Pomitun et al., 2018; Thornton et al., 2009). These changes indicate that in order to adapt the feed production industry to climate change, it is advisable to implement a set of measures, one of which is to increase the acreage of perennial, winter,

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or more drought-resistant crops. Therefore, in order to increase production volumes and reduce the cost of livestock products, it is necessary to use the most productive and adaptive crops and feed harvesting technologies for each natural and climatic zone, capable of providing 20-30% more nutrients compared to traditional feed crops (Shchipak, 2019) .

Studies have shown that small-grain cereal crops are preferable for use as raw materials for canned feed due to their greater drought resistance, resulting from their shorter growing cycle (Edward J. DePeters et al, 1990; Salgado et al, 2013; Celis-Alvarez et al, 2016; Aída Gómez-Miranda et al, 2020; Vianey Colín-Navarro et al, 2021).

The LFI NAAS has identified priority feed crops and their mixtures, based on which a low-cost feed base can be created for the sustainable feeding of cows in the forest-steppe zone of Ukraine, the use of which can ensure an increase in livestock production with the rational use of land resources and savings in energy and funds (Gnoevyi, 2006; Gnoevyi et al, 2007).

One such crop is winter triticale, a hybrid of winter wheat and rye, which successfully combines the high productivity of wheat with the ecological plasticity of rye to abiotic factors. Rye is capable of providing stable yields even in dry years and makes it possible to obtain high-quality raw materials for grain silage, which is almost equal in terms of the content of certain nutrients and even exceeds traditional grain fodder crops and their mixtures in some respects (Baron et al, 2015; Harper et al, 2017).

It is characterized by high grain and green mass yield potential, increased adaptability to growing conditions, in particular winter hardiness, drought resistance, and undemanding soil requirements. In addition, the crop is resistant to fungal diseases, contains more protein and lysine in the grain, and is rich in nutrients in the green mass. These characteristics significantly expand the geography of cultivation, making it possible to actively introduce triticale in regions unsuitable for other grain crops, which makes it possible to consider it as a promising crop for use in feeding cattle (Habtamu et al., 2018; Randhawa et al., 2019).

However, the impact and feasibility of introducing such grain silage into the diet of cows as an unused reserve for creating a stable feed base for feeding high-yield dairy cattle has not yet been definitively determined, which explains the relevance of our research.

Materials and methods. The study was conducted at the State Enterprise "Gontarivka" of the National Academy of Agrarian Sciences of Ukraine in the Chuhuiv district of the Kharkiv region. Laboratory tests of feed included in the diets of the test animals were performed in the department for the assessment and monitoring of the quality of livestock products and feed, in accordance with the requirements of DSTU and generally accepted methods in animal husbandry (Vlizlo, et al., 2012). The energy value of the feed was calculated in accordance with the current standards and methods of DSTU ISO 8066:2015 (2015).

To conduct a scientific and economic experiment using the pair-analogue method, three groups of highly productive cows of the Ukrainian black-and-white dairy breed of the second and third lactations were formed, with 10 heads in each group, with an average daily milk yield of 21 liters, fat content of 3.80%, and protein content of 2.65%. The cows in the first (control) group received the basic diet. In the diets of the animals in the second (control) group, 50% (by nutritional value) of the corn silage was replaced with grain silage made from green mass of a vetch-oat mixture. In the diets of the animals in the third (experimental) group, 100% of the above-mentioned grain silage was replaced with grain silage made from winter triticale. The diets were adjusted after each control milking of the animals.

Table 1.

Research design

Groups		
I (control) (n = 10)	**II (control) (n = 10)**	**III (experimental) (n = 10)**
Basic ration (BR)	BR (50% of corn silage (in terms of nutritional value) replaced with grain silage from a vetch-oat mixture)	BR (50% of corn silage (in terms of nutritional value) replaced with winter triticale grain silage)

The animals were kept tethered, fed twice a day, and had free access to water. Analogues were selected according to age, sex, breed, physiological condition, and individual daily milk yield. The dynamics of changes in milk productivity of cows were determined on days 30, 60, 90, 125, 155, 180, 211, and 244 of the experiment, both individually for each animal and on average for the group (Ibatullin et al., 2017). The diets were adjusted after each control milking of the animals. The diets were balanced in accordance with detailed feeding standards (Bogdanov et al., 2012), (Kandyba et al., 2012).

Milk productivity was recorded based on the results of individual monthly control milkings of cows, with subsequent calculation of the average for each month for the group. The average milk samples were tested monthly for mass fractions (%): fat, protein, lactose, dry matter, dry non-fat residue, and the freezing point and energy content of milk were determined in accordance with DSTU 8396:2015 "Cow's milk"[ii].

Biometric processing of the obtained digital material was carried out using the method of variational statistics, taking into account Student's criterion according to the methodology of M. O. Plohinskiy (Ibatullin et al., 2017). To assess the reliability of the results obtained—the arithmetic means (M), the arithmetic mean error (± m), and the reliability of the difference between the arithmetic means under study (P)—the standard computer mathematical and statistical program Microsoft Excel was used. Changes between groups were considered significant at $p \leq 0.05$.

Research results. As part of the research conducted, as a basis for achieving the main objective of the work, the chemical composition, nutritional value, content, and ratio of organic acids in grain silage and silage fed to animals were determined, the data for which are presented in Table 2.

Analysis of the results obtained shows no differences in the quality indicators of triticale grain silage compared to vetch-oat mixture grain silage, in particular, lactic acid prevailed in both, accounting for 2/3 of the total amount of acids. At the same time, grain silage from winter triticale had a slightly lower total acidity index. It should be noted that corn silage had almost twice the titratable acidity and contained twice as much acetic acid compared to both grain silages. Butyric acid was absent (Table 2).

An analysis of the chemical composition of winter triticale grain silage compared to vetch-oat mixture grain silage and corn silage shows that its use makes it possible to obtain high-quality preserved feed containing 34.1 g of crude protein, surpassing corn silage in this indicator by 11.5 g or 50.9%, while slightly lagging behind grain silage from

[ii] DSTU ISO 8066:2015. (2015) Kormy dlia silskohospodarskykh tvaryn. Metody vyznachennia enerhoiemnosti i pozhyvnosti: Vydannia ofitsiine [Chynnyi vid 2017-01-01]. [Feed for farm animals. Methods for determination of energy content and nutritional value: Official edition]. Kyiv.

a vetch-oat mixture by 2.0 g or 5.5%. It should be noted that in terms of indigestible protein content, grain silage from winter triticale had an advantage over grain silage from a vetch-oat mixture and corn silage, by 36.8% and 120.4%, respectively. It should be noted that the preparation of grain silage from winter triticale made it possible to obtain feed with a higher content of fat compared to grain silage from a vetch-oat mixture and corn silage, fat by 14.7% and 38.3% and sugar by 15.6% and 873.8% (Table 2).

Table 2.

Chemical composition of grain silage and silage (based on natural moisture content)

Indicators, unit of measurement	Grain silage from a vetch-oat mixture	Grain silage from winter triticale	Corn silage
Dry matter, %	37,50	37,13	30,69
Crude ash, %	2,76	3,31	1,54
Crude fat, %	1,29	1,48	1,07
Crude protein, %	3,61	3,41	2,26
Cleavable protein, g	2,74	2,22	1,72
Non-cleavable protein, g	0,87	1,19	0,54
Digestible protein, %	2,38	2,32	1,26
Crude fibre, %	9,43	9,07	6,76
NDF, % DM	22,1	23,6	22,85
ADF, % DM	16,1	14,8	9,31
Starch, %	1,11	1,80	2,21
Sugar, %	3,2	3,7	0,38
Ca, %	0,200	0,237	0,151
P, %	0,118	0,111	0,061
Energy available for exchange, MJ	3,66	3,62	3,17
pH	4,26	4,43	3,67
Total acidity, %	16,4	14,76	29,42
Lactic acid, %	0,91	0,88	1,30
Acetic acid free, %	0,36	0,41	0,88
Acetic acid bound, %	0,1	0,05	0,02
Butter acid free, %	0	0	0
Butter acid bound, %	0	0	0
Total acids, %	1,37	1,34	2,20
Acid balance:			
lactic	66,42	65,67	59,09
acetic	33,58	34,33	40,91
butter	0	0	0

The above differences in chemical composition resulted in an increase in the nutritional value of grain silage prepared from green winter triticale mass compared to corn silage by 0.45 MJ or 14.2%.

Data on the nutrient content and structure of diets at the beginning of the experiment are presented in Table 3.

Analysis of the data in Table 3 shows that the diets of the control and experimental

groups in terms of the content of essential nutrients at the beginning of the experiment almost completely satisfied their daily requirements, since their intake from feed corresponded to the recommended norms. The exception was the total protein content and its components in the diet of the animals in the first group. However, this difference was insignificant, amounting to 3%.

Table 3.

Composition and nutritional value of animal diets (at the start of the experiment)

Nutrient content and diet composition	Groups		
	I group	II group	III group
Alfalfa hay, kg	3	3	3
Alfalfa haylage, kg	3	3	3
Corn silage, kg	28	14	14
Grain silage from a vetch-oat mixture, kg	-	12	-
Grain silage from winter triticale, kg	-	-	12
Concentrated forage, kg	7	7	7
The ration contains:			
dry matter, kg	19,25	19,45	19,41
energy available for exchange, MJ	204,9	204,5	204,0
crude protein, %	2757	2874	2850
cleavable protein, g	2123	2211	2149
non-cleavable protein, g	634	663	702
digestible protein, %	1735	1844	1837
crude fibre, g	3402	3587	3544
NDF, % DM	22,4	22,2	22,6
ADF, % DM	13,3	14,9	14,6
starch, g	3157	2891	3064
sugar, %	585	916	976
crude fat, g	620	625	648
Ca, g	116,3	133,2	123,6
P, g	75,2	80,8	80,0

The use of winter triticale grain silage in animal diets had no significant effect on changes in the energy concentration in the dry matter of the diets of different groups of animals. It was found that replacing corn silage with winter triticale grain silage in the feed mixture of the experimental group, with a slight decrease in starch content, contributed to an increase in crude protein content by 93 g or 3.4%, digestible protein by 26 g or 1.2%, non-digestible protein by 68 g or 10.7%, digestible protein by 102 g or 11.6%, sugar by 391 g or 66.8% and fat by 28 g or 4.5%. It should also be noted that the use of winter triticale grain silage in cow diets instead of grain silage from a vetch-oat mixture with a slight decrease in crude protein content, allows for an increase in the content of indigestible protein by 39 g or 5.9%, as well as an increase in the content of starch by 173 g or 6.0%, sugar by 60 g or 6.6%, and crude fat by 23 g or 3.7%.

The use of winter triticale grain silage instead of corn silage in animal diets resulted in a slight decrease in the energy concentration in the dry matter of the diets. On average for the experiment period, it amounted to 10.70 MJ, with fluctuations during the experiment months ranging from 10.86 to 10.51 MJ/kg DM, which was slightly below

normal. However, this difference was insignificant, averaging only 1.3% for the experiment period. As for the crude fibre content in the dry matter of the diets, the use of grain silage from both winter triticale and vetch-oat mixture caused an increase in this indicator from 176.7 g to 182.6 g/kg DM. It should be noted that the values of both indicators in all groups were within the normal range.

Table 4 gives an idea of the relationship between quantitative and qualitative indicators of milk productivity.

Table 4.

Milk production of cows, (M±m)

Indicators	Groups		
	I group	II group	III group
Quantity of animals, heads	10	10	10
Milk yield during the trial period, kg	4140±162,4	4654±175,2*	4681±185,1*
Daily milk yield, kg	17,03±0,668	19,15±0,721*	19,26±0,762*
Milk yield in reference to basic fat content (3.4%), kg	4791±142,9	5518±148,7**	5546±198,4**
Quantity of milk fat, kg	162,9±4,86	187,6±5,06**	188,5±6,75**
protein, kg	130,4±4,90	147,1±5,56*	149,4±5,40*
Protein to fat ratio	0,80:1	0,78:1	0,79:1

Note. $^{\#}p\leq0,1$; $*p\leq0,05$; $**\ p\leq0,01$

Analysis of the data in Table 4 shows that replacing 50% of corn silage in the feed mixture for cows with winter triticale grain silage had a significant positive effect on their average daily milk yield, increasing it by 2.23 l or 13.1% ($p\leq0.05$). This, in turn, contributed to an increase in the quantity of milk obtained during the experiment (on average per head) by 541 l compared to the control group animals. When converting milk yield to base fat content, the animals in the experimental group outperformed the animals in the control group by 755 l or 15.8% ($p\leq0.01$). It should be noted that due to the slightly higher fat and protein content in the milk of the experimental group animals by 0.09% and 0.04% compared to the first control group, feeding grain silage from winter triticale had a positive effect on the quantity of milk fat and protein obtained from milk. In particular, the animals in the experimental group had an advantage in this indicator by 25.6 and 19.0 kg, or 15.7% ($p\leq0.01$) and 14.6% ($p\leq0.05$).

When comparing productivity indicators with animals fed feed mixtures containing 50% corn silage replaced with grain-silage from a special vetch-oat mixture, no significant difference was found. In particular, the difference in their average daily milk yield was only 0.11 l or 0.6%. In terms of the quantity of milk fat and protein, the animals in the experimental group had an advantage of 0.9 kg and 2.3 kg, or 0.5% and 1.6%.

As for the ratio of protein to fat in the milk of cows in all groups, no significant difference was found in this indicator. Thus, on average, there were about 0.78–0.80 parts of protein per part of fat.

As for the quality indicators of milk, the data obtained indicate that there are no significant differences in the chemical composition and physical and chemical properties of milk between animals of different groups. It should be noted that feeding grain silage, both from a vetch-oat mixture and from winter triticale, caused a slight increase in fat content (by 0.09%) and protein content in milk by 0.01% and 0.04%. At the same time, the difference in the mass fractions of dry matter and dry skimmed milk residue in milk,

compared to animals in the first group, was 0.08% and 0.2% and 0.08% and 0.1% in favour of animals in the second and third groups.

It should also be noted that replacing 50% of corn silage with grain silage from a vetch-oat mixture or winter triticale contributed to an increase in the energy value of milk by 41 J and 50 J, or by 1.5% and 1.8%. It should be noted that laboratory assessment of milk quality in cows of all groups showed the same pattern, which allows us to conclude that it complies with the requirements of DSTU 7671:2014 and DSTU 6082:2009, since the freezing point, as a marker criterion of naturalness in case of falsification with water, was practically unchanged and did not exceed the permissible limits, ranging from minus 0.554 to minus 0.558 °C (Table 5).

Table 5.

Nutritional value and physical and chemical properties of milk from cows of different groups, (M±m)

Показники	Groups		
	I group	II group	III group
Mass content in milk, %			
fat	3,94±0,100	4,03±0,054	4,03±0,101
protein	3,15±0,042	3,16±0,039	3,19±0,047
lactose	4,90±0,035	4,91±0,036	4,94±0,017
dry matter	12,88±0,0,95	12,96±0,075	13,08±0,101
non-fat dry milk solids	8,95±0,050	8,93±0,037	9,05±0,040*
fat : protein	1,25:1	1,28:1	1,26:1
Freezing point, °C	-0,554±0,002	-0,555±0,003	-0,558±0,002
Energy value of milk, J	2827	2868	2877
Ratio: fat : NfDMS	0,440:1	0,451:1	0,445:1
protein : NfDMS	0,352:1	0,354:1	0,352:1

*Note: *p≤0,05*

Discussion. According to our data, it was established that the preparation of grain silage from the green mass of winter triticale made it possible to obtain high-quality canned feed, which contains 37.3% dry matter and 9.18% crude protein per dry matter. It was also found that replacing corn silage with grain silage from winter triticale in the feed mixture of the experimental group of animals contributed to an increase in crude protein content by 93 g or 3.4%. The data obtained are consistent with those obtained by foreign researchers. In particular, in experiments (Khorasani G. et al., 1997), when winter triticale was used as raw material, grain silage with a dry matter content of 34.4% and crude protein content of 12.3% was obtained. The slightly higher crude protein content is explained by the use of nitrogen fertilisers in the cultivation of raw materials. According to data (Harper M. et al. 2017), replacing 10 kg of corn silage with 10 kg of grain haylage in the diets of dairy cows contributed to an increase in the crude protein and NDF content of the diet.

We also found that replacing 50% of corn silage in cow feed mixtures with winter triticale grain silage had a significant positive effect on their average daily milk yield, increasing it by 2.23 litres or 13.1% ($p \leq 0.05$). Regarding the positive effect of using grain silage in feeding dairy cows, the data obtained in our studies are consistent with the results (Gnoievyi I.V. 2006; Gnoievyi V.I. et al. 2007) in whose experiment, when replacing

25 kg of corn silage in the diets of dairy cows with the same quantity of silage from a 4-component mixture of cereal and leguminous grain crops, it contributed to an increase in the average daily milk yield in cows of the experimental group, compared with the control group, by 2.6 kg or 14.5%. At the same time, the fat content in the milk of the experimental group was 0.05% higher than in the control group, which was a result of better provision of digestible protein to the animals in the experimental group, since its content in the combined silage, calculated on a dry matter basis, was more than twice as high as in corn.

However (Khorasani G.R. et al. 1993) found in their studies that the use of winter triticale grain silage in the diets of dairy cows, with a slight increase in productivity, contributed to an increase in milk fat content from 3.6% to 3.9% and protein from 3.2% to 3.35%.

Thus, given that under current climatic conditions, harvesting grain silage from grain fodder crops allows for an increase in dry matter and crude protein yield compared to corn dry matter and crude protein yield compared to corn, with the aim of ensuring a sustainable supply of feed for the livestock industry, which is facing climate change, as well as increasing feed production per unit of land area while reducing its cost, the feasibility of using grain silage made from green mass of winter triticale in feeding dairy cows has been proven.

Conclusions

1. The research has substantiated the possibility and feasibility of using winter triticale grain silage instead of part of corn silage in dairy cattle feed rations.

2. It has been established that replacing 50% of corn silage in cow feed mixtures with winter triticale grain silage contributes to an increase in average daily milk yield by 2.23 litres or 13.1% ($p \leq 0.05$).

3. Feeding grain silage from both vetch-oat mixture and winter triticale contributes to an increase in milk fat content by 0.09% and protein content in milk by 0.01% and 0.04%.

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FACTORS INFLUENCING THE SPEED AND APPEARANCE OF HORSES OF THE ORLOV'S TROTTER OF UKRAINIAN SELECTION

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The research is devoted to determining the factors that influence the speed and exterior of horses of the Orlov's trotting breed of the Ukrainian population. It is proved that stallions and mares have weak and low strength negative relationships between the indicators of speed with linear measurements of the trunk, which confirms the expediency of their consideration when conducting parallel breeding for these features in the direction of preserving the original exterior and expressive harness type, rather than achieving maximum speed.

Using the general linear model, the influence of genetic factors (linear affiliation, linear combination of father and mother, prize performance (speed per 1600 m) of proband ancestors of two rows of pedigree and the number of ancestors of the speed class 2.10 min in three rows of pedigree) and paratypical factors (Year and month of Birth, Gender, Year of testing, Stud Farm, Racetrack, Trainer) was determined.

A significant influence of linear affiliation and linear combination of parent pairs on the speed of horses of the Orlov's trotting breed (32.1 %), as well as the class of speed of ancestors of the first two rows of the pedigree (17.4%) was established. A positive low correlation was established between the prize performance of stallions and their offspring of 2-year-old age at the level of $r=0.183$ ($p<0.05$), 3-year-old age $r=0.280$ ($p<0.05$). The closest relationship was found between the speed indicators of stallions and their offspring aged 4 years and older ($r=0.550$, $p<0.05$), which can be explained by more careful selection of the best speed offspring of stallions for tests at an older age. Maternal influence on the vivacity indicators of offspring is manifested to a very significant positive degree ($r=0.340$) at the age of offspring four years and older. With positive force, this relationship affects only the speed of their older sons ($r=0.397$) and 4-year-old daughters ($r=0.362$). The mother's speed class correlates quite significantly with negative strength with the vivacity of offspring aged 5 years and older.

Such paratypical factors as the trainer (training systems) (225.3 %), the gender of the horses (75.6 %), the racetrack (74.8 %) and the stud farm (69.9%) showed the most significant influence on the conscription performance of horses of the Orlov's trotting

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breed. An indicator of the coefficient of determination (R2) approaching 50% indicates that the speed indicator of the studied horses is determined by the applied model.

Keywords: horses (Equus caballus), Orlov's trotting breed, factors of influence, prize performance, speed, exterior, linear model, correlation

ФАКТОРИ ВПЛИВУ НА ЖВАВІСТЬ ТА ЕКСТЕР'ЄР КОНЕЙ ОРЛОВСЬКОЇ РИСИСТОЇ ПОРОДИ УКРАЇНСЬКОЇ СЕЛЕКЦІЇ

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Дослідження присвячені визначенню факторів, що впливають на жвавість та екстер'єр коней орловської рисистої породи української популяції. Доведено наявність у жеребців і кобил слабкої й низької сили від'ємних зв'язків між показниками жвавості з лінійними промірами тулуба, що підтверджує доцільність їх врахування при проведенні паралельної селекції за цими ознаками в напрямі збереження оригінального екстер'єру і виразного запряжного типу, ніж досягнення максимальної жвавості.

За допомогою загальної лінійної моделі визначали вплив на призову продуктивність генетичних факторів (лінійної належності, лінійного поєднання батька і матері, призової продуктивності (жвавість на 1600 м) предків пробанда двох рядів родоводу і кількості предків класу жвавості 2.10 хв у трьох рядах родоводу) та паратипових факторів (рік та місяць народження, стать, рік випробувань, кінний завод, іподром, тренер).

Встановлено значний вплив лінійної належності і лінійне поєднання батьківських пар на жвавість коней орловської рисистої породи (32,1 %), а також клас жвавості предків перших двох рядів родоводу (17,4 %). Установлено додатний невисокий кореляційний зв'язок призової роботоздатності жеребців та їх потомства 2-річного віку на рівні r=0,183 (p<0,05), 3-річного віку r=0,280 (p<0,05). Найтісніший зв'язок виявлено між показниками жвавості жеребців та їх потомства у віці 4-х років і старше (r=0,550, p<0,05), що можна пояснити більш ретельним відбором для випробувань у старшому віці найкращих за жвавістю потомків жеребців. Материнський вплив на показники жвавості потомства проявляється досить значною позитивною мірою (r=0,340) у віці потомства чотирьох років і старше. З позитивною силою цей зв'язок позначається лише на жвавості їх синів старшого віку (r=0,397) і дочок 4-річного віку (r=0,362). Клас жвавості матері досить значно з від'ємною силою корелює зі жвавістю потомства у віці 5 років і старше.

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Найбільш значущий вплив на призову продуктивність коней орловської рисистої породи проявили такі паратипові фактори як тренер (системи тренінгу) (225,3 %), стать коней (75,6 %), іподром (74,8 %) та кінний завод (69,9 %). Показник коефіцієнту детермінації (R^2), що наближається до 50 % свідчить, що показник жвавості досліджених коней визначається застосованою моделлю.

Ключові слова: коні (Equus caballus), орловська рисиста порода, фактори впливу, призова продуктивність, жвавість, екстер'єр, лінійна модель, кореляція.

Introduction. In domestic and World Horse Breeding, the displacement of local breeds began much earlier than in other branches of animal husbandry and on a larger scale, which led to the disappearance of many horse breeds. Local breeds of domestic animals are a great historical and ethnographic value, a unique material necessary for studying evolution, analyzing the origin of animal varieties, which are characterized by a peculiar exterior and a complex of valuable economic, biological, and adaptive features. One of these breeds is the Orlov's Trotter, the oldest specialized Trotter breed in the world. The breed was created thanks to successful reproductive crossing of the best breeds of horses of the XVIII century (Arabic, Danish, Dutch, thoroughbred horse, Mecklenburg, Norfolk), rational selection and selection, as well as systematic training and long-distance running tests (Hopka & Skotsyk, 2018; Frolova & Maistruk, 2003). The beginning of the creation of the Orlov's trotting horse breed is considered to be 1776.

Breeding of the Orlov's trotting breed is historically traditional for Ukraine, its popularity is due to its versatility. In Ukraine, horses of this breed have been bred since the early 20s of the XIX century (Hopka et al., 2018) with the popularization of prize-winning equestrian sports (Hopka & Tkachuk, 2018), while the best livestock was concentrated in the farms of large landowners who owned spacious and fertile land (Kunets, 2014). The first historically known owners of horses in the territory of the modern Poltava region were the Hetman's herds of Kochubey, Muravyov-Apostolov, general Markov and other horse connoisseurs (Hopka et al., 2018; Frolova & Maistruk, 2003). In 1888, Grand Duke Dmitry Romanov, a representative of the royal family and chairman of the Imperial horse factory, founded a trotting stud farm on the fertile lands of the Mirgorod region. From that time to the present day, the Dibrovsky stud farm retains a leading position in the breeding of horses of the Orlov's trotting breed (Strizhak et al., 2014).

By the end of the nineteenth century, the Orlov's breed was the busiest of the harness-type horses, but later gave way to the American standardbred breed, consolidated for maximum speed over short distances (Carmalt et al., 2014). The system of testing of Orlov's trotters in their creation was based on the development of distance in the Trotter and included not only factory tests for long distances, but also fair competitions, horse races, Imperial prizes, exhibitions of provincial and state scale (Hopka & Skotsyk, 2018; Frolova & Maistruk, 2003). The classic distance was 3 versts (4800 m) in heavy crews, the tests began at the age of 4. Over time, with the introduction of American trotters and in the pursuit of speed, the test system of Orlov's Trotters gradually lost its purpose, getting as close as possible to the American one (early age of testing, short distances, light rocking chairs). The only advantage and salvation for the breed was that in 1910 closed and more expensive prizes were introduced for Orlov's Trotters.

The assessment of the influence of various factors on Horse Performance and the relationship between traits is of interest to many domestic and foreign researchers (Burenko, 2017; Chekhichyn et al., 2024; Hopka & Skotsyk, 2018; Jez et al., 2013; Sole, 2016; Tkachova et al., 2024; Verdegaal, 2021).

Among the factors influencing the effect of horse breeding include: a combination of directed and stabilizing selection of stallions and mares (the intensity of selection is 3-5% and 27-33% of peers, respectively); selection by one complex or complex traits; entropy of information content of breeding data due to the peculiarities of the distribution of traits and the nonlinearity of their interdependence; characteristics of breeding differentials at different stages of breeding; biological features of breeds that regulate fertility and the interval of generation change. Researchers claim that targeted selection for one or more traits among producers and part of Queens is combined with uniform selection and provides improved traits (Suprun, 2014; Tkachova, 2018). The combination of stabilizing selection with heterogeneous selection creates conditions for consolidating the results achieved and reducing the variability of traits in breeds.

Proven (Tkachova et al., 2022) that horses that come from different genealogical branches and are born in different genealogical combinations are characterized by different prize performance.

Demographic parameters affecting the level of breeding of horses of different breeds have been established (Franklin et al., 1980). Consequently, a long generation interval between generations slows down the rate of stabilizing breeding of purebred horses, and crossing – on the contrary – accelerates. Breeding characteristics were divided into direct (gain, speed, handicap, etc.) and indirect (indicators of exterior, interior, blood composition, histology, etc.), the combined use of which in assessing the quality of horses will determine genetic progress.

Horse breeders have long associated the exterior parameters of horses with their physical abilities. Many scientific studies, including modern ones, have been devoted to this issue (Hennes, 2024; Frolova, 2023; Kosenko & Romanenko, 2017; Tkachova, 2018; Tkachova et al., 2024).

Kornienko O. O. established in her research a fairly high correlation coefficient between the speed of horses of the Ukrainian trotting Breed Group in different age periods (r=0.59-0.78), as well as between speed and precocity when detecting a high class of speed of 2.10 min and 2.05 min (0.72 and 0.46, respectively) (Kornienko, 2012).

Sobol O. M. determination of the correlation between speed and measurements and indices of the body structure of horses of the Orlov's trotting breed in leading stud farms of Ukraine established that the most likely relationship was only – speed × metacarpal girth (Sobol, 1992). It is also established that the magnitude and reliability of the correlation relationship depends on belonging to lines and origin from a particular subject of breeding.

As a result of evaluating the performance of Quarter Horses by the BLUP method, it was established (Harkins et al., 1992) the value of the dependence of the working capacity on the distance (10.6-31.8%), the year of the race (5.2-7.8%), the day of the race (up to 19.5%), the individual speed of the horse (15.1-24.4%), and the most influential factor (49.4-70.9%) – the level of struggle, which includes the complex: the composition of the group at the start – the day and year of the race. The speed inheritance coefficient calculated by various methods ranged from 0.00-0.002 to 0.36-0.38, and the repeatability coefficient ranged from 0.20 – 0.34 to 0.42-0.51.

So, the formation of Prize productivity is influenced by both hereditary and paratypical factors, in particular: origin, belonging to a certain genealogical branch, intensity and complexity of selection of the parent pair, generation interval, exterior parameters, group composition at the start, day and year of the race, climatic factors (weather conditions), Organization of rearing and training of young horses.

Taking into account the relevance of the highlighted issue, the aim of the study was to determine the factors that affect the speed and exterior of horses of the Orlov's trotting breed of the Ukrainian population.

Research materials and methods. The material for the research was a database formed based on the materials of breeding accounting of horses of the Orlov's trotting breed of Livestock farming institute of NAAS of Ukraine and State Enterprise "Agency for identification and registration of animals", as well as data from Expedition surveys of stud farms and breeding reproducers of Ukraine during 2004-2024. the presence of livestock was clarified by an expedition survey of breeding subjects. Statistical calculations take into account the entire reproductive composition of the Orlov's trotting breed in Ukraine in dynamics, with the exception of horses with unconfirmed origin.

The performance of horses of the Orlov's trotting breed was evaluated based on the results of testing horses at racetracks in accordance with the "rules for testing breeding horses of trotting, riding and heavy breeds at racetracks of Ukraine" (Rules, 2003). Indicators of Prize productivity (speed at a distance of 1600 m) are taken from the reports of racetrack tests of horses of the Orlov's trotting breed, while horses were divided into gender and age groups (folls and fillyes aged 2, 3, 4 years and older). Speed was assessed on average for each age group. Electronic records included: pedigree, body measurements, results of bonitation and racetrack tests. Horses were divided by gender by age 2, 3, 4 years and older. Scientific and methodological approaches were based on zootechnical and genealogical studies of the Orlov's horse array.

Scientific and methodological approaches were based on zootechnical and genealogical analysis of the array of horses of factory breeds and retrospective analysis of breeding processes in the breed. The influence on the speed and exterior indicators of horses of origin, belonging to genealogical lines and breeding families, and models of selection by linear combinations was established.

In order to determine the strength of the influence of genetic factors on the draft productivity of horses of the Orlov's trotting breed, statistical parameters were calculated: average value, standard error of the average value, limits, standard deviation and coefficient of variation. Using the general linear model (Formula 1), the influence of linear affiliation, linear combination of father and mother, prize performance (speed per 1600 m) of proband ancestors of two rows of the pedigree and the number of ancestors of the speed class of 2.10 min in three rows of the pedigree was determined.

$$Y_{abcd} = \mu + La + Lsm_b + S2_c + S3_{d+e}, \qquad (1)$$

where Y_{abcd} is the studied factors;
μ - general average;
L-linear affiliation;
Lsm-linear combination of father and mother;
S2-prize performance of ancestral proband of two rows of pedigree;
P3 - the number of ancestors of the speed class 2.10 min in three rows of the pedigree;
e-rondome error.

The strength of paratypical factors was also determined using a general linear model (Formula 2), which included factors: Year and month of Birth, Gender, year of testing, stud farm(conditions of detention), racetrack (conditions of detention and training), trainer (training systems):

$$Y_{abcdefg} = \mu + Yb_a + Mb_b + S_c + Yr_d + I_e + St_f + T_{g+e}, \qquad (2)$$

where $Y_{abcdefg}$ is the studied factors;
μ - general average;
YB-year of birth, Mb-month of birth;
S-gender;
Yr-year of testing;
I-racetrack, St-stud farm, t-trainer;
e-rondome error.

The data obtained were uploaded to Microsoft Excel spreadsheets (Baranovsky et al., 2017). Descriptive statistics were used to report frequencies and percentages in the data. The Chi-squared criterion and odds ratio were used to estimate the speed of horses of different genders and ages. The correlation coefficient (r) was used to analyze the relationships between variables. The confidence value was set to P0.05 (95% confidence interval). The data was analyzed using SPSS for Windows version 24.

Experimental studies were conducted in accordance with modern methodological approaches, requirements and standards (DSTU ISO/IEC 17025:2019, 2021), directive 2010/63/EC (2010), the procedure for conducting animal testing in research institutions (law of Ukraine No. 249, 2012) and in accordance with the provisions of the European Convention for the protection of vertebrates used for experimental and other scientific purposes (Strasbourg, 1985).

Research results. In 2024, the breeding registered number of horses of the Orlov's trotting breed in stud farms, breeding reproducers and other owners of horses in Ukraine (excluding the number of the Limarovsky stud farm, which is currently under occupation) amounted to 446 heads, including 21 Stallions-producers, 173 breeding mares, the rest – repair young animals of different ages.

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Table 1.

Quantitative composition of horses of the Orlov's trotting breed of Ukraine as of 01.01.2024

Enterprise	number of horses					
	Total		Stallions		Mares	
	n	%	n	%	n	%
Zaporizhskiy stud	139	31,2	3	14,3	61	35,3
Dibrivskiy stud	96	21,5	3	14,3	32	18,5
Lozivskiy stud	76	17,0	3	14,3	33	19,1
PAE "Komyshanske"	53	11,9	4	19,0	16	9,2
State of emergency "Land of Pereyaslavshchyna"	13	2,9	3	14,3	6	3,5
Other horse owners	69	15,5	5	23,8	25	14,5
Total	446	100,0	21	100,0	173	100,0

The dynamics of the quantitative composition of the Orlov's trotting breed of Ukrainian selection indicates (fig. 1) a significant reduction in horses over the past 10 years.

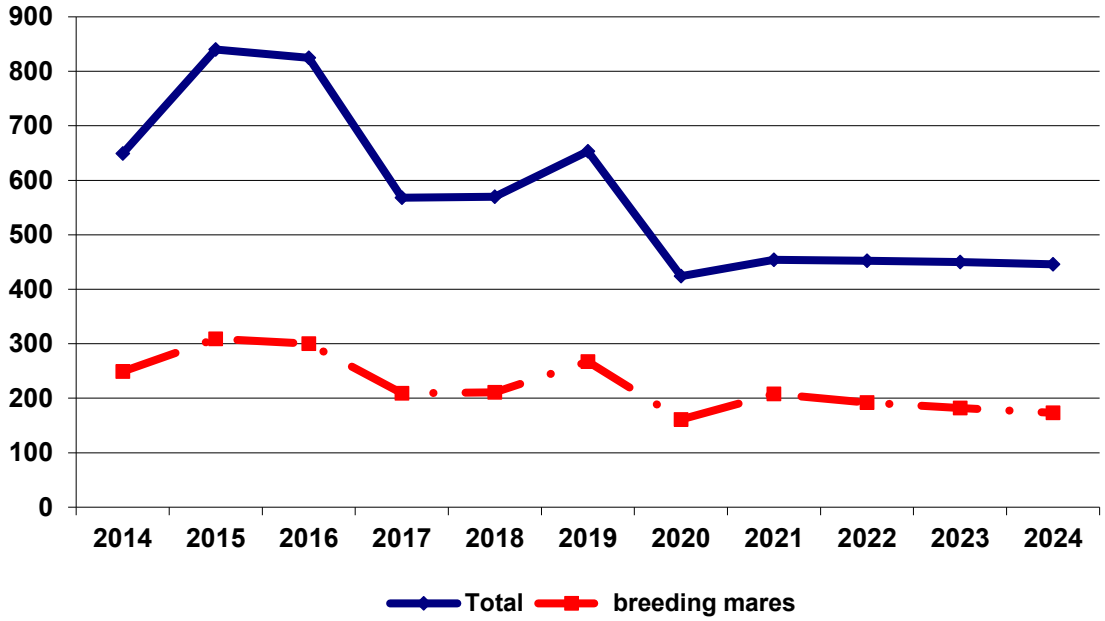

Fig. 1. **Dynamics of the Orlov's trotting breed population in Ukraine (head)**

The leading subjects of breeding for breeding horses of the Orlov's trotting breed are State stud farms – branches of the State Enterprise "Horse breeding of Ukraine": Zaporizhskiy Stud, Dibrivskiy Stud, Lozivskiy Stud, breeding reproducer PAE "Komyshanske" et Sumy region.

Analysis of the average speed of horses of the Orlov's trotting breed at a distance of 1600 m over the past 10 years showed significant fluctuations in this indicator in stallions and mares of different age groups (mares are tested up to and including 4 years of age) (Table 2).

Table 2.

Average speed of horses of the Orlov's trotting breed at a distance of 1600 m

Age group	Number and speed of horses in each age group					
	stallions		mares		together	
	n	speed (min)	n	speed (min)	n	speed (min)
2 years old	194	2.28,3±0,596	183	2.28,5±0,705	377	2.28,4±0,459
3 years old	147	2.17,6±0,794	104	2.18,4±0,788	251	2.18,0±0,568
4 years old	80	2.12,1±0,630	34	2.13,8±1,616	114	2.12,6±0,653
5 years old and older	21	2.08,5±0,648	-	-	21	2.08,5±0,648

Analysis of the dynamics of the speed of horses of different gender and age groups at a distance of 1600 m over the past 10 years showed significant fluctuations in this indicator in all age groups (Table 3).

Over the past 10 years, 7 absolute records have been updated, including one international one, 299 horses of the 2.10 min and faster class have been identified, of which 25 horses have entered the high class of 2.05 min and faster.

Table 3.

Records of speed of horses of the Orlov's trotting breed different gender and age group s at a distance of 1600 m

Year	Gender and age groups						
	2 years old		3 years old		4 years old		older age
	foals	fillys	foals	fillys	foals	fillys	
2010	2.15,6	2.11,2	2.11,6	2.10,6	2.06,7	2.09,0	2.02,5
2011	2.13,0	2.14,2	2.09,9	2.08,7	2.06,6	2.10,3	2.01,2
2012	2.14,2	2.13,4	2.03,5	2.11,2	2.07,3	2.07,9	2.03,9
2013	2.18,5	2.15,1	2.10,0	2.10,8	2.08,1	2.05,3	2.07,3
2014	2.15,5	2.16,0	2.09,5	2.11,5	2.08,0	2.08,6	2.04,9
2015	2.18,7	2.19,5	2.10,0	2.12,2	2.07,1	2.14,9	2.05,9
2016	2.18,4	2.16,9	2.07,8	2.11,7	2.06,1	2.11,7	2.06,2
2017	2.16,6	2.17,2	2.07,1	2.09,4	2.07,2	2.14,6	2.05,1
2018	2.18,4	2.18,3	2.07,0	2.08,9	2.06,1	2.05,7	2.07,0
2019	2.17,2	2.20,8	2.08,7	2.09,7	2.06,3	2.06,1	2.04,6
2020	2.24,6	2.21,6	2.13,1	2.12,6	2.08,2	-	2.04,4
2021	2.20,6	2.20,7	2.11,6	2.08,4	2.06,7	2.07,5	2.03,0
2022	2.20,5	2.20,5	2.11,4	2.13,9	2.08,7	2.08,5	2.04,1
2023	2.14,0	2.13,2	2.09,9	2.11,8	2.06,4	2.08,8	2.04,1

During the research period, for the first time in Ukraine, 2 stallions of the 2.00 min and more speed class were identified (fig. 2): Vratar 2.00, grey., 2009 (Aphorism – Wanda) of the Dibrivskiy stud and the Imperfect VIZ 1.59,5, dk.-bay., 2010 (Final – Izbrannitsa) PAE "Komyshanske". Both record holders showed high speed at foreign racetracks.

The first Orlov's Trotter of Ukrainian selection of speed class 2.00 and faster Vratar 2.00; 3.14,4; 4.24,6, grey, 2009 (Aphorism – Wanda) of the Dibrivskiy stud

The most speeder Orlov's Trotter of Ukrainian selection Imperfect VIZ 1.59, 5, dk-bay, 2010 (Final – Izbrannitsa), PAE "Komyshanske"

Fig. 2. **Horses of the Orlov's trotting breed of Ukrainian selection class of speed 2.00 min and more speed**

Evaluation of the exterior features of young horses of the Orlov's trotting breed established the expressiveness of the desired type, the correctness of the exterior, the overall harmony of development and body structure. This is facilitated by conducting breeding work with this breed, in addition to Prize productivity, also to consolidate the desired original, Bright type. As the expert assessment showed, the main exterior disadvantages of trotting young animals of both breeds remain: sunken loin, poor, short, drooping croup, poor bones, dampness of put joints, end hooves, straight headstock. In young animals of the Orlov's trotting breed, more often there are hooks under the wrist, a large rough head.

The best horses of the Orlov's trotting breed, which received the highest ratings for type and exterior and were characterized by the best measurements and overall development, were both mares and stallions of all age groups that belonged to the Dibrivskiy stud. Accordingly, the average score for the type and exterior of stallions of this farm at the age of 2 years was 7.64±0.04 points, and mares-7.57±0.25 points with measurements, respectively, 157,3-161,0-176,0-21,0 see and 158,0-163,5-176,2-20,0 see at the age of 3 years, the average score of stallions was, respectively, 7.70±0.24 points, mares-7.94± 0.17 points, with measurements 158,7-162,0-178,9-21,25 see and 161,25-163,0-181,5-20,25 see

The parameters of the average indicators of record speed of stallions-producers at a distance of 1600 m during the study period were 2.07.8 minutes,breeding mares – 2.18.5 minutes. According to linear measurements of the body, breeding stallions and breeding mares met the requirements of the elite premium class for the Orlov's trotting breed (Table 4).

Table 4.

Characteristics of horses by speed and linear measurements

Group n	n	speed на 1600 m, min.	Linear body measurements, sm			
			height at the withers	Circumferen-tial torso length	chest circum-ference	Meta-carpal girth
Stallions	21	2.07,8±0,07	162,7±0,63	166,0±0,63	183,7±1,07	20,8±0,13
Mares	173	2.18,5±0,81	161,2±0,25	164,7±0,33	183,7±0,37	20,3±0,04

Analysis of the record performance at a distance of 1600 m of stallions-producers of the Orlov's trotting breed showed fluctuations in the indicator in the range of 2.02,8-2.33.0 minutes.

In terms of height at the Withers of stallions, the indicator fluctuated within the sample was 157-172 cm, while the average indicator was 162.7±0.63 cm. According to the circumferential length of the trunk, the fluctuation of the indicator within the sample was 161-175 cm, while the average indicator was 166.0±0.63 cm. In terms of chest circumference, the limits of the indicator within the sample were 173-196 cm, while the average indicator was 183.7±1.07 cm. In terms of metacarpal circumference,the discrepancy within the sample was 19-22.5 cm, with an average of 20.8±0.13 cm.

Of all the mares tested, only 13.8% have a high speed class of 2.10 minutes faster. Among these mares, almost half (45.0 %) are produced in the Dibrivskiy stud farm, 35 % - in Zaporizhskiy Stud, 15 (3 mares) – in the PAE "Kamyshanskoe" 1 mare in the private enterprise "Land of Pereyaslavshchyna". At the same time, Mares of the lowest classes of speed (2.40,1 min. C quieter) a little – 4.9 %. The vast majority of mares have speed classes of 2.10,1-2.15.0 min (31.1 %) 2.15,1-2.20 min (24.1 %).

Table 5.

Distribution of mares of the Orlov's trotting breed of Ukrainian selection by speed classes

Speed classes	Number and proportion of mares	
	n	***%***
2.05,7-2.10,0	20	*13,8*
2.10,1-2.15,0	45	*31,1*
2.15,1-2.20,0	35	*24,1*
2.20,1-2.25,0	16	*11,0*
2.25,1-2.30,0	16	*11,0*
2.31,1-2.40,0	6	*4,1*
2.40,1-2.50,0	3	*2,1*
2.50,1 and quieter	4	*2,8*
Total:	145	*100*

It is proved that the speed indicators of breeding Stallions weakly and negatively correlate with Body Measurements (Height at the withers r=-0.040, circumference of the body r=-0.148, chest circumference r=-0.40, metacarpal circumference r=-0.072).

It is established that in enterprises where breeding mares are the most lively, they are also larger in linear measurements. To establish the presence of relationships between these features, a correlation analysis was performed (Table. 6).

Table 6.

Correlations (r) between Prize performance indicators of linear measurements of mares

Indicator	**Relationship of prize performance with torso measurements (r)**			
	height at the Withers	**circumferential torso length**	**chest circumference**	**metacarpal girth**
Rekord speed	-0,061	-0,148	-0,040	-0,072
Speed with age				
2 years old	-0,137	-0,229	-0,163	-0,215
3 years old	-0,108	-0,182	-0,073	-0,006
4 years old	-0,078	-0,043	-0,040	-0,050
Studs	Relationship of prize performance with torso chest circumference (r)			
	height at the Withers	circumferential torso length	chest circumference	metacarpal girth
Dibrovsky stud farm	0,266	0,085	0,069	0,057
Zaporizhia stud farm	-0,138	-0,139	-0,040	0,118
Limarovsky stud farm	-0,139	-0,173	0,100	-0,184
Lozovsky stud farm	-0,102	-0,109	-0,306	-0,519
PSP "Komyshanskoe"	0,183	-0,163	0,418	0,221
Other horse owners	0,020	-0,059	-0,359	-0,261

It was found that there are low-level negative relationships between mares ' speed indicators and torso measurements. However, analyzing the correlations between the record speed and measurements of mares of various subjects of breeding, positive connections were established, therefore, it can be stated that in the Dibrovsky stud farm and in the breeding reproducer of the PSP "Kamyshanskoe" they achieved a low but positive breeding effect of combining the main breeding characteristics of horses of the Orlov's trotting breed.

Thus, the presence of weak and low strength negative relationships between the indicators of speed with linear measurements of the body in stallions and mares is proved, which confirms the expediency of their consideration when conducting parallel breeding according to these characteristics in the direction of preserving the original exterior and expressive harness type, rather than achieving maximum speed.

Analysis of horse pedigrees determined that the domestic population of horses of the Orlov's trotting breed is structured along 7 genealogical lines. The largest share of successors was established in the Barchuk-Zapad (33.3 %) and pilot (23.8%) lines. Stallions of the Pion genealogical lines (2.05,1 min) and pilot lines (2.05,2 min) are characterized by indicators of the highest speed at a distance of 1600 m. The best indicators of torso measurements are inherent in stallions of the Warrior, Barchuk-Zapad, pilot and Vetra lines.

The analysis of variance established (table. 7) significant influence of linear affiliation and linear combination of parent pairs on the speed of horses of the Orlov's trotting breed (32.1%), as well as the class of speed of ancestors of the first two rows of the pedigree (17.4%).

Table 7.

Influence of genetic factors on the performance of horses

Factors	Degree of freedom	F	Coefficient of determination (R^2)
Linear affiliation	29	32,1*	0,381
Linear combination of father and mother	18	17,4*	
Prize productivity (speed per 1600 m) of ancestors of two rows of pedigree	14	7,8	
Number of ancestors of the speed class 2.10 min in three rows of the pedigree	6	3,2	

*Note. * $p<0.05$*

A positive low correlation was established between the prize performance of stallions and their offspring of 2-year-old age at the level of r=0.183 ($p<0.05$), 3-year-old age r=0.280 ($p<0.05$). The closest relationship was found between the speed indicators of stallions and their offspring aged 4 years and older (r=0.550, $p<0.05$), which can be explained by more careful selection of the best speed offspring of stallions for tests at an older age.

Correlation analysis data indicate that maternal influence on the offspring's speed indicators is quite significant to a positive extent (r=0.340) at the age of offspring four years and older. This relationship has a positive effect only on the speed of their older sons (r=0.397) and 4-year-old daughters (R=0.362) (Table 8).

Table 8.

Correlations between mares speed indicators and their offspring of different sexes

Family group	correlation coefficient (r)			
	2 years old	3 years old	4 years old	older
Mares × sons	0,100	0,047	-0,121	0,397
Mares × daughters	0,033	0,014	0,362	–
Mares × offspring	0,012	-0,015	0,340	0,397

It is noteworthy that the speed of the mother affects the speed of sons only after they reach the age of 5 years and older, and the speed of daughters - earlier - at the age of four years. Therefore, it can be assumed that the speed of the offspring is more affected by the speed of the parents, which requires further study.

The mother's speed class correlates quite significantly with negative strength with the vivacity of offspring aged 5 years and older (Table 9).

Table 9.

Correlations between the speed class of mares and their offspring

Mares speed class	correlation coefficient (r) with the vivacity of offspring at age			
	2 years	3 years	4 years	5 years and older
2.20 min and faster	0,014	-0,004	-0,006	-0,552
2.15 min and faster	-0,020	0,156	-0,179	-0,699
2.10 min and faster	0,136	0,081	0,089	-0,752

To determine the influence of the stud farm on the speed indicators of breeding mares of the Orlov's trotting breed, average speed indicators were estimated and significant differences were established between the studied groups (Table 10).

Table 10.

Indicators of speed at a distance of 1600 m of mares of the Orlov's trotting breed of Ukrainian selection of various breeding subjects

Subject of breeding	n	characteristics of mares by speed for a distance of 1600 m (min)			
		record speed	2 years	3 years	4 years
Dibrivskiy stud	29	2.14,3±1,22	2.27,7±1,33	2.14,1±0,90	2.11,6±0,90
Zaporizhskiy stud	61	2.17,0±1,03	2.27,4±1,08	2.16,7±0,62	2.15,8±1,26
Limarovsky stud farm	19	2.27,1±2,94	2.35,8±3,13	2.23,6±2,17	2.17,3±2,04
Lozivskiy stud	12	2.22,9±3,19	2.28,6±2,22	2.18,5±2,09	2.13,3±2,30
PAE "Komyshanske"	14	2.16,2±2,01	2.22,6±1,59	2.14,3±2,73	2.13,0±0,95
Individuals	11	2.21,9±3,32	2.24,5±3,33	2.21,6±5,08	-
On average:	145	2.18,5±0,81	2.28,1±0,79	2.17,2±0,59	2.14,6±0,84

The busiest horses in terms of average record speed belong to the Dibrivskiy stud farm and the breeding loudspeaker of the PSP "Kamyshanskoe". The most precocious horses (in terms of speed at the age of 2 years) belong to the breeding loudspeaker of the PSP "Kamyshanskoe" and individual owners of horses.

To determine the influence of the racetrack on the speed indicators of breeding mares of the Orlov's trotting breed, the average speed indicators at various racetracks in Ukraine were estimated (Table 11).

Table 11.

Characteristics of mares of the Orlov's trotting breed of Ukrainian selection of various subjects of breeding business by speed at a distance of 1600 m

Hippodromes	n	characteristics of mares by speed when testing at a distance of 1600 m (min)			
		record speed	2 years	3 years	4 years
Kyevan	74	2.17,5±0,98	2.26,4±0,78	2.16,2±0,93	2.13,0±1,25
Odessan	68	2.19,6±1,31	2.29,9±1,38	2.18,1±0,73	2.15,4±1,07
On average:	142	2.18,5±0,81	2.28,1±0,79	2.17,2±0,59	2.14,6±0,84

It was found that Mares tested at the Kievan Hippodrome with a high probability ($p>0.95$-0.99) prevailed in the speed of their peers tested at the Odessan Hippodrome, both in record speed and in speed detected in all age periods.

Based on the calculation of the general linear model, it was found that the studied paratypical factors had a statistically significant impact on the draft productivity of horses of the Orlov's trotting breed during the study period. The most significant influence on the conscription performance of horses of the Orlov's trotting breed was shown by such factors as the trainer (training systems), the gender of the horses, the racetrack and the stud farm (conditions of detention) (table. 12). An indicator of the coefficient of determination (R^2) approaching 50% indicates that the speed indicator of the studied horses is determined by the applied model.

Table 12.

Influence of various factors on the conscription performance of horses

Factors	Degree of freedom	F	F coefficient of determination (R^2)
Year of birth	11	14,2*	0,435
Month of birth	9	12,8*	
Gender	2	75,6*	
Year of testing	14	18,1*	
Stud (conditions of detention)	2	69,9*	
Racetrack (conditions of detention and training)	45	74,8*	
Trainer (Training System)	3	225,3*	

*Note. * $p<0.05$*

Discussion. Thus, The conducted research proved the influence of various factors on the formation of Prize productivity and exterior indicators of horses of the Orlov's trotting breed of Ukrainian selection as components of improving the efficiency of selection models in the process of improving the breed. The obtained data allow us to improve the quality of horses, and, consequently, its competitiveness, which is the key to the preservation and development of the breed in conditions of a limited gene pool. The influence of different forces on the draft performance of horses of factors is proved: year and month of Birth, Gender, year of testing, stud farm (conditions of detention), racetrack (conditions of detention and training), trainer (training systems). The results of the research are consistent (with discrepancies) with the results of other researchers studying the prize performance of horses of different breeds.

Consequently, it was found that the speed of horses is affected by the year of birth, the year of testing and the month of birth, which can be attributed to significant differences between horses born at different times. Our research is also consistent with the results of other scientists on the effect of horse sex on their speed (Jelinek, 1988; Ojala et al., 1981; Štrbac & Trivunović, 2013). Exterior features are also determined by the genotype and are associated with the speed of trotting horses.

So, the results of our research can be included in models for predicting the productive potential of horses of the Orlov's trotting breed of the Ukrainian part of the population. This system of genetic assessment should lead to increased genetic improvement and increased competitiveness of trotting horses.

Conclusions:

1. The influence of breeding Stallions, Breeding mares and structural breed units on the speed indicators of horses of the Orlov's trotting breed is proved. A significant influence of genetic factors – linear affiliation and linear combination of parental pairs- on the speed of horses of the Orlov's trotting breed (32.1 %), as well as the class of speed of ancestors of the first two rows of the pedigree (17.4%) was established.

2. The difference between the speed indicators of horses raised in different enterprises and tested at different racetracks is established. The calculation of the general linear model determined the factors that with high probability had a statistically significant impact on the conscription performance of horses of the Orlov's trotting breed, which were kept and tested in various natural, climatic and technological conditions: trainer (training system) ($F=225.3$, $p<0.05$), horse sex ($F=75.6$, $p<0.05$), racetrack (training conditions) ($F=74.8$, $p<0.05$) and stud farm (conditions of detention) ($F=69.9$, $p<0.05$).

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STRESSFUL SEASONAL FACTORS OF INFLUENCE ON MILK PRODUCTIVITY AND QUALITY OF COW'S MILK

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The research is devoted to a topical issue – establishing the influence of seasonal changes on the quality indicators of cow milk in the forest-steppe of Ukraine. Researchers from different countries and climatic regions have proven the impact of seasonal changes on the milk productivity of cows. Studies were conducted on cows of the Ukrainian red-pock dairy breed, in which milk productivity was taken into account by the method of control milking during January-August and the fat and protein content in milk was determined. The experiment was divided into three stages according to the actual ambient temperature: I – from -3 °C to +9 °C, II – from +10 °C to +24 °C, III – from +24.5 °C to +36.4 °C. the actual average air temperature was – +7 °C, +21 °C and 28 °C, respectively.

At the first stage of the experiment, the average daily milk yield of experimental cows was 19.6 kg, during the first – the coldest period of research (from January 2 to March 25) – their productivity increased by 0.2 kg. At the second stage of research, during the spring warming (from March 26 to May 26), the average daily milk yield increased by 0.7 kg. At the end of the hottest third period of the study (from May 27 to August 31), the daily milk yield decreased by 1.1 kg compared to the first period and by 1.8 kg compared to the second period.

Differences between the indicators of fat and protein content in the milk of experimental cows were established. At the first stage of the experiment, the average fat content in the milk of experimental cows was 3.93%, protein – 2.98 %. During the coldest period of the year studied, the fat content in milk increased by 0.14 % ($p<0.01$), protein – by 0.24 % ($p<0.01$). At the end of the second stage of the study, the fat and protein content in milk increased slightly, by 0.05% and 0.02%, respectively. During the hottest period of research, the fat content in the milk of experimental cows increased by 0.14 %. The protein content in milk decreased slightly (by 0.06%) at the end of the third study period.

Thus, it is proved that seasonal changes affect the milk productivity of cows, in particular, the daily milk yield, fat and protein content in milk, which is consistent with studies by other scientists conducted in different countries. Further research should be aimed at finding innovative ways to offset the negative factors of seasonal changes on the productivity of dairy cattle.

Keywords: dairy cattle, milk productivity, daily milk yield, milk fat, milk protein

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СТРЕСОВІ СЕЗОННІ ФАКТОРИ ВПЛИВУ НА МОЛОЧНУ ПРОДУКТИВНІСТЬ І ЯКІСТЬ МОЛОКА КОРІВ

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Дослідження присвячені актуальному питанню – встановленню впливу сезонних змін на показники якості молока корів в умовах Лісостепу України. Дослідниками різних країн і кліматичних регіонів доведено вплив сезонні змін на молочну продуктивність корів. Дослідження проведені на коровах української червоно-рябої молочної породи, в яких обліковували молочну продуктивність методом контрольних доїнь впродовж січня-серпня і визначали вміст жиру і білка у молоці. Дослід було розділено на три етапи за фактичною температурою зовнішнього середовища: I – від -3°C до +9°C, II – від +10°C до +24°C, III – від +24,5°C до +36,4°C. Фактична середня температура повітря становила відповідно – +7°C, +21°C та 28°C.

На першому етапі досліду середній добовий надій молока дослідних корів становив 19,6 кг, за перший – найбільш холодний період досліджень (з 2 січня по 25 березня) – їх продуктивність зросла на 0,2 кг. На другому етапі досліджень впродовж весняного потепління (з 26 березня по 26 травня) середній показник добового надою підвищився на 0,7 кг. Наприкінці найбільш спекотного третього періоду досліджень (з 27 травня по 31 серпня) показник добового надою знизився на 1,1 кг у порівнянні з першим періодом і на 1,8 кг у порівнянні з другим періодом.

Встановлено відмінності між показниками вмісту жиру і білка у молоці дослідних корів. На першому етапі досліду середній вміст жиру у молоці дослідних корів становив 3,93 %, білка – 2,98 %. Впродовж найбільш холодного дослідженого періоду року вміст жиру у молоці підвищився на 0,14 % ($p<0,01$), білка – на 0,24 % ($p<0,01$). Наприкінці другого етапу досліджень вміст жиру і білка у молоці незначно підвищився, відповідно на 0,05 % і 0,02 %. За найбільш спекотний період досліджень вміст жиру у молоці дослідних корів підвищився на 0,14 %. Вміст білка у молоці наприкінці третього дослідного періоду незначно знизився (на 0,06 %).

Таким чином, доведено, що сезонні зміни впливають на молочну продуктивність корів, зокрема – на добовий надій, вміст жиру і білка у молоці, що узгоджується із дослідженнями інших вчених, проведених у різних країнах. Подальші дослідження мають бути спрямовані на пошук інноваційних засобів нівелювання негативних факторів сезонних змін на продуктивність молочної худоби.

Ключові слова: молочна худоба, молочна продуктивність, добовий надій, молочний жир, молочний білок

Introduction. Cow milk production is known to vary with the season and environmental factors (Borshch, 2021; Gauly & Ammer, 2020; Skliarov et al., 2022). Consequently, Picinin and co-authors established a correlation between climatic

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conditions and the physicochemical properties of raw milk, as well as the total volume of milk produced in the conditions of dairy farms in Brazil (Picinin et al., 2019). According to their research, an increase in temperature from 6.2 °C to 31.3 °C led to a significant decrease in the content of milk protein (by 4.09 %), fat (by 5.75 %), also decreased by 1.31% the content of skimmed dry matter (SNF) and by 16.8 % – the content of somatic cells, but the total content of microorganisms in milk increased by 13.7 %. South Korean scientists have studied 1.5 million people. data and established the negative impact of heat stress on the productivity and milk quality of Holstein cows (Lee at al., 2023).

Many scientists prove that the summer season is the most critical for milk production. Experiments on Holstein cows in the conditions of 3,328 dairy farms in the Lombard region of Italy were studied (Bertocchi et al., 2014) results of analysis of 508613 milk samples and established a significant association with seasonal changes in such indicators as the content of dry matter, skimmed milk residue powder, fat and protein in milk. In particular, the most critical season in terms of milk quality was summer, especially July. Tančin and co-authors also on Holstein cows proved the influence of factors of the season of the year on milk quality indicators (Tančin et al., 2020). Parmar and co-authors (Parmar et al., 2020) established the variability of milk density depending on seasonal fluctuations throughout the year. The highest fat and protein content in milk was observed in the autumn-winter period, and the lowest – in the summer. Studies of fat and protein content in cow's milk on large farms under different weather conditions throughout the year have also established seasonal patterns (Feliciano et al., 2023).

It has been proven (Ayemele, 2021) that heat stress causes oxidative stress in the body, resulting in an increase in the content of reactive oxygen species in cells. Significantly higher levels of stress indices catalase, SOD, GSH reductase, and Malone dialaldehyde were found in lactating cows in summer. Increased milk production during this period leads to oxidative tissue damage due to the induction of heat stress. In the work of Rodney J. Feliciano et al. (2020) noted that climate change affects the microbial safety of dairy products. Under conditions of heat stress, the susceptibility of lactating cows to microbial contamination increases, and accordingly, microbial contamination of milk increases. The researchers propose developing models to quantify microbial pollution to evaluate risk reduction strategies, which will be a key step in prioritizing the creation of a climate-resilient dairy industry.

Zazharska et al., 2024) examined the composition of whole milk of cows of different technological groups by season of the year and found that the fat content in the milk of cows of all groups was significantly lower in summer, and the highest in winter. All cows had the lowest content of somatic cells in autumn, and the highest rate – in cows at the beginning of lactation and primiparous – in winter, and in cows of the second lactation – in spring. The lowest urea content in milk in all animal groups was observed in summer. The lowest protein level was observed in autumn (3.27±0.11%), and the highest - in winter (3.39±0.11%) in the volume milk of cows at the beginning of lactation. Sara Pacheco-Pappenheim et al. (2021) link the fatty acid and triacylglycerol composition of cow's milk to seasonal changes. In their research, they associate significant changes in the fatty acid composition of milk with increased intake of C18:3 cis-9,12,15 from grass in spring and summer. The triacylglycerol profile, in turn, depended on the fatty acid composition of the milk. At the same time, low - and medium-molecular groups of the triacylglycerol profile increased in winter and decreased in summer, while high-molecular groups increased in summer and decreased in winter.

They are particularly concerned with the impact of seasonal climate changes on livestock production in countries with arid climates. Thus, studies of the milk quality of Holstein cows in the north-eastern regions of Iran have proven (Toghdory A. at all., 2022)

that livestock productivity is influenced by various factors due to the complex interaction between the animal and the environment. The main factors influencing the quality of milk, these researchers consider the temperature and humidity of the environment. They attribute their conclusions to factors – an increase in temperature from 6.2 to 31.3 °C led to a significant decrease in the content of milk protein (by 4.09 %), fat (by 5.75 %). Depending on the increase in ambient temperature, the content of skimmed dry matter (SNF) decreased by 1.31% and the content of somatic cells (by 16.8 %). But with an increase in ambient temperature, the total content of microorganisms in milk increased by 13.7 %.

At the same time, in different regions of the world, the seasons of the year differ in climatic conditions. Consequently, Iranian scientists prove (Nateghi et al., 2024), in contrast, milk obtained in summer had a significantly higher dry matter content and better microbiological quality compared to milk obtained in winter. Scientists attribute seasonal fluctuations in the composition of cow's milk to differences in diets, because in summer the animals consumed fresh grass on pastures, and in winter – mixtures of dry components. Seasonal changes in milk quality are primarily associated with the feeding diet of cows and other researchers (Magan et al., 2021; Hayes et al., 2023). Insufficient dry matter intake reduces milk synthesis, which is associated with biological changes in the mammary gland (Gao et al., 2019).

Correa-Calderón with co-authors (Correa-Calderón at al., 2022) add that at least a 40% decrease in milk productivity is associated with a decrease in feed dry matter intake, however, the greatest direct impact on overall metabolism and cell thermal resistance. The results of their experiments show that heat stress reduces the transcription of genes associated with metabolism, and, accordingly, increases the concentration of genes associated with inflammation in breast tissues, which leads to a decrease in milk protein synthesis.

Other researchers have shown that in cows exposed to heat or cold stress, body responses included changes in energy balance and nutrient distribution (Razzaghi et al., 2022). The ability of an animal to synthesize milk fat largely depends on the availability of substrates for lipid synthesis from the diet, rumen fermentation, or adipose tissue reserves that can be altered in the face of climate change.

Stojnov et al. (Stojnov et al., 2024) link dairy productivity and milk quality of cows to their calving season in the context of future climate changes in Bulgaria. 199 Holstein cows were examined for 286 lactations. Cows calving in spring had the highest average milk yield (8522.2 kg) and maximum daily milk yield (38 kg), while cows calving in summer had the lowest milk yield (8082.7 kg) and minimum daily milk yield (35.7 kg). In terms of milk composition, fat and protein content, no significant influence of the calving season was found, but there was a tendency to lower the percentage of fat in milk in cows calving in the summer (3.68 %) and higher in cows calving in the spring (3.71 %). As for the percentage of protein in milk, the lowest values were observed in cows calving in autumn (3.19 %) and the highest in cows calving in summer (3.27 %).

Therefore, in conditions of loose keeping, a decrease in fat content was observed during the summer period with the lowest indicator in July and the highest in December. The highest protein content in raw milk was observed from November to January. The average level of somatic cells increased in winter.

Taking into account the relevance of the issue covered in information sources, the aim of the research was to establish the influence of seasonal changes on the quality indicators of cow's milk.

Research materials and methods. The research was conducted in LLC "Pechenezhskoe" Kharkiv region on cows of the Ukrainian red-pock dairy breed. During

2022, control milking of 70 cows was carried out (January-August). The conditions of keeping, feeding, watering and milking regimens during the studies of experimental animals were the same. The experimental cows were clinically healthy, were on 2-4 lactation periods, and their average age was 64.4±3.9 months. The average live weight of the experimental animals was 581±22 kg. Cows were fed with balanced diets. The diet of experimental cows consisted of the following components: corn silage (8.0 kg), triticale haylage+oats (12.0 kg), pea straw (1.0 kg), beer pellets (5 kg), 1.7 kg mixed feed (5.8 kg), sunflower meal (1.6 kg). Control accounting of feed mixture consumption was carried out every 10 days. At the beginning of the experiment, feed samples were selected to determine their chemical composition and nutritional value in the laboratory for assessing the quality of feed and animal products of the Institute of animal husbandry of the National Academy of Sciences. The results of the analysis of the feed mixture of cows in the first half of the transit period are shown in Table 1.

Table 1.

Chemical composition of the feed mixture of experimental cows

Feed mix components, kg	First Transit period	second transit period
Corn silage	8,0	10,0
Haylage triticale+ oats	6,0	9,0
Pea straw	2,0	0,5
Meadow hay	1,0	-
Fresh beer pellets	-	10,0
Sorghum cornage	1,4	2,5
Mixed feed	1,3	2,3
Sunflower meal	1,7	5,0

According to the results of the analysis, the nutritional value of the diet in comparison with the need was established (Table. 2). Consequently, the diet of experimental animals in the first half of the transit period contained 13.04 kg of dry matter, 129.7 MJ of metabolic energy, and 1628 g of crude protein. The level of content per 100 kg of live weight in the first half of the transit period was: Exchange energy – 25.13 MJ, dry matter – 2.24 kg, crude protein – 280.2 g.

Table 2.

Content of metabolic energy and nutrients in the diet of experimental cows during the first transit period

Indicator	content in the diet	need
Exchange energy, MJ	222	250
Dry matter, kg	20,5	20,0
Crude protein, g	3587	3500
Digestible protein, g	2569	2550
Raw fiber, g	19,4	18,0

The daily feed intake of Experimental Animals, based on the control feeding data, was almost complete – residues ranged from 1 to 3% of the set value.

After calving, the cows began the second phase of the transit period, characterized by the formation of colostrum in the udder, and later – intensive milk production. During this period, the feeding ration was adjusted with an advance payment of feed to increase milk production with the introduction of dairy feed – fresh beer pellets and sorghum corsage. The nutritional value of the diet of experimental cows of the second transit period is shown in Table 3.

Consequently, in the second phase of the transit period, cows of the control group received a diet containing 20.5 kg of crude matter, 222 MJ of exchange energy and 3587 g of crude protein, including 2569 g of the rumen-soluble fraction of crude protein and 1018 g of the insoluble protein fraction in the rumen, or 71.62 and 28.4% of the total amount of crude protein, respectively.

The proposed composition and nutritional value of the feed mixture is universal for the total number of cows in a certain transit period, and the satisfaction of the needs of animals with different milk productivity in the required amount of energy and nutrients was carried out by feeding to their heart's content. That is, the feed mixture was in the feeder around the clock and the determining factor was and is the indicator of dry matter consumption in absolute and relative terms.

Control milking was performed twice a day-in the morning and in the evening using portable buckets. Sanitary and hygienic treatment of udders and teats in cows of all groups was carried out in the same way. Samples of milk from each cow were taken using a probe, in proportion to the morning and evening milk yields, when sampling were guided by the European requirements of Codex Alimentarius, Vol. 13 "methods of analysis and sampling" and DSTU ISO 707:2002 "milk and dairy products, instructions for sampling". Samples were delivered to the laboratory with a preservative (broad-spectrum MicroTabs tablets, manufactured in the USA).

The experiment was divided into three stages according to the actual ambient temperature: I – from -3°C to +9°C, II – from +10°C to +24°C, III – from +24.5°C to +36.4°C. the actual average air temperature was – +7°C, +21°C and 28°C, respectively.

Biochemical parameters of milk were determined in a certified laboratory for assessing the quality of livestock products. The mass fraction of protein and protein (casein+whey proteins) was determined by rapid infrared spectrometry (DSTU 8396:2015, 2017). All experimental studies were conducted in accordance with modern methodological approaches, requirements and standards (DSTU ISO/IEC 17025:2019, 2021), directive 2010/63/EC (2010) and the procedure for conducting animal testing in research institutions" (law of Ukraine No. 249, 2012). The experiments were performed in accordance with the provisions of the European Convention for the protection of vertebrates used for experimental and other scientific purposes (European convention, 1986).

Research results. The climatic conditions of the research region are analyzed. LLC "Pechenezhskoe" is located in the North-Eastern District closer to the center of the Kharkiv region within the village of Pechenegi on the southern dam of the Pecheneg reservoir of the Seversky Donets River Basin (Erofeeva & Sashkova, 2011). The village is adjacent to large woodlands and a complex of artificial ponds has been created. The type of climate at the location of the farm is temperate continental, The Zone is forest – steppe. Summers are warm and, due to the proximity of the reservoir, quite humid. Winters are moderately mild with a predominance of cloudy and moderately frosty weather. During the year, the air temperature usually ranges from-8 °C to +27 °C, occasionally it is below-19 °C and above 33 °C. The warm season in the region lasts 3.7

months., usually from May 18 to September 8 with a maximum average daily temperature above 21 °C (July) with a minimum of +17 °C. The cold season lasts 3.9 months. from November 18 to March 13 with a minimum average daily temperature below 4 °C. The coldest month is January with an average temperature maximum of – 7 °C (January) and a minimum of- – 2 °C. The region is characterized by precipitation of 400-650 mm per year, mainly from April to October, in winter the snow cover is maintained for up to 110 days.

Differences in the indicators of daily milk yield of cows at different air temperatures during the year were established (Table. 3).

Table 3.

Dynamics of dairy productivity of cows with seasonal changes

Indicators	Air temperature, °C		
	-3 – +9	**+10 – +24**	**+24,1 – +36,4**
Duration of the period, days	83	60	100
Average daily milk yield at the beginning of the period, kg	19,6±0,56	19,8±0,51	20,5±0,61
Average daily milk yield at the end of the period, kg	19,8±0,51	20,5±0,61	18,7±0,40

At the beginning of the experiment, the average daily milk yield of experimental cows was 19.6 kg, during the first – the coldest period of research (from January 2 to March 25) – their productivity increased by 0.2 kg.

At the second stage of research, during the spring warming (from March 26 to May 26), the average daily milk yield increased by 0.7 kg.

At the end of the hottest third period of the study (from May 27 to August 31), the daily milk yield decreased by 1.1 kg compared to the first period and by 1.8 kg compared to the second period.

Differences between the indicators of fat and protein content in the milk of experimental cows were also established (table. 4).

Table 4.

Dynamics of fat and protein content in cow's milk during seasonal changes

Indicators	Air temperature, °C		
	-3 – +9	**+10 – +24**	**+24,1 – +36,4**
Average mass fraction of fat in milk at the beginning of the period, %	3,93±0,09	4,07±0,06	4,04±0,04
Average mass fraction of fat in milk at the end of the period, %	4,07±0,06	4,12±0,03	4,18±0,01
Average mass fraction of protein in milk at the beginning of the period, %	2,98±0,05	3,22±0,03	3,23±0,01
Average mass fraction of protein in milk at the end of the period, %	3,22±0,03	3,24±0,03	3,17±0,01

Consequently, at the beginning of the studies, the average fat content in the milk of experimental cows was 3.93%, protein – 2.98 %. During the coldest period of the year studied, the fat content in milk increased by 0.14 % ($p<0.01$), protein – by 0.24 % ($p<0.01$).

At the end of the second stage of the study, the fat and protein content in milk increased slightly, by 0.05% and 0.02%, respectively.

During the hottest period of research, the fat content in the milk of experimental cows increased by 0.14 %, which may be associated with a decrease in daily milk yield, because it is known that these signs are negatively related (Alphonsus, 2015; Yoon J. T. et al., 2004). The protein content in milk decreased slightly (by 0.06%) at the end of the third study period.

Discussion. The variability of productivity indicators and the content of fat and protein in cow's milk can be associated with the influence of various factors: climatic parameters, the duration of the World Day, exercise (rehabilitation), and so on. Most researchers believe that milk production varies significantly due to seasonal changes. It is known that milk productivity and milk composition vary depending on environmental conditions, including air temperature. Many studies indicate a negative effect of heat stress on milk production and changes in its composition (Barash et al., 2001; Bouraoui et al., 2002; Bohmanova et al., 2007; West et al., 2003; Schneider Y. et al., 2014). The results of our research are consistent with studies conducted by other domestic scientists (Polupan et al., 2022), that seasonal changes, in particular – air temperature affects milk productivity, fat and protein content in cow's milk in the forest-steppe region of Ukraine. It was found that at the population level, among the mentioned environmental factors, the herd (15-22%), the year of first calving (4.7-12%) and birth (4.2-12%) have the most significant influence on the phenotypic variability of milk productivity of first-born heifers (0.05 - 0.2%) and calving (1.5-2.1%). A number of other researchers report a greater impact of the herd and year and a smaller impact of the calving season and especially birth on the milk productivity of first – born heifers.

So, analyzing the experience of researchers and their own research results, it is planned to further adapt dairy farming in Ukraine to climate change, which requires additional research in determining the degree of vulnerability of livestock industries under the influence of climate change, as well as in finding ways to prevent them. According to climate forecasts of different temperature zones, local and regional strategies for reducing heat stress for dairy cattle should be adjusted to mitigate potential losses of dairy production due to heat stress. Reducing the body temperature of animals during the heat contributes to their consumption of more feed, and the introduction of special feed elements into the diet reduces the release of electrolytes from the body through the skin. In this aspect, the development and use of drugs and probiotics in animal husbandry – anti-stress products of synergistic action, vitagens, immunomodulators, organic acids, mineral compounds-is becoming increasingly relevant. An important direction of leveling heat stress is the development and application of stress-free and adaptive technologies for keeping animals, taking into account actual and possible changes in the environment, the spread of technologies for ecological and organic production of livestock products.

Conclusion. It is proved that seasonal changes affect the milk productivity of cows, in particular, the daily milk yield, fat and protein content in milk. Further research should be aimed at finding innovative ways to offset the negative factors of seasonal changes on the productivity of dairy cattle.

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FATTENING QUALITIES OF PIGS OF VARIOUS BREEDING DIRECTIONS IN PUREBRED BREEDING, CROSSING AND HYBRIDIZATION IN THE CONDITIONS OF MODERN PORK PRODUCTION

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In order to determine the influence of breed and breeding methods on the productive characteristics of pigs in the process of rearing and fattening, seven experimental groups were formed with animals of different genotypes and breeding directions. Three methods of pig breeding were used in the experiment: Pure breeding (intra–linear), crossbreeding between breeds and breed–linear hybridisation. It was found that the highest live weight gains were achieved by hybridisation with the terminal parental line PIC–337, while purebred breeding with specialised parental lines showed limited efficiency under industrial conditions. A comparison between large white pigs and landraces shows that the landrace has a slightly better growth potential, but the increase in live weight remains moderate. It has been proven that piglets of the PIC–337 endline, which were selected for increased growth energy, are clearly superior to the analogues of the dam breeds in all important growth indicators such as average daily growth during the suckling period and during rearing, as well as total weight at the end of rearing; they consumed more feed during rearing, and converted it more efficiently into live weight gain. At the same time, the hybrids are superior to the indigenous animals in breed–linear hybridisation for all indicators of growth intensity, especially during the rearing phase. The advantage of the hybrids over the local forms in the range of 2–13% is due to the influence of the inheritance of the terminal boar of the PIC–337 line. It was found that animals with the genotype (¼L×¼LW)½PIC–337) were more productive than similar hybrids with (¼LW×¼L)½PIC–337, suggesting that the use of landrace sows as the dam line is appropriate in the creation of hybrids with maximum realisation of the heterotic effect. Thus, the use of crossbreeding and three–line hybridisation can significantly improve piglet productivity both during the suckling period and during rearing. The hybrid animals showed the best results, confirming the effectiveness of heterosis, and the use of landrace sows as the dam line provides an additional improvement in the growth indicators of the offspring. It was found that an intermediate type of inheritance characterised hybrids (¼LW× ¼ L)½PIC–337 with 9–13% lower productivity than purebred animals PIC–337, but with better conservation. Instead, the hybrids (¼L× ¼ LW)½PIC–337) showed marked heterosis, especially in terms of growth rate, absolute growth, and conservation. It was found that the animals of the PIC–337 parental line had significant advantages in fattening in terms of growth rate, reduction in fattening time and increased feed conversion efficiency compared to the parental breeds, making them promising for commercial pork production with high animal turnover rates. Hybrids involving the PIC–337 parent line are characterised by high preservation and close to the indicators of the pure line for feed conversion, but had slightly lower growth rates and feed efficiency. These results indicate an intermediate form of inheritance of these traits, and, considering the significantly higher number of piglets in the nests of hybrid pigs, the further use of hybrids in intensive pig breeding systems is feasible, taking into account their genetic characteristics.

Keywords: pigs, breed, crossbreed, hybrid, preservation, growth rate, feed conversion

ВІДГОДІВЕЛЬНІ ЯКОСТІ СВИНЕЙ РІЗНОГО СЕЛЕКЦІЙНОГО СПРЯМУВАННЯ ЗА ЧИСТОПОРОДНОГО РОЗВЕДЕННЯ, СХРЕЩУВАННЯ І ГІБРИДИЗАЦІЇ В УМОВАХ СУЧАСНОГО ВИРОБНИЦТВА СВИНИНИ

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Для визначення впливу породи та методів розведення на продуктивні характеристики свиней у процесі дорощування та відгодівлі було сформовано сім експериментальних груп тварин різного генотипу та напрямку селекції. В експерименті застосовували три методи розведення свиней: чистопородне (внутрішньолінійне), міжпородне схрещування та породно–лінійна гібридизація. Встановлено, що найвищі прирости живої маси забезпечуються при застосуванні гібридизації з використанням термінальної батьківської лінії PIC–337, тоді як чистопородне розведення у спеціалізованих материнських лініях демонструє обмежену ефективність у промислових умовах. Порівняння свиней великої білої та ландрас порід засвідчує, що порода ландрас має дещо кращий потенціал росту, але приріст живої маси залишається помірним. Доведено, що поросята термінальної лінії PIC–337, які селекціонуються в напрямку підвищення енергії росту суттєво переважають аналогів материнських порід за всіма основними показниками росту такими як, середньодобові прирости у підсисний період та під час дорощування, а також загальною масою по завершенню дорощування, вони під час дорощування споживали більше корму, й ефективніше його конвертували у приріст живої маси. Водночас гібридні тварини за породно–лінійної гібридизації значно переважають помісних за всіма показниками інтенсивності росту, особливо в період дорощування. Виявлена перевага гібридів над помісними формами в межах 2–13% зумовлена впливом спадковості термінального кнура лінії PIC–337. Встановлено, що тварини з генотипом (¼Л×¼ВБ)½PIC–337) виявились продуктивнішими за аналогічних гібридів з (¼ВБ×¼Л)½PIC–337, що вказує на доцільність використання свиноматок породи ландрас як материнської лінії при створенні гібридів із максимальною реалізацією гетерозисного ефекту. Таким чином застосування міжпородного схрещування та трилінійної гібридизації дозволяє суттєво покращити продуктивність поросят як у підсисний період, так і під час дорощування. Гібридні тварини показали найвищі результати, що підтверджує ефективність гетерозису, а використання свиноматок породи ландрас в якості материнської лінії забезпечує додаткове покращення ростових показників потомства. Встановлено, що гібриди (¼ВБ×¼Л)½PIC–337 характеризувалися проміжним типом успадкування з продуктивністю, що була на 9–13% нижчою за чистолінійних тварин PIC–337, але з кращою збереженістю. Натомість гібриди (¼Л×¼ВБ)½PIC–337) виявили яскраво виражений гетерозис, особливо у темпах росту, абсолютному прирості та збереженості. Встановлено що під час відгодівлі тварини батьківської лінії PIC–337 мали виражені переваги у швидкості

росту, скороченні періоду відгодівлі та підвищеній ефективності використання корму, порівняно з материнськими породами, що робить їх перспективними для комерційного виробництва свинини з високими темпами обороту поголів'я. Гібриди з участю батьківської термінальної лінії PIC–337 характеризуються високою збереженістю і близькими до чистолінійних показниками кормоспоживання, але мали дещо нижчі темпи росту та ефективність корму. Ці результати вказують на проміжну форму успадкування цих ознак та з врахуванням суттєво вищої кількості поросят в гніздах гібридних свиней на доцільність подальшого використання гібридів у системах інтенсивного свинарства з урахуванням їх генетичних особливостей.

Ключові слова: свині, порода, помісь, гібрид, збереженість, інтенсивність росту, конверсія корму.

Introduction. The use of the latest genetic technologies and breeding methods can significantly improve the growth indicators of animals and the efficiency of feed payment in increments, which contributes to improving production efficiency and product quality. In particular, as noted (Li Q. et al., 2022), thanks to genomic selection, it is possible to identify genes and alleles associated with the synthesis of growth hormones, which can accelerate this process and significantly affect its intensity in pigs. In addition, according to (Kim S. W. et al., 2022; Wientjes Y. C. J. & Calus, M. P. L., 2017), the genotype of animals and their breeding methods determine the effectiveness of feed assimilation, which indicates the presence of a genetic predisposition to more rational use of them. According to the study (De Vos, C. J. et al., 2020; Wu X. L. & Zhao S., 2021), different genotypes of pigs show different efficiency in feed assimilation, which is explained by the variability of their metabolic processes. These differences determine the ability of some animals to convert nutrients into muscle tissue more efficiently, while others are less productive in this aspect. A similar opinion is expressed by (Li H. et al., 2020), noting that genetic factors associated with the regulation of appetite and metabolism significantly affect the level of feed assimilation. Mutations in the genes responsible for the metabolism of essential nutrients – proteins, fats and carbohydrates – can significantly change the efficiency of feed use, which is directly related to the productivity of animals and the economic performance of pig farms. In this regard, as noted (Do D. N. et al., 2013; Amer P. R. et al., 2014; Li Q. et al. 2020; Jin L. et al., 2023), modern genetic breeding programs actively integrate genome information to improve fattening characteristics, which contributes to increasing the profitability of pork production.

In their studies (Dube B, et al., 2013), and (Šprysl M., et al., 2005; Zhou P, et al. 2023; Li H., et al., 2022) consider an approach to genetic selection that includes economic factors to identify and use genes that are key to increasing fattening productivity, which ultimately contributes to more efficient and more competitive pork production. In turn (Schroyen M. & Tuggle C. K., 2015; Kasper, C. et al., 2020; Roth K, et al., 2022; Yang C., et al., 2023; Xie Z. et al., 2023), note that the genotype of an animal affects the functioning of the immune system, which determines the ability of pigs to resist diseases. Increased resistance to diseases not only reduces the cost of Veterinary Measures but also contributes to better assimilation of feed, which has a positive effect on the overall productive characteristics of animals. Therefore, selecting genes associated with immune resistance can significantly improve fattening outcomes.

Also important factors in improving the productive qualities of pigs are their breeding methods. As noted (Christiansen G. M. et al., 2014), the widespread use of crossbreeding in pig breeding is due to the advantages of hybrid strength (Heterosis) and

a high level of breed compatibility. However, according to the data (Sørensen M. K. et al., 2008; Vashchenko O. V., 2017; Bates R. O., 2020; Wu X. L. & Zhao S., 2021; Kremez M. et al., 2025) the resulting increase in productivity due to heterosis, as a rule, is not preserved in subsequent generations, which makes it necessary to preserve purebred lines for reproduction and further improvement. At the same time, the different orientation of inheritance of reproductive and fattening traits limits the full use of the hybrid power effect. In this regard, a more effective strategy is increasingly used in modern pig breeding – intra–breed or breed–linear hybridization (Povod M. et al., 2021; Lykhach V. et al., 2023; Baranovskyi A. M. & Tkachuk O. M., 2024; Tatsii O., 2021). Within the framework of this approach, maternal lines are selected separately, which are usually represented by Yorkshire and landrace breeds, as well as paternal (terminal) lines that include Duroc, Petren breeds or combinations thereof. These genotypes are used to improve the meat and fattening qualities of offspring. It is important that all lines are kept separately and regularly checked for combinative ability (Clutter A. C. et al., 2004; Vashchenko O. V., 2016; Iversen M. W. et al., 2019; Bates R. O., 2020), which provides a steady increase in productivity in commercial livestock. So, according to information (Smith W. C. et al., 1990), hybrids in which Duroc or Hampshire breeds are used as final producers showed better fattening and meat qualities compared to the Great White × landrace combination, which makes them more effective for use in conditions of intensive meat production. According to the study (Shuplik V. & Shcherbatiuk N., 2024), descendants of specialized parent breeds such as Duroc and Pietrain showed higher growth rates than Animals of the Great White and landrace breeds. Also, as reported (Baranovsky A. M. & Tkachuk O. M., 2024), when comparing different methods of breeding breeds of pigs, Bolshaya Belaya, landrace, Pietrain during purebred breeding and crossing, it was found that in terms of growth indicators, local animals showed the best dynamics throughout the entire growing period. At the end of fattening, crossbred animals ½ large white × ½ landrace reached a weight of 100 kg in 10 days, and animals from the combination ¼ large white × ¼ landrace × ½ Pietrain were 8 days faster than their purebred counterparts of the large white breed. At the same time, according to the study (Maribo H. B. et al., 2018), Danish pigs obtained by three-breed hybridization under the Duroc × landrace × Yorkshire (DLY) scheme showed an average daily weight gain of 15.5% higher than in animals of the Pietrain × landrace × Yorkshire (PLY) combination, and also had 6.9% better feed efficiency, indicating the advantage of the DLY genotype for use in intensive meat production. And as a result, in Danish breeding systems, the Duroc is the main parent breed. A similar situation is observed in the pork market in China, where according to reports (Bergamaschi M. et al., 2020) Duroc has become the preferred option for specialized parent pig breeding, mainly as claimed (Strathe A. B. et al., 2010) due to the high growth rate, good feed pay, high slaughter yield and the percentage of lean meat in the carcass. As a result, as reported (Liu X. et al., 2019), more than 70% of commercial pork production in China comes from dly animals, which are obtained by hybridizing Duroc Boars with local sows (landrace × Yorkshire). Where those other results cited in their research (Nielsen B. & Velander I., 2018), when comparing the fattening performance of purebred Duroc pigs and their D(LY) – Duroc × (landrace × Yorkshire) hybrids. Their experiments showed no significant difference in the average daily weight gain of purebred and hybrid animals. In contrast, purebred duroks showed 5.9% (0.09 kg) better feed efficiency than hybrid animals D(LY). At The Same Time (Bergamaschi M. et al., 2020) reports that for purebred breeding of pigs of the Duroc, landrace and Yorkshire breeds in terms of economic efficiency of feeding pigs of the Duroc breed, the lowest indicators were found both in terms of growth and feed efficiency, among the compared breeds, so the feed conversion rate was the best in

animals of the landrace breed, it was 10–15% better than in analogues of the Great White, and 8–12% better than in representatives of the Duroc breed. The highest growth rate was shown by pigs of the large white breed, 4.4% higher than in animals of the landrace breed, and 5.9% higher than in their counterparts of the Duroc breed. In contrast to their findings in the messages (Kasper C. et al., 2020; Liu S. et al., 2023) the advantage of hybrid pigs using Duroc animals in the final production phase is noted. Also based on the results of the study (Maribo H. et al., 2018), during the fattening period, crossbreeds of Danish breeding pigs (landrace × Yorkshire sows in combination with Danish Duroc Boars) showed higher average daily increments: by 143–165 G when fed ad libitum and by 88 g – with a limited regime, as well as better by 0.04–0.07 kg feed efficiency compared to similar combinations, where German pietren Boars were used as the final form. According to the data (Chernenko O. M. et al., 2022), in the conditions of Ukraine, young animals obtained as a result of hybridization using pigs of Danish origin (¼Y×¼L×½D) showed better fattening indicators compared to local animals according to the ½Y×½L scheme. In particular, the increase in live weight was higher by 5.4%, the efficiency of feed use by 5.2%, and the weight of 100 kg of these pigs reached 2.9% faster.

Thus, Duroc Boars are a world leader in use as the final form in the hybridization system. However, as noted (Do D. N. et al., 2013) in recent years, some weaknesses of boars of this breed have been identified, which include low heritability of feed efficiency, reduced multiple pregnancies, and a tendency to lose weight under abnormal conditions. Therefore, due to the growing demands of the market, more and more commercial breeding companies are seeking to develop new parent lines based on a combination of other pig breeds. Unlike the duroks, as believed (Li Q. et al., 2020), Yorkshire pigs are not only more intense in growth and have a higher content of lean meat, but also have an attractive exterior, good meat qualities, and increased stress resistance. Considering the differentiation of demand, breeding companies carry out targeted work to create new parent lines of the Yorkshire breed. Thus, the Dutch firm Topigs Norsvin (TN) uses large white pigs as the final breeding male to form the TN Tempo line, which is characterized by high viability of the offspring, strong musculature of the limbs, fattening efficiency, and good feed conversion rates (Nielsen T. & Larsen S., 2018; Topigs Norsvin, 2022).

The world leader in the production of breeding pig products (Pig Improvement Company, PIC) has developed synthetic terminal lines of boars based on a combination of several breeds (Genetic Update Programs, 2025). Among the PIC terminal boards, the main ones are the PIC–337, PIC–800, and PIC–359 lines, each of which has its own advantages and purpose. The PIC–337 boar is a versatile terminal boar bred on the basis of a combination of breeds with high growth rates and excellent feed conversion. It is characterized by a stable high daily growth rate, high–quality carcass, and uniformity of offspring, which ensures economic efficiency in commercial production (Pig Progress, 2023). The PIC–800 line, based on the Duroc breed, is characterized by increased viability of piglets, improved average daily growth and high quality of meat – the meat is juicy and tender. Thanks to these characteristics, the PIC–800 is suitable for producing piglets with increased taste and stress resistance (PIC Genetics, 2023; Topigs Norsvin, 2022).

The PIC–359 boar is based on the pietren breed and is designed to produce lean meat with a high content of muscle tissue. This boar shows good muscle depth, efficient feed conversion, and high meat productivity, making it the optimal choice for markets focused on lean pork (PIC Genetics, 2023).

As noted (Kremez M. et al., 2024), the use of boars of the synthetic parent line PIC–337 as a terminal form in the cultivation of piglets contributed to an increase in rearing efficiency. In particular, the average daily growth increased by 15.1%, nest weight

at the end of the period by 19.4%, and feed conversion improved by 1.7%, compared to offspring from Boars of the Great White and landrace breeds.

The opposite results were obtained in their studies (Bergamaschi M. et al., 2020), who reported that purebred pigs of the large white breed had a higher average daily increase of 4.4% compared to animals of the landrace breed, while the feed conversion rate was better by 10–15% in animals of the landrace breed. The results are consistent with the data (Baranovsky D. & Tkachuk O., 2024), which indicate that Landrace pigs were inferior to their peers of the large white breed in terms of growth rate: in 2 months, by 3.4%, in 4 months, by 1.8%, in 6 months, by 2.4%, and in 8 months – by 1.5%. But local pigs (½ large white × ½ landrace) exceeded both large white breeds (by 1.1% at 2 months, 2.5% at 4, 1.7% at 8 months) and landraces (by 4.7%, 4.5%, 2.4% and 3.2%, respectively, at 2, 4, 6, and 8 months). This indicates the effectiveness of interbreeding in increasing the growth rate of young animals. Whereas (Santiago G. et al., 2022) did not establish significant differences in the productivity of large white and Landrace pigs during fattening. Thus, the average daily feed consumption for fattening pigs of the landrace breed was 2.14 kg, which is 1.4% more than in the large white breed. In terms of feed conversion, landrace animals had an indicator of 2.37 kg, which is 1.7% worse than their counterparts in the Great White breed. At the same time, in terms of growth rate, landrace animals were ahead of representatives of the Great White breed by 0.7%, with an average daily growth of 906 G against 900 g for the Great White. Whereas in research (Kremez M. et al., 2024), opposite results were established. Thus, during rearing, purebred piglets of the large white breed were inferior to landrace animals in terms of average daily growth by 4.1%, and by 4.0% in terms of live weight of piglets at the end of the period. At the same time, local animals obtained as a result of direct and reverse crossing of these breeds did not have significant differences in growth intensity indicators. However, these crossbreeds were characterized by a higher feed consumption of 0.7–4.8% and at the same time showed a more efficient feed payment by increments of 2.2–5.3% compared to the original parent breeds. Whereas, analysis of fattening productivity of Mother breeds in the northern states of the United States and Canada during purebred breeding and crossing over the past five years (Collins C. L. et al., 2017) showed that at the beginning of the study, Landrace pigs had slower growth, were significantly fatter than large white animals, and were inferior to them and their crossbreeds in terms of feed conversion rate. At the same time, over five years, landraces showed a significant improvement in productive indicators, and at the end of the study, their genetic value reached the level of other breeds.

Geoclimatic conditions significantly influence the manifestation of fattening signs. However (Zhou P, et al., 2023) studying the age of reaching 100 kg of live weight and fat thickness at 100 kg in three populations of large white pigs from Canada (n=500), Denmark (n=295) and the United States (n=1500) revealed the relative stability of these indicators regardless of regional breeding of the breed.

As reported (Yurchenko O. S. et al., 2024) most industrial farms in Ukraine use foreign genotypes of pigs, testing the combinational ability of which in rather harsh conditions of Ukraine, as believed (Lykhach V. Ya. et al., 2023) should be carried out with a certain frequency, which is what our work is devoted to.

The aim of the study was to determine the influence of breed and breeding methods on the productive characteristics of pigs in the process of rearing and fattening.

Research material and methodology. To achieve the research goal, seven experimental groups of animals of different genotypes and breeding directions were formed on the basis of LLC "NPP "Globinsky Pig Complex" (Table 1).

Table 1.

Scheme for studying the influence of the breed and breeding method on the fattening qualities of pigs

Indicator	pig group and its purpose						
	I Control	II experi-mental	III experi-mental	IV experi-mental	V experi-mental	VI experi-mental	VII experi-mental
Number of animals, head	200	200	100	200	200	200	200
Breeding method	purebred (intralinear)			crossing		hybridization	
Breed of the mother	LW	L	L–65	LW	L	♀ LW ×♂L	♀ L ×♂ LW
Genotype of boars	LW	L	PIC–337	L	ВБ	PIC–337	PIC–337
Genotype of offspring	LW	L	PIC–337	1/2 LW 1/2 L	1/2 L 1/2LW	(1/4 LW 1/ 4L) 1/2 PIC–337	(1/4 L 1/4 LW 1/2 PIC–337

According to the study scheme, seven groups of experimental piglets were formed during the weaning of piglets in the study of the reproductive qualities of sows. First (control) and groups II–VII (experimental). In the experiment, three approaches to reproduction were used: purebred (intralinear) breeding (groups I, II, and III), interbreeding, and breed-linear hybridization (groups VI and VII).

Genotypic structure of the maternal forms: Large White (LW), landrace (L), as well as combinations of – LW×L and – L×LW, and sows of the parent terminal Line L–65. Boars are represented by breeds LW, L, and hybrid line PIC–337. Accordingly, the offspring's genotype varied from purebred to complex hybrids of Type (1/4LW×1/4L) × 1/2PIC–337 and (1/4L1/4LW1/2)×PIC–337.

The conditions for keeping animals in all groups were unified: the suckling period was 28 days, rearing was 49 days, and fattening was 100 days. The preservation of animals, growth intensity, and feed efficiency indicators were monitored during the experiment, considering the genotype and breeding methods.

To assess the productivity of pigs, the fattening quality index was used according to the formula adapted by M. I. Berezovsky in the presentation (Ladyka V. I. et al. , 2023):

$$I = A^2/ (B\ C)\ ,$$

where: a – gross gain for the fattening period, kg; B – number of days of fattening; C – feed consumption per 1 kg of weight gain.

Feeding, keeping, caring for animals, and preventive measures were carried out per the current European legislation on the welfare of farm animals (European Union, 2010).

The obtained experimental data were subjected to statistical processing by methods of variation statistics per the recommendations (Ladyka V. I. et al., 2023) using a personal computer and MS Excel 2016 software tools.

Research results. When comparing the growth intensity and safety of Pigs during rearing between groups of animals of different breeding orientation (maternal breeds –

large white (group 1) and landrace (Group 2), and the parent line PIC–337 (Group 3), which was selected for increased growth rate, it was found that piglets of the terminal line PIC–337 had a birth weight of 1.43 kg, which is highly likely ($p<0.001$) by 13.5% more compared to analogues of large white and by 10.9% compared to with landrace animals (Table. 2).

Table 2.

Growth rate of purebred and purebred piglets during the suckling period and during rearing

Indicator	experimental groups		
	1	2	3
Number of piglets put up for rearing, head	150	150	150
Birth weight of piglets, kg	1,26±0,005	1,29±0,010	1,43±0,006 *bb ggg lll mmm nnn ooo*
Weight of piglets at weaning at 28 days, kg	6,72±0,029	6,75±0,05	8,04±0,03 *bbb ggg*
Average daily growth from birth to 28 days, g	195±0,77	195±1,52	236±0,93 *bbb ggg lll mmm nnn ooo*
Weight of piglets at the end of rearing, kg	26,60±0,11	26,81±0,20	32,60±0,13 *bbb ggg lll mmm nnn ooo*
Absolute growth rate, kg	19,88±0,08	20,06±0,15	24,56±0,10 *bbb ggg lll mmm nnn ooo*
Average daily gain from 28 days to 77 days	406±1,61	409±3,41	501±1,82 *bbb ggg lll mmm nnn*
Number of piglets transferred to fattening, head	146	147	145
Safety of piglets on rearing	97,3	98,0	96,7

Note. Here and further the probability of differences between groups: [a] –1 and 2; [b] – 1 and 3; [c] – 1 and 4; [d] –1 and 5; [e]– 1 and 6; [f]– 1 and 7; [g]– 2 and 3; [h] – 2 and 4 [i] – 2 and 5, j – 2 and 6; [k] – 2 and 7;[l] – 3 and 4; [m] –3 and 5; [n] – 3 and 6;[o] – 3 and 7;[p] – 4 and 5; [q] – 4 and 6; [r] – 4 and 7; [t] – 5 and 6;[u] – 5 and 7;[v] – 6 and 7

When weaned at the age of 28 days, the weight of linear piglets PIC–337 was 8.04 kg, which is 19.6% higher compared to Animals of the LW and 19.1% higher compared to analogues of the landrace breed ($p<0.001$).

The average daily growth during the suckling period in piglets of the terminal line reached 236 g, 21.0% more ($p<0.01$) than piglets of both mother breeds. At the end of rearing, the weight of piglets of the PIC–337 terminal line reached 32.60 kg, while in the LW it was 22.6%, and in animals of the landras breed it was 21.6% less, compared to the peers of the terminal line ($p<0.001$).

The average daily growth during rearing in piglets of the terminal line was 501, which is highly likely ($p<0.001$) to be 23.4% higher compared to the peers of the large white breed and 22.5% higher than in animals of the landrace breed, which contributed to an increase in their absolute weight gain, which in piglets of the synthetic line PIC–337 was 24.56 kg, which is 23.5% more compared to the large white and 22.4% more than landraces ($p<0.001$).

During rearing, piglets of all groups that were analyzed showed high rates of piglet safety: 97.3% in the Large White, 98.0% in the landras, while among animals of the synthetic line PIC–337, it was 0.6–1.3% lower and amounted to 96.7%.

Comparing the parent breeds, great white and landrace, we found similar results in the leading indicators. There was a tendency for landrace piglets to predominate in terms of average daily increments of 3 g, which caused them to have 0.18 kg more absolute increments. Also, piglets of this group had a slightly higher preservation rate of 0.7%. However, these differences are insignificant, indicating a comparable genetic potential of both breeds selected in the maternal direction.

In the table. 3. The results of comparison of growth characteristics in the suckling period and during rearing of piglets obtained as a result of direct and reverse crossing of animals of maternal breeds and hybrid young pigs obtained by combining cross sows from such crossing and Boars of the synthetic parent line are presented.

Table 3.

Growth rate of cross–breed and hybrid pigs during the suckling period and during rearing

Indicator	experimental groups			
	4	5	6	7
Number of piglets put on rearing, head	150	150	150	150
Weight of piglets at birth, kg	1,34±0,010 *cc hhh*	1,36±0,006 *iii*	1,35±0,005 *jjj*	1,39±0,005 *f kkk rrr vvv*
Weight of piglets in 28 days, kg	6,98±0,05 *ccc hhh*	7,04±0,02 *ddd iii*	7,12±0,02 *eee jjj qq*	7,24±0,*025 fff kkk rrr uuu vv*
Average daily growth from birth to 28 days, g	201±1,77 *ccc hh*	203±0,75 *dd iii*	206±0,73 *eee jjj qq tt*	209±0,69 *fff kkk rrr uuu vvv*
Weight of piglets at the end of rearing, kg	27,53±0,22 *ccc h*	27,83±0,11 *ddd iii*	29,35±0,10 *eee jjj qqq ttt*	31,54±0,10 *fff kkk rrr uuu vvv*
Absolute growth rate, kg	20,55±0,16 *ccc h*	20,79±0,08 *ddd iii*	22,23±0,07 *eee jjj qqq tt*	24,30±0,08 *fff kkk rrr uuu vvv*
Average daily gain from 28 days to 77 days, g	419±3,15 *ccc*	424±1,53 *ddd*	454±1,41 *eee qqq ttt*	496±1,66 *fff kkk rrr uuu vvv*
Number of piglets transferred to fattening, head	147	148	148	148
Safety of piglets on rearing, %	98,0	98,7	98,7	98,7

The weight of piglets at birth in local groups averaged 1.35 kg, while in hybrid groups, 1.37 kg, which is 0.02 kg or 1.5% more. The average daily weight gain during the suckling period in hybrid piglets was 2.7% higher ($p<0.01$) – 207.5 g compared to 202 g in cross animals, which contributed to their advantage in absolute weight gain by 2.1–2.4% and, together with a larger weight at birth, caused an excess of live weight at weaning by 0.17 kg or 2.4% ($p<0.01$).

During rearing, a higher growth rate was also found in hybrids compared to local piglets. Thus, according to the average daily weight gain during this period, hybrid animals prevailed by 53.5 g or 12.7% ($p<0.001$) of cross-country analogues – 475 g against 421.5 g. this caused a significant difference in the absolute weight gain, which in

hybrids was 23.27 kg, which exceeded the indicators of crossbreeds by 2.6 kg or 12.6% ($p<0.001$) and together with the larger mass of animals at the beginning of rearing led to an excess of hybrids over crossbreeds at the end of rearing by 10.0% or 2.77 kg ($p<0.001$).

The safety of hybrid piglets in rearing was consistently high – 98.7%, while in crossbreeds it ranged from 98.0–98.7%, which did not significantly affect the overall results.

When comparing hybrid groups 6 and 7, taking into account their genotype, the advantages of animals of Group 7 were established, where the maternal basis was local sows (♀L×LW) over animals of Group 7, where the maternal basis was crossbreeds (♀LW×L), by birth weight by 0.04 kg or 3.0% ($p<0.001$), by weight at weaning – by 0.12 kg or 1.7%, ($p<0.01$), on average daily gains during rearing by 42 g or 9.3% ($p<0.001$), which led to their advantage in absolute gains by 2.07 kg and contributed to an increase in body weight in 77 days to 31.54 kg, which is 2.19 kg or 7.5% more than in animals of Group 6 ($p<0.001$).

When comparing the growth characteristics of piglets of purebred, local, and hybrid origin during the suckling period and at the rearing stage, a clear relationship was established between the genotype of animals and the intensity of their growth (Tables 2 and 3). Thus, the weight of piglets at birth in purebred animals of maternal breeds averaged 1.28 kg, while in crossbred piglets this indicator was 5.9% higher at the level of 1.35 kg. At the same time, hybrid animals had an even higher birth weight – an average of 1.37 kg, which is 7.5% higher than purebred animals and 1.5% higher than crossbreeds. The average daily weight gain during the suckling period was lowest in purebred pigs – 195 g, while crossbreeds had an average daily weight gain of 202 g (+3.6%), and hybrids – 207.5 g (+6.4% for purebred pigs and +2.7% for crossbreeds). Due to this, taking into account the different large–fruited animals of these groups, the live weight of piglets at weaning in purebred pigs was 6.74 kg, in crossbreeds it was higher by 4.1%, and in hybrids by 6.6% compared to purebred pigs and by 2.4% in hybrids compared to crossbreeds.

At the end of the rearing period, the live weight of purebred piglets averaged 26.71 kg, while in crossbreeds it was 3.7%, and hybrid animals – 14.0% more ($p<0.001$) compared to purebred animals. At the same time, hybrid animals prevailed in this indicator by 10.0% of local analogues ($p<0.01 – 0.001$). This is caused by higher absolute increases in live weight during rearing, which amounted to 19.97 kg in purebred animals, 3.5% in crossbreeds, and 16.5% in hybrids compared to purebred animals and 12.6% compared to crossbreeds, respectively, larger. This, in turn, was determined by higher average daily increments in the period from 28 to 77 days, which amounted to 407.5 g in purebred piglets, 3.4% in crossbreeds, and 16.6% more in hybrid piglets compared to purebred animals. While hybrids outperformed their local counterparts by 12.7% in this indicator.

In all groups, high safety of animals during the rearing period was revealed. In purebred groups, it averaged 97.65%, in crossbreeds – 98.35%, and in hybrid animals – 98.7%. Despite the small difference, there is a tendency to increase the safety of piglets during crossing and hybridization, which further emphasizes the advantages of using heterosis in breeding programs.

Along with a general increase in productive traits as they move from purebred to hybrid forms, the influence of the mother breed on the growth rate of piglets was also revealed. In particular, the best indicators were demonstrated by animals in which landrace was used in the maternal line.

When comparing the growth rate of purebred animals of the parent terminal Line (Group 3 – PIC–337) and intraspecific hybrids (groups 6 and 7), it was found that the

birth weight of piglets in hybrids of Group 6 was lower by 5.6% compared to purebred animals of the PIC–337 line ($p<0.001$) and in hybrids of Group 7 – by 2.8% ($p<0.001$). The average daily growth in the suckling period was highly likely highest in Pure-Line young animals of the terminal line PIC – 337 (236 g), while in Group 6 it was lower by 12.7% and in Group 7 – by 11.4% compared to 3, which indicates an intermediate type of inheritance of this trait. Different growth rates also led to different masses of hybrid animals compared to pure-line PIC – 337, so it was less in Group 6 by 11.4%, and in Group 7 by 10.0% compared to Group 3. Also, during weaning, it was found that the weight of piglets of Group 7 was 7.24 kg, which exceeded the same indicator in Group 6 (7.12 kg) and indicates a certain manifestation of heterosis in Group 7.

In terms of growth intensity during the growing season, hybrids of Group 6 were inferior to pure–line hybrids. Thus, the average daily increase in Group 6 was 9.4% lower than the pure line indicator ($p<0.001$), while this indicator in Group 7 was 496 g, which is almost equal to the indicator of pure line PIC–337 (501 g), and exceeds the same indicator in Group 6 by 9.2%. This led to the fact that the absolute increase in Group 7 (24.30 kg) was almost at the level of PIC–337 (24.56 kg, 1.1% less), while in Group 6 it was 22.23 kg and was 10.5% lower compared to pure–line analogues. This determined the fact that the hybrids of Group 7 almost did not differ from the animals of the PIC–337 line in terms of the weight of piglets at the end of rearing, which turned out to be only 3.3% lower, while in animals of Group 6 this difference was 11.1% or 3.25 kg, which indicates different levels of combinational ability of such combinations

It is also important that the safety of piglets in hybrid groups 6 and 7 was higher by 2.1% compared to the pure line PIC–337 (98.7% vs. 96.7%), which is also a sign of heterosis, particularly in the viability of young animals.

Against the background of a constant rise in the price of feed resources, the most important indicator is the efficiency of using feed by animals of various breeding directions. Thus, during rearing, the average daily feed intake of purebred animals of maternal lines averaged 0.76 kg, while in piglets of the paternal genotype, this indicator was higher by 9.2% and amounted to 0.83 kg (Table 4).

Table 4.

Use of feed and its effectiveness by purebred and purebred piglets during rearing

Indicator	experimental groups		
	1	2	3
Average daily feed consumption, kg	0,77	0,75	0,83
Amount of feed eaten per rearing, kg	37,80	36,93	40,52
Feed conversion from 28 days to 77 days, kg	1,90	1,84	1,65

This, with the same duration of the rearing period, led to an 8.4% increase in the total amount of feed eaten during this period in animals of the terminal line compared to analogues of maternal lines. In our opinion, this, combined with high increments, indicates more active metabolic processes in animals of this line. This conclusion is confirmed by feed conversion data. On average, this indicator in maternal genotypes was 1.87 kg, while in the PIC–337 group, it was 1.65 kg, which is 11.8% less, and indicates better feed assimilation and higher biological efficiency of the terminal line.

Comparison of the effectiveness of feed use by local piglets (groups 4 – LW LW×L L, 5 – L×LW) and pedigree hybrids (groups 6 – (LW×L)×PIC–337, 7 – (L×LW)×PIC–337) in The growing time showed that the average daily feed intake of the hybrids was 0.83 kg, which is 9.9% more than that of the local ones. Overall, they ate

3.68 kg more, which is due to faster growth and higher nutrient requirements. At the same time, the feed conversion rate in hybrids was better – 1.75 kg against 1.79 kg in crossbreeds (an improvement of 2.2%), that is, they needed less feed to form 1 kg of growth. This confirms the effect of Heterosis and the economic feasibility of using hybrids (Table 5).

Table 5.

Use of feed and its effectiveness by local and hybrid piglets during rearing

Indicator	experimental groups			
	4	5	6	7
Average daily feed consumption, kg	0,76	0,75	0,80	0,86
Amount of feed eaten per rearing, kg	37,12	36,89	39,14	42,23
Feed conversion from 28 days to 77 days, kg	1,81	1,77	1,76	1,74

Comparison of purebred mother piglets and crossbreeds showed almost the same feed intake (0.760 and 0.755 kg/day, respectively). Total consumption in crossbreeds was 1.0% lower, and their conversion rate was 4.3% better than that of purebred animals of the parent breeds.

Comparative analysis of the effectiveness of the use of feed of purebred animals of the parent genotype and hybrids based on them during rearing shows that the average daily feed intake in animals of the parent line was 0.83 kg, while in hybrids of groups 6 and 7 it turned out to be 3.6% lower. In terms of the total amount of feed eaten during the rearing period, piglets of Group 6 ate it 3.4% less, while their counterparts from Group 7 consumed it 4.2% more compared to analogues of Group 3. In terms of feed conversion, purebred animals of Group 3 had an indicator of 1.65 kg, which is 6.7% better compared to hybrids of Group 6 and 5.5% better with animals of Group 7.

Comparative analysis of fattening indicators of pigs of the parent line PIC–337 relative to the average value of the mother breeds (great white and landrace) revealed significant differences in most of the studied parameters (Table. 6). Thus, the safety of livestock in the parent group was at the level of 98.62%, which was almost at the level of the average indicator of maternal lines and indicates an equally high level of animal safety, regardless of genotype.

The greatest advantages were found in terms of growth indicators. The initial live weight of PIC–337 piglets exceeded the average value of parent breeds by 22.07% ($p<0.001$), which is associated with a higher growth rate of these animals in previous periods of ontogenesis. The growth rate of these animals was also higher during fattening. Thus, the average daily growth of pigs of the paternal line was dominated by 22.29% by the average indicators of maternal breeds (1124 g against 920.5 g) ($p<0.001$), which led to their superiority in absolute growth during this period by 22.09% ($p<0.001$) and led to an excess of these animals in live weight at the end of fattening – by 22.08 % ($p<0.001$), and the average daily growth – by 22.29%, which highlights much more intensive growth. This growth rate ensured a faster achievement of the slaughter condition, which is confirmed by the age indicator of reaching a live weight of 120 kg. In PIC – 337, this age was 154.8 days, which is only 86.24% of the average for maternal breeds (177.55 days ($p<0.01–0.001$). Thus, animals of the terminal line reached the target weight 22–23 days earlier.

Table 6.

Preservation, growth rate and efficiency of feed of purebred and purebred pigs during fattening

Indicator	experimental groups		
	1	2	3
Number of pigs at the end of fattening, heads	145	145	143
Safety of fattening livestock, %	99,32	98,64	98,62
Weight of pigs at the beginning of fattening, kg	26,60±0,11	26,81±0,20	32,60±0,13 *bbb ggg lll mmm nnn ooo*
Weight of pigs at the end of fattening, kg	118,30±0,46	119,25±1,00	145,00±0,57 *bbb ggg lll mmm nnn ooo*
Absolute fattening gain, kg	91,70±0,37	92,43±0,82	112,40±4,64 *bbb ggg lll mmm nnn ooo*
Average daily gain from 78 days to 178 days, kg	917±3,60	924±7,69	1124±4,64 *bbb ggg lll mmm nnn ooo*
Age of reaching live weight 120 kg, days	178,9±0,72 *aaa bbb cc ddd ee efff*	176,2±1,42 *ggg ii jjj kkk*	154,8±0,62
Average daily feed intake during fattening, kg	2,52	2,46	2,73
Amount of fattening feed consumed, kg	252,3	246,2	273,1
Fattening feed conversion, kg	2,75	2,66	2,43
Fattening quality index	30,56	32,07	51,99

Animals of the parent line had an average daily feed consumption per Rhine of 2.73 kg, which is 9.21% more than the average value of the parent breeds (2.49 kg). The total amount of feed consumed on fattening animals of the PIC–337 line (273.1 kg) exceeded the average indicator of Mother breeds by 9.44 % (249.25 kg). However, despite the large volumes of consumption, the feed conversion in the paternal line was 8.62% better – 2.43 kg against the average value of 2.71 kg in the maternal forms, which indicates a higher efficiency of converting feed resources into live weight gain

Especially significant was the advantage of the parent line in terms of fattening qualities index. The indicator in pigs of the PIC–337 line was 51.99, which exceeds the average value of Mother breeds by 62.29%.

When comparing the indicators of safety, growth intensity and efficiency of feed use in cross-country and hybrid pigs during the fattening period (Table. 7). It showed that the safety of livestock in all groups remained consistently high, ranging from 99.3% to 100%. This indicates that there is no significant impact of breeding methods on survival in the process of fattening and creating optimal conditions for keeping animals.

At the beginning of fattening, hybrids had a weight 10.02% higher than crossbreeds, and their average daily growth exceeded the indicators of crossbreeds by 7.71% (1040.5 g; $p<0.001$). This provided a 7.67% higher increase in live weight and a final advantage of 8.19% at the end of fattening, as well as a 9.5% reduction in the age of reaching 120 kg.

Hybrids consumed 6.1% more feed, but had a better 1.52% conversion rate and a 17.64% higher fattening quality index.

Between the hybridization variants, the best results were shown by animals of Group 7 – the initial weight of which was 7.48% more, the average daily and absolute gains of 1.18% and 1.84% higher, which provided a 3.08% higher final weight at the end

of fattening, and a 2.23% reduction in the age of reaching 120 kg. Despite a slightly higher feed intake of 0.75%, its conversion was more efficient by 1.15 %, which increased the fattening quality index by 4.77 %.

Table 7.

Preservation, growth rate and efficiency of feed of cross-breed and hybrid pigs during fattening

Indicator	experimental groups			
	4	5	6	7
Кількість свиней по завершенню відгодівлі, голів	146	148	147	148
Safety of livestock on fattening, %	99,3	100,0	99,3	100,0
Weight of pigs at the beginning of fattening, kg	27,53±0,22	27,83±0,11	29,35±0,10	31,54±0,10
Weight of pigs at the end of fattening, kg	123,45±1,11 *ccc hh*	125,16±0,52 *ddd iii*	132,45±0,47 *eee jjj qqq ttt*	136,54±0,44 *fff kkk rrr uuu vvv*
Absolute fattening gain, kg	95,92±0,73 *ccc hh*	97,33±0,37 *ddd iii*	103,10±0,31 *eee jjj qqq ttt*	105,00±0,34 *fff kkk rrr uuu vvv*
Average daily gain from 78 days to 178 days, kg	959±7,53 *ccc hh*	973±3,87 *ddd iii*	1031±3,11 *eee jjj qqq ttt*	1050±3,14 *fff kkk rrr uuu vvv*
Age of reaching live weight 120 kg, days	173,4±1,37 *lll rrr qqq*	171,7±0,71 *mmm ttt*	164,9±0,54 *nnn vvv*	161,2±0,58 *ooo*
Average daily feed intake during fattening, kg	2,53	2,54	2,68	2,70
Amount of fattening feed consumed, kg	252,8	254,2	267,9	270,2
Fattening feed conversion, kg	2,64	2,61	2,60	2,57
Fattening quality index	34,91	36,28	40,90	42,85

Comparison with pure-line pigs PIC–337 (Group 3) showed that hybrids had a higher safety (99.3–100.0% vs. 98.62%), but lower by 6.6–8.3% average daily and absolute increments. The final weight of hybrids (132.45–136.54 kg) was 5.9–8.7% lower, and the age of reaching 120 kg was 4.1–6.5% higher.

The average feed intake in hybrids (2.68–2.70 kg) almost did not differ from PIC–337 (2.73 kg), but the conversion rate was 5.8–7.0% worse, which led to a 17.5–21.3% decrease in the fattening quality index in hybrids compared to pure PIC–337 animals.

So, hybrids with the participation of PIC–337 are characterized by high safety and close to pure–line feed consumption levels, but have lower growth rates and feed efficiency. This indicates an intermediate inheritance of traits and confirms the feasibility of using hybrids in intensive pig breeding systems, considering their genetic characteristics.

Discussion. Our conclusions regarding the fact that purebred pigs of the mother breeds of large white and landrace breeds are characterized by relatively stable growth rates, and higher values of fattening productivity were achieved by pigs of the landrace breed compared to Animals of large white breed when purebred their breeding coincided with reports (Kremez M. et al., 2024), who claim that Landrace pigs outnumbered their peers of the large white breed in terms of average daily increments of 4.1%, and 4.0% in

terms of live weight of piglets at the end of the period and the information described in the paper (Collins C. L. et al., 2017). At the same time, they contradict the message (Santiago G. et al., 2022), which did not establish significant differences in the productivity of excellent white and Landrace pigs during fattening, and statements (Bergamaschi M. et al., 2022), who reported that purebred pigs of large white breed had a higher average daily increase of 4.4% compared to analogues of the landrace breed, while the feed conversion rate was better by 10–15% in animals of the landrace breed. They also do not match the information (Baranovsky D. & Tkachuk O., 2024), which indicate that Landrace pigs were inferior to their peers of the large white breed in terms of growth rate at 6 – by 2.4%, and at 8 months – by 1.5%.

Our conclusions that purebred pigs of the mother breeds of large white breed and Landrace are inferior to their local counterparts in terms of growth intensity by 3–6% and feed conversion by 4.3% are identical to the reports (Baranovsky D. & Tkachuk O., 2024; Lisnyi V. A. & Nazarenko I. V., 2002; Chernenko O. M. et al., 2022; Dudka E. I., 2019), but contradict the statements (Kremez M. et al., 2024) that crossbreeding animals obtained as a result of direct and reverse crossing of these breeds did not have significant differences in growth intensity indicators, but they were characterized by a higher feed consumption by 0.7–4.8% and at the same time showed an effective 2.2–5.3% feed payment in increments compared to the original parent breeds.

The results obtained by US are entirely consistent with the scientific data on the advantages of the parent terminal line PIC–337 for intra–line breeding over animals of the mother breeds by 22.0% in terms of growth rates during rearing and fattening, by 11.8% in terms of feed efficiency and have a reduction in the duration of fattening by 21–23 days with the data (Kremez M. et al., 2024; Genetic Update Programs, 2025).

Our conclusions regarding the fact that hybrid animals (LW×L)×PIC–337 and (L×LW)×PIC–337 show a significant advantage over local animals in terms of growth intensity during rearing and fattening and have better feed efficiency, coincided with reports (Chernenko O. M. et al., 2022; Baranovskyi D. & Tkachuk O., 2024; Kasper C. et al., 2020; Liu S. et al., 2023), but not consistent with the reports (Nielsen B. & Velander I., 2016), who in their studies, when comparing the fattening performance of purebred Duroc pigs and their D(LY) – Duroc × (Landrace × Yorkshire) hybrids, did not find a significant difference in the average daily weight gain of purebred and hybrid animals.

Our reports that a more effective combination in hybridization is the combination of (L×LW)×PIC–337, combining high increments, optimal feed conversion, and reduced fattening time, which leads to an increase in overall production efficiency, partially coincided with the conclusions made in their studies (Kremez M. et al., 2024).

Thus, according to the results of our research, using purebred pigs of the parent line allows achieving maximum growth rates and the best feed conversion. Still, hybridization provides better preservation of young animals and a large number of nests, which is a significant factor in increasing the overall productivity of pig breeding.

Conclusions.

1. Relatively stable growth indicators characterize purebred pigs of the mother breeds of the large white breed and Landrace. Still, they are inferior to local and hybrid analogues regarding growth intensity and feed efficiency.

2. Pigs of the parent terminal line PIC–337 for intra-line breeding predominate animals of the mother breeds by 22.0% in terms of growth rates during rearing and fattening, by 11.8% in terms of feed efficiency, and have a reduction in the duration of fattening by 21–23 days.

3. Crossbred animals (LW×L and L × LW) exceed purebred analogues in all the main economically advantageous characteristics, particularly in terms of live weight by

3–6% and feed conversion by 4.3 %.

4. Hybrid animals – (LW×L)×PIC–337 and – (L×LW)×PIC–337 show a significant advantage over local animals in terms of growth intensity during rearing and fattening, and have better feed efficiency.

5. A more effective combination in hybridization is the combination of (L×LW)×PIC–337, combining high increments, optimal feed conversion, and reduced fattening time, which increases overall production efficiency.

6. Using purebred pigs of the parent line allows you to achieve maximum growth rates and the best feed conversion. However, hybridization provides better preservation of young animals and a large number of nests, which is a significant factor in increasing the overall productivity of pig breeding.

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THE INFLUENCE OF FERTILISERS AND PRE-SOWING SEED TREATMENT ON THE YIELD OF INDUSTRIAL HEMP (*CANNABIS SATIVA* L.)

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After a long-standing prohibition on cultivation, industrial hemp is being reintroduced to agriculture. Its importance is difficult to overestimate in the context of global ecological and economic trends in crop production. Considerable attention is paid to optimising the hemp fertilisation by using compound fertilisers and pre-sowing treatment of seeds with growth stimulants, which promotes early plant development especially under adverse growing conditions. A positive effect was established from the use of the following humic preparations Humifield, 1R Seed Treatment, Ultra Boost, and Zinovii grand for pre-sowing seed treatment and foliar application in combination with plant protection agents such as insecticides and fungicides. These treatments were applied against the background of high application rates of compound mineral fertilisers: Polifoska 8:24:24 9S at 165 kg/ha + UAN-32 at 300 kg/ha, and Ecoplant at 200 kg/ha + UAN-32 at 300 kg/ha. The application of humic preparations for pre-sowing treatment and in combination with foliar pesticides increased the seed yield by 0.14–0.21 t/ha and the straw yield by 0.45–0.53 t/ha. The use of Ultra Boost and Zinovii grand for foliar application enhanced the oil content in seeds by 0.5%. The growing conditions were found to have a significant influence on seed yield formation, under hot and dry conditions, seed yield decreased by 46%, whereas straw yield slightly increased from 4.77 t/ha in 2023 to 5.09 t/ha in 2024. In view of these findings, particular attention was paid to the nature of the correlations between the economically valuable characteristics of hemp, such as the duration of the the growing season, plant height, seed and straw yield, and oil content.

The study found that correlation coefficients can vary significantly depending on the contrast of growing conditions. Thus, correlation behaviour can be used as a tool to select varieties for cultivation and develop adaptive cultivation technologies.

Keywords: industrial hemp, fertilisers, pre-sowing treatment, seed yield, straw yield.

ВПЛИВ ДОБРИВ ТА ПЕРЕДПОСІВНОЇ ОБРОБКИ НАСІННЯ НА ФОРМУВАННЯ УРОЖАЙНОСТІ КОНОПЕЛЬ ПОСІВНИХ (*CANNABIS SATIVA* L.)

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Після тривалої заборони на вирощування в культуру землеробства повертаються коноплі посівні. Їхнє значення важко переоцінити в контексті еколого-економічних тенденцій розвитку галузі рослинництва в світі. Значна увага приділяється оптимізації удобрення конопель посівних шляхом застосування комплексних добрив, передпосівної обробки насіння стимуляторами росту, що сприяє розвитку рослин на ранніх етапах, особливо в несприятливих умовах вирощування. Встановлена позитивна дія використання гумінових препаратів – Гуміфілду, 1R Seed treatment, Ultra Boost та Zinovii grand для передпосівної обробки насіння та позакореневого застосування у сумішах з засобами захисту рослин – інсектицидами й фунгіцидами на фоні високих норм комплексних мінеральних добрив Поліфоска 8:24:24 9S, 165 кг/га + КАС-32, 300 кг/га та Екоплант, 200 кг/га + КАС-32, 300 кг/га. Застосування гумінових препаратів для передпосівної обробки та сумісного внесення з пестицидами по листу сприяло збільшенню врожайності насіння на 0,14–0,21 т/га і врожайності соломи на 0,45–0,53 т/га. Використання Ultra Boost та Zinovii grand для листової аплікації збільшило вміст олії в насінні на 0,5 %. Встановлено істотний вплив умов вирощування на формування урожайності насіння – в посушливих і спекотних умовах вона зменшилася на 46 %, в той час як урожайність соломи, навіть, дещо, зросла – з 4,77 т/га у 2023-му році до 5,09 – у 2024-му. Враховуючи це, було звернено увагу на характер кореляційних зв'язків між господарсько-цінними ознаками конопель – тривалістю вегетаційного періоду, висотою рослин, урожайністю насіння та соломи, вмісту олії. Встановлено, що за контрастності умов вирощування кореляційні зв'язки можуть істотно змінюватися за силою. Таким чином, поведінка кореляцій може бути використаною для підбору сортів для вирощування та створення адаптивних технологій вирощування.

Ключові слова: коноплі посівні, добрива, передпосівна обробка, урожайність насіння, урожайність соломи.

Introduction. Fertilisers are regarded as one of the most important factor in crop yield management, accounting for the largest share of input costs (O. A. Prymakov and M. P. Kozorizenko, 2015). According to Deng G. et al. (2019), nitrogen is the most critical factor, followed by potassium and phosphorus fertilisers. Nitrogen fertilisers influence plant height, stem diameter, and the ratio of generative to vegetative parts of the plant (E. Campiglia et al., 2017).

Just as nitrogen is key for the growth and structure of hemp plants, it also contributes to a reduction in water usage by 19–29%, depending on plant density

(Mishchenko S. V. et al., 2022). According to Tang K. et al. (2016), for optimal crop nutrition an application rate of 60 kg of nitrogen per hectare is sufficient, whereas 60–100 kg/ha of nitrogen promotes the development of high-quality fibre. However, high fertiliser rates should be applied taking into account varietal characteristics and the intended use of the raw material (I. M. Laiko and S. V. Mishchenko, 2022, Campiglia E. et al., 2017).

The application rates of nitrogen fertiliser must be determined with consideration of seeding rates, as these can vary significantly, as well as the influence of environmental conditions. Some scientists note that in order to achieve both high yields and high-quality fibre, optimal application rates are 251–273 kg/ha for nitrogen, 85–195 kg/ha for phosphorus, and 212–238 kg/ha for potassium (Deng G. et al., 2019). In continuous cropping systems, it is recommended to apply organic fertilisers at rates of 20–40 t/ha or in the form of $N_{200}P_{100}K_{240}$ (Kabanets V. M. et al., 2017, 2020; Laiko H., 2024). Several authors highlight waste products from sericulture and similar materials as particularly promising organic fertilisers (Łochyńska M. et al., 2019, 2022; Laleh S. et al., 2021). However, in Ukraine, assessing their fertiliser effectiveness remains practically unfeasible.

Biostar-type fertilizers may also prove effective for hemp crops. These fertilisers have been developed based on the metabolic products of red earthworms, a combination of cattle manure and plant biomass, and can be used for foliar feeding (Dan A. I. et al., 2015; Stramkale V. et al., 2021). The application of nitrogen fertilisers requires strict control, considering environmental and economic aspects; therefore, it is recommended to use nitrogen inhibitors (urease or nitrification inhibitors) in combination with nitrogen fertilisers (Ahmadi F. et al., 2024).

Increasing the application rates of phosphorus fertilisers may lead to the accumulation of heavy metals. Moreover, there is evidence suggesting a weak hemp yield response to this nutrient (Wielgusz K. et al., 2022; Łochyńska M., Frankowski J., 2019), although some data indicate that phosphorus may play a role comparable to that of nitrogen. This inconsistency is likely related to the agrochemical properties of soils and specific climatic conditions.

The use of potassium fertilisers also remains a subject of debate. For instance, according to Varga I. et al. (2024), potassium fertilisation may not significantly affect stem height, diameter, or quality indicators such as cellulose and lignin content in hemp stems[87]. Chinese researchers say that the optimal NPK ratio for hemp cultivation is 3:1:2.

The significant nutrient requirements of industrial hemp increase the need to optimise the fertilisation system. One approach to addressing this issue involves the use of humic substances. The issue requires detailed study, as humic substances can significantly enhance the effect of macronutrients (Šerá B., Novák F. (2022), Bernstein N. et al., 2019). This effect may be particularly relevant under conditions of unstable and insufficient moisture (Da Cunha Leme Filho J. F. et al., 2020). Attention should be paid to the possibility of using humic preparations during pre-sowing seed preparation and throughout a long part of the growing season (Ievinsh G., 2017).

Materials and methods. The material for the study was the Hlesia variety of industrial hemp, developed by breeders at the Institute of Bast Crops of the National Academy of Agrarian Sciences of Ukraine. The vegetation period is 118 days. The variety is characterized by plant heights of up to 263 cm, with technical stem lengths reaching 173 cm. The potential stem yield may reach 8.0 t/ha, fiber yield 2.5 t/ha, and seed yield 2.1 t/ha.

The following fertilisers were used to fertilise the crops: Polifoska (165 kg/ha), Ecoplant (200 kg/ha), and UAN-32 (300 kg/ha), the latter applied in combination with the first two. Polifoska 8:24:24 9S is a universal granular compound fertiliser recommended for various crops. It primarily promotes seed germination and root system development. Ecoplant is a complex granular fertiliser, the main components of which are potassium (28–34%), phosphorus (4–6%), magnesium (8–12%), calcium (10–17%), and sulphur (8–16%). The fertiliser also contains the following micronutrients: iron (Fe) – 1340 mg/kg, boron (B) – 1000 mg/kg, zinc (Zn) – 900 mg/kg, copper (Cu) – 240 mg/kg, manganese (Mn) – 150 mg/kg, chromium (Cr) – 6.3 mg/kg, molybdenum (Mo) – 1.5 mg/kg, and cobalt (Co) – 0.37 mg/kg.

Plant nutrition was optimised by pre-sowing seed treatment and foliar application of humic preparations Humifield (0.2 kg/t), 1R Seed treatment (1.0 kg/t), and Zinovii grand (1.0 kg/t) following the recommended rates. Humifield (0.2 kg/t) and Ultra Boost (2.0 l/ha) were used for foliar treatment.

Humifield is a growth stimulator that contains fulvic and humic acids in concentrations of 80 and 750 g/kg, respectively, along with 100–120 g/kg of amino acids, a similar amount of potassium, and 9–10.2 g/kg of micronutrients. 1R Seed Treatment contains 10% humic acids, 3% fulvic acids, and 6% micronutrients. Zinovii grand is a complex growth stimulator comprising up to 8.0% organic matter, up to 2.0% nitrogen, 3.5% potassium, and 0.1% phosphorus. The preparation also includes micronutrients such as manganese, zinc, copper, molybdenum, boron, and iron. Ultra Boost is a humic growth stimulator containing 14.9% humic acids and 12% micronutrients.

Field experiments were conducted on chernozem soils with a humus content of up to 2.68%. A detailed agrochemical analysis is given in Table 1.

The experimental design involved the study of two factors: fertiliser application (Factor A) and humic preparations (Factor B). The variants were arranged randomly, with three repetitions. The size of the accounting (harvested) plot was 300 m².

Table 1.

Agrochemical characteristics of soils

Field number 540/33	**Level of development according to the index NDVI**		
Soil characteristics	**low**	**moderate**	**high**
pH (1:1) soil	8.0	8.1	8.1
pH buffering	7.2	7.2	7.2
Soluble salts, mmol/cm	0.10	0.19	0.33
Organic matter, %	2.2	3.2	7.9
Nitrate nitrogen, mg/kg	7.4	12.5	24.6
Mobile phosphorus, mg/kg	44	25	28
Potassium, mg/kg	23	31	43
Calcium, mg/kg	2109	3130	4181
Magnesium, mg/kg	85	244	555
Sodium, mg/kg	13	16	39
Sulphur, mg/kg	9	12	12
Zinc, mg/kg	0.43	0.38	0.48
Iron, mg/kg	37.6	26.6	83.7
Manganese, mg/kg	3.6	4.2	5.5
Copper, mg/kg	0.16	0.40	0.79

Research results. According to the obtained data, the application of humic substances within the fertilisation system positively affected plant height, straw yield, and seed yield. However, this effect was observed to depend on the application rate of the respective preparation (Table 2). The use of 200 g/t for pre-sowing seed treatment did not lead to a significant increase in plant height. In contrast, the 1 kg/t application rate of the preparations 1R Seed Treatment and Zinovii grand increased hemp plant height. A positive effect was also observed from the foliar application of Ultra Boost (2 l/ha) and Zinovii grand (2 kg/ha), which were applied in the middle of the growing season in a mixture with the insecticide Belt (0.15 l/ha) and the fungicide Custodia (0.6 L/ha). Under these treatment conditions, plants reached their maximum height.

Table 2.

The influence of fertilisation on the Hlesia variety yield (2023–2024)

Fertiliser (A)	Treatment variant (B)	h, см	Seed yield, t/ha	Straw yield, t/ha
Polifoska 8:24:24 9S, 165 kg/ha + UAN-32, 300 kg/ha	No treatment	224	0.89	4.54
	Humifield, 0.2 kg/t	226	0.88	4.57
	1R Seed treatment, 1 kg/t	253	0.95	4,67
	Zinovii grand 1, kg/t	248	0.96	4.67
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	229	0.89	4.61
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	266	1.03	4.99
	Zinovii grand, 1 kg/t + Zinovii grand, 2 kg/ha	263	1.01	4.94
Ecoplant, 200 kg/ha + UAN-32, 300 kg/ha	No treatment	230	0.84	4.82
	Humifield, 0.2 kg/t	232	0.85	4.95
	1R Seed treatment, 1 kg/t	254	0.96	5.27
	Zinovii grand, 1 kg/t	247	0.95	5.23
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	239	0.87	5.08
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	264	1.05	5.35
	Zinovii grand 1 kg/t + Zinovii grand 2 kg/ha	262	1.02	5.33
LSD_{05} (A)		3.6	0.06	0.07
LSD_{05} (B)		8.4	0.10	0.14
LSD_{05} (AB)		15.7	0.12	0.19

Seed and straw yield indicators showed a similar reaction. The lack of a noticeable effect from the application of Humifield is likely due to the low application rate and indicates the need for dosage adjustment. The influence of the preparation was also weak when it was used for crop foliar spraying. In contrast, pre-sowing seed treatment with 1R Seed Treatment and Zinovii grand contributed to a slight increase in seed yield. However, the observed deviation was almost within the least significant difference (LSD).

The application of humic preparations, both as part of pre-sowing seed treatment and in combination with foliar application alongside plant protection products, resulted in a significant increase in seed yield by 0.14–0.21 t/ha and straw yield by 0.45–0.53 t/ha.

Thus, using humic preparations may serve as a valuable resource for enhancing the productivity of hemp raw materials. However, it should be emphasized that further research in this area is necessary, especially considering the relatively high cost of humic products, which is one of the reasons for the frequent scepticism of producers towards this group of substances.

A similar effect was also observed on the oil content in seeds. Pre-sowing treatment tended to increase oil content, but it was within the range of the least significant difference. The use of foliar application of Ultra Boost and Zinovii grand increased the seed oil content by almost 0.5% (Table 3).

Table 3.

The influence of fertilisers and growth stimulators on the oil content in hemp seeds (2023–2024)

Fertilizer	Treatment variant	Oil content, %
Polifoska 8:24:24 9S, 165 kg/ha + UAN-32, 300 kg/ha	No treatment	29.1
	Humifield, 0.2 kg/t	29.0
	1R Seed treatment, 1 kg/t	2.1
	Zinovii grand, 1 kg/t	29.1
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	29.1
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	29.6
	Zinovii grand, 1 kg/t + Zinovii grand, 2 kg/ha	29.6
Ecoplant, 200 kg/ha + UAN-32, 300 kg/ha	No treatment	29.2
	Humifield, 0.2 kg/t	29.3
	1R Seed treatment, 1 kg/t	29.5
	Zinovii grand, 1 kg/t	29.5
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	29.3
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	29.7
	Zinovii grand, 1 kg/t + Zinovii grand, 2 kg/ha	29.7
LSD_{05} (A)		0.07
LSD_{05} (B)		0.14
LSD_{05} (AB)		0.22

It should also be noted that growing conditions significantly impact the yield formation. Moisture deficiency combined with high temperatures caused the signs of water and temperature stress, which primarily affected the seed yield. In 2023, the average seed yield reached 1.38 t/ha, whereas in 2024 it did not exceed 0.74 t/ha, representing a decrease of nearly 46%. The straw yield under these conditions showed an opposite trend — 4.77 t/ha in 2023 and 5.09 t/ha in 2024.

Studying the relationships between yield structure elements under different conditions becomes relevant in this regard. The correlation network also reveals specific changes depending on the growing conditions. Thus, plant height at the stage of biological maturity had a strong direct correlation with the duration of the growing season ($r = 0.79$), seed yield ($r = 0.71$), and oil content ($r = 0.73$) in 2023. A moderate direct correlation with straw yield ($r = 0.47$) was also identified. The pattern of the relationships changed slightly: the correlation between the plant height and the duration of the growing season decreased ($r = 0.31$) while the correlation with straw yield increased ($r = 0.74$) in 2024.

Seed yield correlated with the duration of the growing season (r = 0.68) in 2023, while in the following year, this relationship was not statistically significant. A consistent correlation was observed between seed yield and oil content, regardless of the year, with coefficients ranging from r = 0.64 to 0.68. As for hemp straw yield, under more favourable conditions, it had a moderate correlation with plant height (r = 0.34...0.47). Under the conditions of moisture deficit and elevated temperatures, a moderate correlation emerged between straw yield and seed yield (r = 0.49), along with a strong correlation with plant height (r = 0.74) and oil content in seeds (r = 0.83). The authors think that creating a system of relationships could help to develop adaptive growing techniques. The nature of these relationships is shown in the graph of straw yield regression depending on plant height in Fig. 1**.**

Analysis of variance revealed that the studied factors had varying effects on the formation of economically valuable traits. Plant height during biological maturity was more influenced by factor B, i.e. pre-sowing seed treatment. No significant interaction between the factors was observed.

In 2023, the duration of growing season was influenced only by factor B. However, under the more extreme conditions of 2024, fertilisation had a significantly greater impact on forming this indicator, and interaction between factors was also observed. A change in influences was also observed for seed yield characteristics and oil content. Under favorable conditions, an interaction between the factors was evident, while it was insignificant under stress conditions. These results suggest that the use of humic preparations is quite effective for enhancing economically valuable traits of industrial hemp, but further research is required.

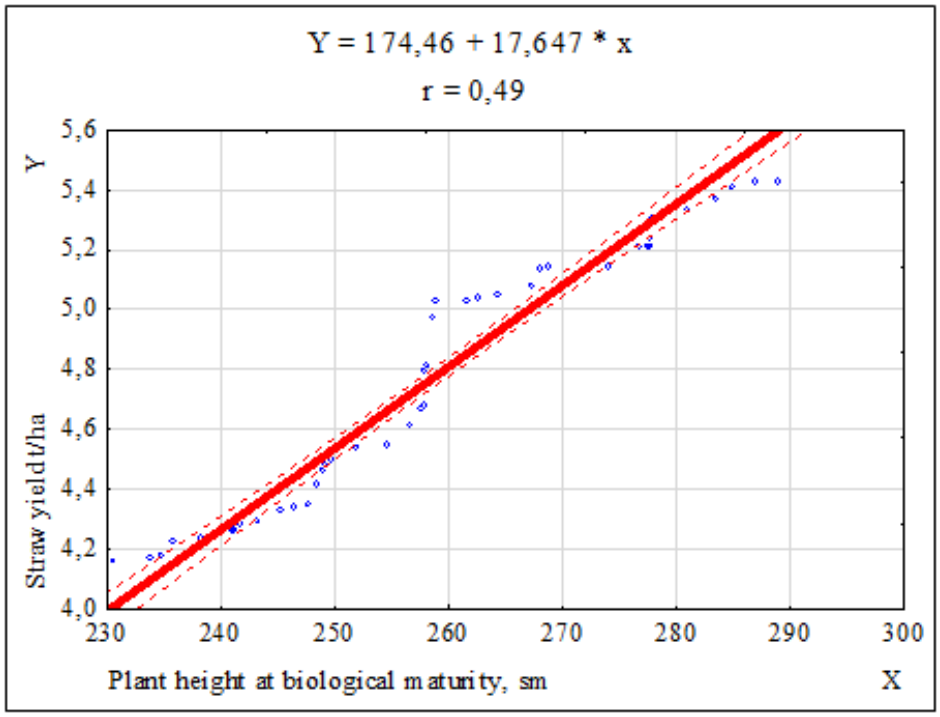

Figure 1. **Graph of straw yield regression depending on plant height**

Discussion. Industrial hemp is considered a crop that does not require highly specialized cultivation techniques. Indeed, due to its sustained growth habit, this plant can produce yields even under continuous cropping conditions. However, it is precisely this feature that highlights the importance of developing effective fertilisation systems for growing hemp. The results obtained in this study fully support earlier findings

emphasizing the importance of high mineral fertiliser application rates, as reported by O. A. Prymakov and M. P. Kozorizenko (2015) and G. Deng et al. (2019). The high nitrogen fertiliser application rates used in both the experiment and the production fields of the host farm were based on the convincing evidence presented by Mishchenko S. V. et al. (2022), K. Tang et al. (2016), and I. M. Laiko and S. V. Mishchenko (2022), and Campiglia E. et al. (2017).

Under practical farming conditions, it was impossible to establish the effectiveness of organic fertilisers as recommended by A. I. Dan et al. (2015) and V. Stramkale et al. (2021). However, the experiment has confirmed the effectiveness of humic acid-based preparations.

The obtained results largely correlate with the findings of B. Šerá and F. Novák (2022) and N. Bernstein et al. (2019). Given the substantial differences in temperature and moisture conditions between the two study years, it was possible to verify J. F. Da Cunha Leme Filho et al. (2020) conclusions regarding the effectiveness of humic substances under unstable and insufficient moisture conditions. In addition, the results confirm the conclusions of G. Ievinsh (2017), which emphasise the relevance of the comprehensive use of humic preparations — both for pre-treatment of seeds and for foliar application.

Ukraine faces a similar problem of a lack of theoretical knowledge and empirical data, as do most countries worldwide, including developed ones. This is primarily due to the long-standing prohibition on growing this crop, which many scientific publications discuss. Scientists are debating the challenges of selecting appropriate varieties depending on cannabinoid content, growing conditions, intended use, and other factors. At the same time, the hemp sector in Ukraine and globally is experiencing rapid revitalization and development. Therefore, creating and implementing research programmes related to hemp production are highly relevant and necessary.

Conclusions.

1. The analysis of theoretical materials and original research outcomes has allowed for the formulation of conceptual conclusions that define the strategic directions for future research programs. Due to the long-standing prohibition on hemp cultivation in many countries, there is a significant deficit of both theoretical and practical knowledge. Nevertheless, key principles for managing hemp agroecosystem productivity have been outlined, including the selection of varieties based on the intended product use, their adaptive potential, and other relevant criteria.

2. An effective method for increasing yield is the use of humic preparations for pre-sowing seed treatment and foliar application. This was demonstrated in the treatments involving the application of 1R Seed Treatment at 1 kg/t + Ultra Boost at 2 L/ha, as well as Zinovii grand at 1 kg/t + Zinovii grand at 2 kg/ha. Foliar application is optimally carried out in combination with plant protection products throughout the growing season. The use of these substances also increases the seed oil content.

3. The growing season conditions significantly influence the seed yield. Temperature and water stress can cause a nearly 50% reduction in yield, while their impact on straw yield is almost negligible .

4. To develop adaptive cultivation technologies, it is advisable to study the relationships between the economically valuable characteristics of industrial hemp. Particular attention should be given to correlations that vary depending on the growing conditions. In particular, a correlation between seed yield and the duration of the growing season ($r = 0.68$) was observed in 2023, whereas in 2024, this relationship was not statistically substantial. Under more favourable conditions, straw yield had a moderate correlation with plant height ($r = 0.34... 0.47$), whereas under moisture-deficient and high-

temperature conditions, it demonstrated a moderate correlation with seed yield (r = 0.49) and a strong correlation with plant height and oil content in seeds – 0.74 and 0.83, respectively.

5. Humic preparations can be an effective method for achieving stable hemp yields, provided that scientifically justified rates are applied – at least 1 kg/t of seeds for pre-sowing treatment and 2 l/ha for foliar application.

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BIOLOGICAL CONTROL OF CUCUMBER DISEASES IN THE CLOSED GROUND

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The study was conducted in the closed ground conditions of a farm enterprise in the Poltava region. The species composition of pathogens of the culture, which was dominated by fungi of the genera Fusarium and Rhizoctonia, was determined. The proportion of occurrence of Alternaria cucurbitae, Pseudoperonospora cubensis, Erysiphe cichoracearum was insignificant. In order to control the prevailing diseases, the biofungicides Trichoplant, R., Mikohelp, R. and Fitohelp, S. were studied. their effectiveness was compared with the chemical preparation Previkur Energy, RK.

The positive effect of applying cucumber seeds of the Kibria hybrid with biofungicides based on Bacillus subtilis and Trichoderma lignorum on sowing qualities was noted. Germination energy increased with the use of biologics on average over the years of research by 2.0 %, 4.9% and 10.0% compared to the control (82.5 %). Indicators of laboratory germination in the variants with seed treatment Trichoplant, R. and Mikohelp, R. were 95.4% and 96.3%, respectively, while in the control version – 92.5%. The stimulating effect of biologics on growth processes (seedling and Root Length) was revealed. For the use of Trichoplants, P. and Mikohelp, R. The length of the seedling on average exceeded the control by 6.0 mm, and the roots by 3.0 mm and 6.0 mm, respectively. The studied drugs were effective in controlling cucumber root rot. In the version with the fungicide Previkur Energy, RK. the development of the disease was recorded at the level of 1.3% and 1.7 % (respectively, years of study), technical efficiency averaged 85.3 %. Among biofungicides, the highest technical efficiency over the years of research was provided by Mikohelp, R.– 80.5% and 76.9%. When applied, the average yield of commercial fruits per 1 m^2 was 25.2 kg, which exceeded the control by 6.8 kg/m^2 or 36.9 %. A statistically significant increase in yield was observed in the variants using Phytohelp, C. (by 4.0 kg/m^2) and Trichoplant, R. (by 6.5 kg/m^2).

Keywords: phytosanitary monitoring, pathogenic complex, cucumber root rot, closed ground, biofungicides, technical efficiency.

БІОЛОГІЧНИЙ КОНТРОЛЬ ХВОРОБ ОГІРКІВ В ЗАКРИТОМУ ГРУНТІ

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Дослідження проведено в умовах закритого грунту фермерського підприємтва Полтавського району. Визначено видовий склад збудників хвороб культури, в якому домінували гриби родів Fusarium та Rhizoctonia. Частка трапляння Alternaria cucurbitae, Pseudoperonospora cubensis, Erysiphe cichoracearum виявилася незначною. З метою контролю переважаючих хвороб досліджувалися біофунгіциди ТрихоПлант, р., МікоХелп, р. та ФітоХелп, с. Їх ефективність порівнювалася з хімічним препаратом Превікур Енерджі, рк.

Відмічено позитивний вплив аплікації насіння огірка гібриду Кібрія біофунгіцидами на основі Bacillus subtilis і Trichoderma lignorum на посівні якості. Енергію проростання зросла за використання біопрепаратів в середньому за роки досліджень на 2,0 %, 4,9 % та 10,0 % у порівнянні з контролем (82,5 %). Показники лабораторної схожості у варіантах з обробкою насіння ТрихоПлант, р. і МікоХелп, р. становили 95,4 % і 96,3 % відповідно, тоді як у контрольному варіанті – 92,5 %. Виявлено стимулюючий ефект біопрепаратів на ростові процеси (довжину проростку та корінця). За використання ТрихоПлант, р. і МікоХелп, р. довжина проростка в середньому перевищувала контроль на 6,0 мм, а корінців на 3,0 мм і 6,0 мм відповідно препаратів. Досліджувані препарати виявилися ефектвними у контролі кореневих гнилей огірків. У варіанті з фунгіцидом Превікур Енерджі, рк. розвиток захворювання реєструвався на рівні 1,3 % та 1,7 % (відповідно років дослідження), технічна ефективність в середньому становила 85,3 %. Серед біофунгіцидів найвищу технічну ефективність за роками досліджень забезпечив МікоХелп, р.– 80,5% та 76,9%. За його внесення середня врожайність товарних плодів з 1 м^2 становила 25,2 кг, що перевищувало контроль на 6,8 кг/м^2 або 36,9 %. Статистично достовірне збільшення врожайності відмічено у варіантах із застосуванням ФітоХелп, с. (на 4,0 кг/м^2) і ТрихоПлант, р. (на 6,5 кг/м^2).

Ключові слова: фітосанітарний моніторинг, патогенний комплекс, кореневі гнилі огірків, закритий грунт, біофунгіциди, технічна ефективність.

Introduction. The growing demand for fresh vegetable products, especially in the off-season period, which has been observed in recent years in Ukraine, requires an increase in the area of closed ground and contributes to the intensive development of greenhouse vegetable growing. Currently, according to the state statistics service of Ukraine, closed ground areas occupy about 6 thousand hectares. A significant share in the structure of greenhouse agrocenoses, both in terms of area and gross yield, falls on the cucumber crop (Verheles, P. M., 2021; Havii, V. M., & Pryplavko, S. O., 2021; Dudchenko, V. V., et al., 2024).

Modern technologies for growing cucumbers in the off-season period involve the use of various types of cultivation facilities and substrates. Closed ground is a relatively stable ecosystem, favorable for the growth and development of vegetable crops, but small areas of greenhouses, permanent use of substrates, limited species composition of plants and other factors lead to deterioration of the phytosanitary state of artificial agrocenosis, significant crop losses and deterioration of the quality of vegetable products (Yarovyi, H. I. et al., 2018).

When growing vegetable crops in closed ground, an important issue is the phytosanitary condition of plantations and the protection of plants from harmful organisms, including infectious diseases of various etiologies (Bondarenko, S. V., & Stankevych, S. V. 2021; Kovalenko, N. P. et al., 2024; Kyryk M. M. et al., 2012). The results of monitoring observations in cultivation facilities of various types allowed us to identify the dominant complex of pathogens under different growing conditions. Since the vast majority of registered and identified pathogens have a wide range of nutrient plants, they are able to parasitize various types of indoor crops from year to year, which contributes to the accumulation of infectious potential, creating a dangerous phytosanitary situation (Yarovoy G. I. et al. , 2018; Tkalenko G., 2020). In addition, the closed ground regime determines the number of pathogen generation and continuous infectious load in greenhouses. Pathogens respond quickly to changes in environmental factors, as they have a rather short development cycle compared to plants. Fungi are a certain environmental indicator that indicates a violation of the abiotic conditions of the greenhouse. As a result of an increase in their number, conditions are created for the development of a complex of diseases on plants.

An analytical review of publications of domestic and foreign phytopathologists suggests that among diseases of closed ground, Root and basal rot (34.3%), verticillosis and fusarium wilt (6.5% and 4.6%) are the most common (Kovalenko, N. P. et al., 2024; Onyshchenko, O. et al., 2019; Ta Y. et al., 2024).

The results of the analysis of greenhouse substrates and samples of affected plants from greenhouses conducted by employees of the Institute of plant protection of the National Academy of Sciences of Ukraine indicate the same type of species composition of pathogens under various technological factors and conditions (Tkalenko G. et al., 2019). Dominant on cucumber culture in various types of cultivation facilities are root and root rot, which manifests itself throughout the growing season and can cause mass death of plants (Pelykh, V. Yu. et al., 2023). Their pathogens (primarily fungi of the genera *Pythium, Fusarium, Rhisoctonia*) are characterized mainly by a necrotrophic way of feeding (Heflish A. A. et al., 2021; Sharma D. & Shukla A., 2021).

The main causes of root rot are unfavorable conditions for the growth and development of cucumber plants. Delayed development of the root system and local death of the cow root parenchyma creates favorable conditions for microbial damage. Weakened tissues quickly colonize various types of pathogenic fungi, in particular: *Fusarium culmorum* (W. G. Sm.) Sacc., *F. solani* App. et Wr., *F. oxysporum* Schlecht., *Rhizoctonia solani* Kuhn., *Ascochyta cucumis* Fautr.) and so on. Thus, the rotting of root system tissues is a consequence of a combined pathological process involving abiotic and biotic stress factors. The dependence of the depth of the pathological process on the manifestation of root rot (the degree of development of the disease) on the humidity of the substrate, sharp fluctuations in the temperature of the substrate, and the concentration of salts in the soil solution is proved (Kyryk M. M. et al., 2012; Zhang S. et al., 2008).

You should pay attention to the particular danger of developing root rot during the fruiting phase, since during this period it is impossible to influence the course of the infectious process and stop the development of the disease. The reason for this situation

is the latent form of the infectious process before the fruiting period and the manifestation of symptoms during the onset of stressful conditions (Perez-Hernandez A. et al., 2020). According to research by phytopathologists of the Institute of plant protection of the National Academy of Sciences of Ukraine, epiphytotic development of root rot of various etiologies in closed ground during the growing season can lead to the death of 25% to 50% of plants (Tkalenko H. M. et al., 2020).

The defeat of *Pythium de barianum* Hesse and *Rhizoctonia solani* Kuerhn fungi is somewhat less common in closed ground conditions. Waterlogging of the substrate contributes to the development of these pathogens. According to Mahmoud A. F., Abdalla O. A. (2021) of the 56 fungal isolates isolated from root rot-affected cucumber plants, 17.9 % (10 isolates) belonged to *Rhizoctonia solani*. Subsequent studies have shown a high level of pathogenicity of this species for cucumber plants – 76.8 % (Mahmoud A. F. & Abdalla O. A., 2021). In addition, the authors isolated the fungi *Pythium aphanidermatum*, *Fusarium solani*, *Drechslera halodes* and *Macrophomina phaseolina* from the substrate of experimental greenhouses.

To prevent the spread of root rot, it is important to know the sources of infection (affected seeds, soil and plant residues), since infectious structures of pathogens (sclerotia, chlamydospores, etc.) can persist in the soil and other substrates for up to 6-8 years (Balvas-Hremiakova, K. M. & Horal, S. V., 2019).

So, to improve the phytosanitary condition of cucumber crops in closed ground, it is advisable to search for effective and environmentally friendly preparations.

The problems of the modern market of vegetable products dictate an increase in requirements for greening the technology of growing vegetables by reducing the use of pesticides and introducing biologics (Tkalenko H. M. et al., 2020; Amer M. & Osama A., 2021). Currently, an active search is underway for bioagents that can replace chemical fungicides without losing their effectiveness. To date, more than 50 biologics based on fungi and bacteria that have fungistatic properties are known.

The antagonistic properties of fungi of the genus *Trichoderma spp* are best studied. bacteria of the genera *Bacillus* and *Pseudomonas*, which effectively control a wide range of pathogens and exhibit growth-stimulating properties (Igbal S. et al., 2024; Ta Y. et al., 2024). Preparations based on them are recommended both for processing seed and planting material, and for spraying plants during the period of active growth.

Long-term studies of domestic scientists indicate a higher efficiency of bioagents in closed ground than in open ground. This fact is associated with the regular use of certain drugs (for several years in a row) in the technology of growing vegetable crops and the inclusion of active agents in the structure of agrocenosis (Pyliak, N. V., & Bakreu, S. P. et al., 2022; Serhiienko, V. H. et al., 2024).

Thus, the use of biologics in the protection system in combination with preventive, agrotechnical and organizational and economic measures can ensure stable yields of vegetable crops.

The aim of the study is to study the effect of biologics on the sowing qualities of cucumber seeds of the Kibria hybrid in closed ground conditions and their ability to control crop diseases.

Materials and methods of research. The analysis of the phytosanitary condition of cucumbers of the Kibria hybrid was carried out in a film greenhouse against a natural background during the cultivation periods of 2023 and 2024, accounting was carried out in accordance with the phases of crop development according to generally accepted methods (Omeliuta, V. P. et al., 1986).

In order to diagnose diseases, a visual method was used. The percentage and extent of damage were determined by examining ten central plants in non-contiguous

repetitions in ten different greenhouse areas. Accounting for the development of root rot was carried out in accordance with the methodological recommendations (Trybel, S. O. et al., 2001). Plants with symptoms of damage were selected for further analysis in the laboratory to determine the species belonging of pathogens. Based on the results of route surveys, the spread and development of the disease in this location was established.

To control root rot, biological preparations Fitohelp, S., Trichoplant, R., Mycohelp, R. were used, the effectiveness of which was compared with the chemical fungicide Previkur Energy, R. K.

Calculations of the technical effectiveness of drugs were performed according to the formulas proposed in "methods of testing and application of pesticides" (2001).

Research results. Based on the results of phytosanitary monitoring, the species composition of pathogens of cucumbers in closed ground conditions was determined: root rot (*Fusarium spp.* and *Rhizoctonia solani* Kuehn.), *Alternaria cucurbitae* Letendre et Roum.), false powdery mildew (*Pseudoperonospora cubensis* Rostowz.), powdery mildew (*Erysiphe cichoracearum* DC. *f. cucurbitacearum* Pot.) and others.

Evaluating the structure of the pathogenic complex, a significant spread of root rot was noted (fig. 1, 2), the pathogens of which are *Fusarium spp*. and *Rhizoctonia solani* pose a threat to the development and fruiting of cucumber plants. Their share in 2023 was 57.9 %. Leaf – stemmed infections had a much lower level of manifestation: Erysiphe cichoracearum – 19.8 %, *Pseudoperonospora cubensis* – 15.3 %, *Alternaria cucurbitae* – 5.4 %.

The species composition of phytopathogens found on cucumber plants of the Kibria hybrid changed somewhat in 2024. During cultivation, there were no signs of powdery mildew damage.

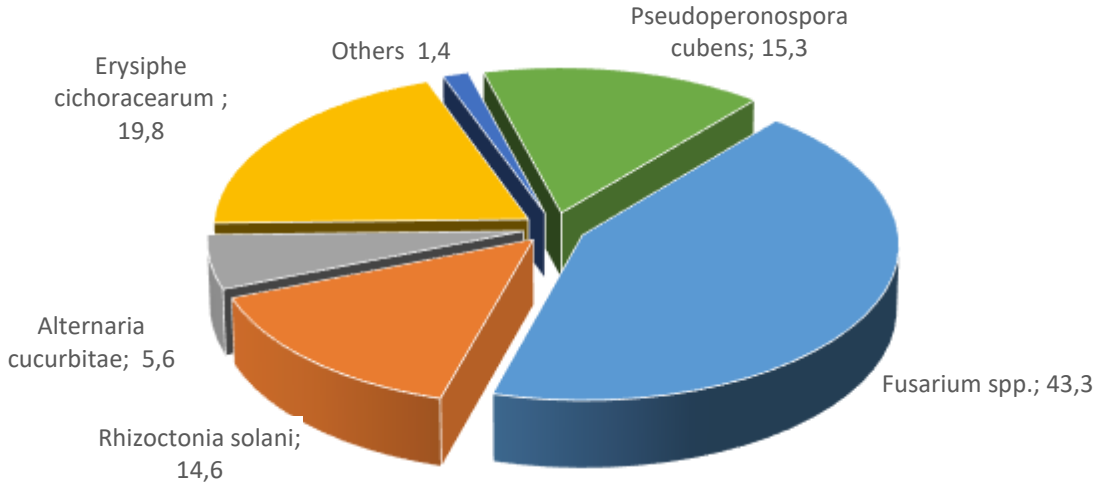

Fig. 1. **Structure of the pathogenic complex of cucumbers of the hybrid Kibria (Closed ground, 2023)**

In general, the level of manifestation of leaf-stem infections increased compared to the previous year: alternariosis by 0.2 % (fig. 2), powdery mildew by 2.3 %. Proportion of *Fusarium spp* fungi. almost unchanged, while the manifestation of *Rhizoctonia solani* increased by 11.7 %.

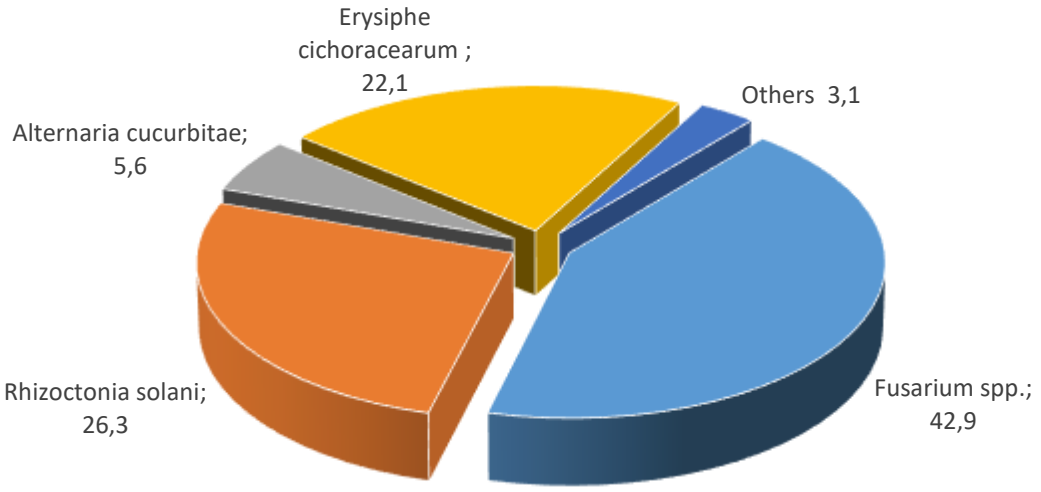

Fig. 2. **Structure of the pathogenic complex of cucumbers of the hybrid Kibria (closed ground in 2024)**

The main sources of primary infection for most identified phytopathogens are seeds and soil substrate. The phytoexpertiza of cucumber seeds of the Kibria hybrid made it possible to determine not only the sowing qualities and level of contamination of seeds with phytopathogens, but also the effect of the studied biopesticides on growth processes (Table. 1).

Table 1.

Influence of microbiological preparations on seed sowing qualities and morphometric parameters of seedlings and roots of the Kibria hybrid (average over the years of research)

Indicator	Experiment option				
	Control (water)	Previkur Energy, RK.	Fitohelp, S.	Trichoplant, R.	Mikohelp, R.
Germination energy, %	82,5	82,7	84,5	87,4	92,5
Laboratory germination rate, %	92,5	93,2	93,1	95,4	96,3
Infection rate, %	3,0	-	1,0	1,2	0,5
Field germination rate, %	83,0	76,5	80,5	83,2	84,3
Seedling height, mm	19,0	18,0	23,0	25,0	25,0
Root Length, mm	13,0	13,0	14,0	16,0	18,0

It is necessary to note the high sowing qualities of cucumber seeds of the Kibria Hybrid during the years of research. The germination energy in the control (seeds treated with fresh boiled water) was 82.5%, when it was treated with the chemical fungicide Previcur Energy, R. K. The Indicator almost did not change and amounted to 82.7%,

while when seeds were treated with biologics based on *Bacillus subtilis* and *Trichoderma lignorum*, it increased by 2.0% and 4.9% compared to the control. The maximum level of germination energy of 92.5% was observed in the variant using the drug Mycochelp, R., The basic bioagents of which are both *Trichoderma lignorum* and *Bacillus subtilis*. This trend was also observed in determining laboratory similarity. High indicators were registered in the variants with seed treatment with biologics Trichoplant, R. and Mikohelp, R. – 95.4% and 96.3%, respectively, which is 2.9% and 3.8% more than in the control version. For the use of Previkur Energy, RK. and Fitohelp, S. (bioagent – Bacillus subtilis) laboratory similarity indicators were observed at almost the same level – 93.2% and 93.1%, respectively. When sowing cucumber seeds in pallets, field germination slightly decreased; the best indicators were noted for the use of preparations based on the fungus Trichoderma lignorum. Micromycete contamination is almost nonexistent.

The stimulating effect of the studied biologics on the length of the seedling and Root was noted. The best effect was obtained with the use of Trichoplant, R. and Mycohelp, R. The Seedling length in both variants was 25.0 mm, while in the control – 19.0 mm. A similar positive effect of biopesticides was observed on the roots (16.0 mm and 18.0 mm, respectively, of these drugs), and in the control – 13.0 mm. Seed treatment with the chemical fungicide Previkur Energy, RK. did not affect the studied indicators.

In order to identify diseases and study the dynamics of their spread and development, phytosanitary monitoring was carried out every 7 days during the growing season. The dominance of root rot was revealed, the first signs of which were observed on plants after planting seedlings in the ground. An increase in infection was observed before the flowering phase, and later the disease led to the death of plants with signs of Fusarium infection. The dynamics of root rot development of cucumbers of the Kibria hybrid in the conditions of a film greenhouse differed over the years. The disease developed more actively in 2024, which can be explained by a violation of the temperature and irrigation regime in the greenhouse. At the beginning of fruiting in the control version, the spread of root rot by year was recorded at the level of 11.3% and 16.5%, while at the end of the growing season, the indicator increased to 19.6% in 2023 and 26.5% in 2024.

During the growing season, in order to improve the phytosanitary condition of cucumber plants with irrigation water, biologics and a chemical fungicide were applied three times (Table 2).

Table 2.

Effectiveness of biologics in protecting cucumbers hybrid Kibria from root rot

Options	Norm consumption, l / ha	development of the disease in the fruiting phase, %		technical efficiency, %	
		2023	2024	2023	2024
Control (water)		8,2	12,6		
Previkur Energy, RK. (Etalon)	3	1,3	1,7	84,1	86,5
Phytohelp, S.	3	3,5	5,2	57,3	58,7
Trichoplant, P.	3	2,0	3,1	75,6	73,6
Mikohelp, R	3	1,6	2,9	80,5	76,9
LSD_{05}		3,2	4,5		

During the fruiting phase, the control variant recorded the highest level of root rot development – 8.2% and 12.6%, respectively, of the study years. Soil fungicide Previcur Energy, R. K. well controlled the disease, the intensity of which was noted at the level of 1.3% (2023) and 1.7% (2024). Biopesticide Fitohelp, C. based on Bacillus subtilis almost halved the manifestation of root rot in the years of research, but the technical effectiveness of the drug did not exceed 60%. For the introduction of a chemical fungicide, this indicator in 2023 was 81.4%, and in 2024 – 86.5%, which was higher by 26.8% and 27.8% than for the use of a one-component bacterial preparation. Biologics whose bioagent is the fungus Trichoderma lignorum have proven to be more effective in curbing the development of root rot. The use of Trichoplant, R. allowed to reduce the development of the disease in 2023 to an economically imperceptible level of 2.0%, while the following year the indicator increased to 3.1%. Technical efficiency of Trichoplant, P. it was quite high in 75.6% and 73.6%, respectively, of the study years. The best development of root rot among biologics was controlled by Mikohelp, R. The intensity of the disease manifestation in the variant with its introduction in 2023 was almost equal to the indicator in the variant with Previkur Energy, RK. – 1.6%. The technical efficiency with the introduction of Mycohelp, R. was the highest in the years of research 80.5% and 76.9% compared to other biopesticides.

The studied biologics not only effectively protected plants from root rot, but also contributed to better development of plants with high vital potential. In the variants using biopesticides, the average number of flowers per plant significantly increased. Thus, due to the introduction of the bacterial preparation Fitohelp, S. There was an increase in the formation of flowers by 9.2 PCs., fungal fungicide Trichoplant, R. – 12.3 PCs., and the combined drug Mikohelp, R. na – 12,0 PCs. compared to control. The reference preparation almost did not affect the formation of generative organs of cucumbers, the average number of flowers in the variant was almost equal to the control – 27.2 PCs. (Table. 3).

Table 3.

Effect of drugs on the growth and fruiting of cucumber hybrid Kibria plants (average over the years of study)

Option	average amount per plant, PCs		Weight of collected fruits from one plant, kg	yield of commercial fruits kg / m^2	yield increase	
	flowers	fruit			kg / m^2	%
Control (water)	26,4	19,5	6,5	18,4	-	-
Previkur Energy, RK (Etalon)	27,2	22,1	7,0	20,6	2,2	111,9
Phytohelp, S	35,6	27,9	7,8	22,4	4,0	121,7
Trichoplant, P.	38,7	30,4	8,3	24,9	6,5	135,3
Mikohelp, R	38,4	31,8	8,4	25,2	6,8	136,9
LSD_{05}					1,19	

The productivity of one plant with the use of Mycohelp, R. increased by 12.3 pieces of fruit compared to the control. Biologics Fitohelp, S. and Trichoplant, R. also stimulated fruit formation; the number of fruits in variants with their introduction increased to 27.9 and 30.4 PCs./ plants that are 8.4 and 10.9 PCs. more than in control.

Thus, the use of biologics not only helped to reduce the manifestation of root rot, but also stimulated fruit formation, which provided an increase in crop yield.

Crop growth was observed in all variants with the use of biologics. The best result was provided by the combined preparation Mikohelp, R. The average yield of commercial fruits in this variant with 1 m2 was 25.2 kg, which exceeded the control by 6.8 kg/m^2 or 36.9%. The yield also increased statistically significantly in the variants with the introduction of Phytochelp, C. (by 4.0 kg/m^2) and Trichoplant, R. (by 6.5 kg/m^2).

Cucumber plants grown on soil substrates using the studied biologics remained green longer, and the flowering period was extended, which made it possible to collect an additional crop of greens.

Discussion. Most modern publications cited in the introductory part of the article indicate that the productivity of cucumbers in closed ground depends on the phytosanitary state of coenoses. Analysis of samples of affected plants from greenhouses conducted by employees of the Institute of plant protection of the National Academy of Sciences of Ukraine indicates the same type of species composition of pathogens under various technological factors and conditions, which is consistent with the data of our research.

The most dangerous, according to S. V. Bondarenko and S. V. Stankevich, for the development and fruiting of cucumbers are root and basal rot, the harmfulness of which is manifested in a decrease in crop productivity and deterioration of the quality of commercial fruits. This is fully confirmed by the results of our research.

Tkalenko G. M., Borzykh O. I., Ignat V. V. note the relevance of the use of biological plant protection products in agrocenoses of Ukraine. Especially important according to Tkalenko G. M., Balvas-Gremyakova K. M. is the greening of the protection of indoor vegetable crops, since these products are consumed mainly in fresh form. That is why the goal of our research is to find effective biologics to protect cucumbers from dominant diseases.

The results of our own observations confirm the data of foreign phytopathologists Amer M., Osama A., Heflish A. A. and Al-Askar A. A. relatively high efficiency of control of pathogenic fungi with biofungicides.

Most often, preparations based on bacterial (Bacillus subtilis) and fungal (Trichoderma lignorum) bioagents are used to protect vegetable crops. Domestic scientists Borzykh A. I., Sergienko V. G., Tkalenko G. M. and others pay attention to this in their scientific works.

Application of seeds with biologics based on these microorganisms contributed to an increase in germination energy and laboratory germination by an average of 2.0-5.0 %, which is consistent with the data of Onishchenko O., Chayuk O., Morgun O. V. In addition, their positive effect on the growth and development of roots and seedlings was observed, which contributed to an increase in the total length of the STEM by an average of 33.0% and the root by 18.5% compared to untreated plants, which is consistent with our research. Despite the rather high technical efficiency of the chemical fungicide Previcur Energy, RK. (84.1% and 86.5%, respectively, of the study years), it is also advisable to introduce biologics based on Trichoderma lignorum, the effectiveness of which is on average lower than indicated (78.1% and 75.3%) (Amer M. & Osama A., 2021).

Conclusions.

1. Changes in the species composition of pathogens of cucumbers in closed ground conditions over the years of research are determined. So, the distribution of *Fusarium spp.* in 2023, it was 43.3%, while in 2024 there was a decrease to 42.9 %; *Rhizoctonia solani* progressed from 14.6% to 26.3 %; the level of *Alternaria cucurbitae* increased by only 0.2 %; *Pseudoperonospora cubensis* was registered only in 2023 (the share was 15.3 %); the level of spread of *Erysiphe cichoracearum* in in 2024, it reached 22.1%, which exceeded the previous year's figure by 0.3%.

2. The effect of biofungicides on the sowing qualities of cucumber seeds of the Kibria hybrid was studied. Application of seeds with biologics based on *Bacillus subtilis* and *Trichoderma lignorum* contributed to an increase in germination energy by 2.0% and 4.9% (on average over the study years) compared to the control (82.5%). The highest rates were observed in the variant using the combined drug Mycohelp, R. – 92.5%. A similar trend was observed when determining laboratory germination in variants with seed treatment with biologics Trichoplant, R. and Mikohelp, R., The Indicator was 95.4% and 96.3%.

3. The stimulating effect of the studied biologics on growth processes (seedling and Root Length) is elucidated. The best effect was observed with the use of Trichoplant, R. and Mycohelp, R. The Seedling length in both variants averaged 25.0 mm, exceeding the control by 6.0 mm. Similar results were obtained when studying their effect on root development (16.0 mm and 18.0 mm, respectively, drugs, the indicator in the control is 13.0 mm).

4. The technical effectiveness of the studied drugs in the control of root rot was studied. Soil fungicide Previcur Energy, RK. well controlled the disease, the development of which was recorded at the level of 1.3% and 1.7% (respectively, years of research), technical efficiency averaged 85.3%, which exceeded this indicator for the use of biologics. However, the introduction of the two – component preparation Mycohelp, R. provided the highest technical efficiency among the studied biologics-80.5% and 76.9%.

5. The use of the combined preparation Mikohelp, R. contributed to the maximum increase in the yield of commercial fruits from 1 m2 (25.2 kg). Crop growth was observed in all variants with the use of biologics. The yield also increased statistically significantly in the variants with the introduction of Phytohelp, C. (by 4.0 kg/m^2) and Trichoplant, R. (by 6.5 kg/m^2).

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THE ROLE OF ADIPONECTIN, LEPTIN, AND THEIR RATIO IN THE PATHOGENESIS OF OBESITY AND INSULIN RESISTANCE IN HORSES

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Metabolic syndrome in horses is a multifactorial pathological condition characterized by abdominal obesity, insulin resistance, hormonal dysfunctions, and chronic low-grade inflammation. A key aspect in the pathogenesis of this syndrome is the imbalance of adipokines, particularly leptin and adiponectin, which may play a crucial role in the development of metabolic disturbances. The aim of this study was to determine the changes in leptin, adiponectin levels, and their ratio (leptin-to-adiponectin ratio, LAR) in horses with varying degrees of body condition and to evaluate their association with insulin resistance development.

The study involved 18 clinically healthy horses aged 5–10 years, divided into a control group (n=9; body condition score [BCS] 4–6 according to Henneke scale) and an obese group (n=9; BCS ≥7). Serum concentrations of adiponectin and leptin were measured by enzyme-linked immunosorbent assay (ELISA), along with glucose and insulin levels. Insulin sensitivity index (RISQI) and LAR were calculated.

Results demonstrated that obese horses had significantly higher leptin levels ($p<0.001$) and significantly lower adiponectin concentrations compared to controls. This resulted in more than a threefold increase in LAR ($p<0.001$), indicating marked disruption of hormonal regulation of adipose tissue. Additionally, elevated glycemia, hyperinsulinemia, and decreased RISQI values were observed, confirming insulin resistance in overweight horses.

These findings suggest that LAR can serve as a sensitive early biomarker of metabolic distress and insulin resistance in horses. Its use is recommended for early

identification of at-risk animals, monitoring the effectiveness of preventive measures, and substantiating personalized strategies for diet and physical activity modification aimed at preventing complications associated with metabolic syndrome.

Keywords: *horses, obesity, leptin, adiponectin, insulin resistance*

РОЛЬ АДИПОНЕКТИНУ, ЛЕПТИНУ ТА ЇХ СПІВВІДНОШЕННЯ У ПАТОГЕНЕЗІ ОЖИРІННЯ Й ІНСУЛІНОРЕЗИСТЕНТНОСТІ У КОНЕЙ

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Метаболічний синдром у коней є поліетіологічним патологічним станом, що характеризується абдомінальним ожирінням, інсулінорезистентністю, гормональними дисфункціями та хронічним низькоградусним запаленням. Особливу увагу в патогенезі цього синдрому привертає дисбаланс адипокінів, зокрема лептину й адипонектину, який може відігравати ключову роль у розвитку метаболічних порушень. Метою дослідження було визначення змін рівнів лептину, адипонектину та їх співвідношення (leptin-to-adiponectin ratio, LAR) у коней із різним ступенем вгодованості та оцінка їх зв'язку з розвитком інсулінорезистентності.

У дослідженні було обстежено 18 клінічно здорових коней віком 5–10 років, яких розподілено на контрольну групу (n=9; BCS 4–6 за шкалою Хеннеке) та групу з ожирінням (n=9; BCS ≥7). У сироватці крові тварин визначали концентрації адипонектину та лептину методом імуноферментного аналізу, рівні глюкози та інсуліну, а також розраховували індекс чутливості до інсуліну (RISQI) та співвідношення LAR.

Результати показали, що у тварин з ожирінням рівень лептину був статистично достовірно вищим ($p<0,001$), а концентрація адипонектину — достовірно нижчою порівняно з контролем. Це зумовило понад трикратне зростання LAR ($p<0,001$), що свідчить про істотне порушення гормональної регуляції жирової тканини. Також спостерігалися підвищення глікемії та гіперінсулінемія, а також зниження RISQI, що є індикатором інсулінорезистентності у коней із надмірною вгодованістю.

Отримані результати свідчать про те, що показник LAR може бути інформативним раннім біомаркером метаболічного дистресу та інсулінорезистентності у коней. Його використання доцільне для раннього виявлення тварин групи ризику, моніторингу ефективності профілактичних заходів та обґрунтування персоніфікованих стратегій корекції раціону та

фізичної активності з метою попередження ускладнень, асоційованих з метаболічним синдромом.

Ключові слова: *коні, ожиріння, лептин, адипонектин, інсулінорезистентність.*

Introduction. A pressing issue today is the development of equine metabolic syndrome (EMS), a term used to describe horses that exhibit a range of problems, including obesity, regional obesity, insulin resistance, and susceptibility to laminitis. Other names originally proposed for this syndrome included peripheral Cushing's syndrome, insulin resistance syndrome, syndrome X, omentum Cushing's syndrome, and central obesity.

The specific aetiology of this syndrome is currently unknown. According to widespread data, genetic predisposition, an unbalanced diet, insufficient physical activity, increased stress levels, chronic inflammation in the body, or a combination of these factors contribute to its development. New data obtained during the study of the pathogenesis of this pathology have made it possible to identify its components: decreased insulin-dependent glucose utilisation by tissues, hyperinsulinemia, hyperglycaemia, hypertriglyceridaemia, low levels of cholesterol, high-density lipoproteins (HDL), microalbuminuria, decreased fibrinolytic activity of the blood, as well as hyperleptinaemia and leptin resistance. It should also be noted that the combination of individual components of the syndrome can be considered within the framework of metabolic syndrome only in the presence of insulin resistance.

There is little epidemiological data on the prevalence of metabolic syndrome, but according to the available literature, it has been established that in different horse populations in the United Kingdom, the pathology occurs in 21% to 45% of animals. In other countries, obesity occurs in 10% of adult Icelandic horses in Denmark, 8%–29% of horses in Canada, 24.5% of Australian riding horses and ponies, and 35% and 51% of adult light breed horses in the United States (Robin C. A. et al., 2015; Wyse C. A. et al., 2008; Harker I. J., Harris P. A. & Barfoot C. F., 2011).

Studies have generally shown that metabolic syndrome in horses is more common in physically inactive animals, and insulin concentration is significantly higher in older horses and ponies compared to younger ones, while adiponectin concentration in the blood is lower in older animals compared to younger ones, which is consistent with the age-related relationship and identification of metabolism. However, gender and seasonality do not affect most markers of metabolic identification in animals (Hart K. A. et al., 2016; Wray H. et al., 2013; Buff P. R. et al., 2002; Kaufman K. L. et al., 2025).

In metabolic syndrome, which is a consequence of insulin resistance, modern researchers pay special attention to the role of visceral adipose tissue in connection with the synthesis and release of various adipokines by adipocytes (Galic S., Oakhill J. S. & Steinberg G. R., 2010; Napoli G. et al., 2023).

Today, scientists recognise that adipose tissue is one of the most important organs in our body, involved in the regulation of many different functions. These include: coagulation, appetite regulation, immune defence, glucose and lipid metabolism, angiogenesis, fibrinolysis, homeostasis and control of vascular tone (Tong H. V. et al., 2017).

Adipose tissue cells are a source of many biologically active substances: adiponectin, leptin, angiotensin, resistin, visfatin, acetylating protein, sex steroids, glucocorticoids, TNF α, IL 6 and free fatty acids, which affect metabolism. Obesity disrupts the balance of pro-inflammatory and anti-inflammatory adipokines, contributing

to the development of many diseases, including metabolic syndrome (Wasim M. et al., 2016).

An increase in the volume of visceral adipose tissue disrupts the secretion of adipokines and leads to the development of chronic low-intensity inflammation, which is mediated by the infiltration of macrophages into adipose tissue (Hemat Jouy S. et al., 2024). The link between inflammation and metabolic syndrome has been confirmed by a number of studies (Eckel R. H., Grundy S. M. & Zimmet P. Z., 2005; Monteiro R. & Azevedo I., 2010), as is the link between an increase in visceral fat mass and the development of metabolic syndrome (Després J. P. & Lemieux I., 2006).

Current research indicates that visceral adipose tissue functions as a paracrine and endocrine organ, secreting a number of adipokines, some of which have pro-inflammatory and atherogenic effects: leptin, tumour necrosis factor α (TNF α), resistin, interleukin 6 (IL 6), fatty acid binding protein, while others have anti-inflammatory and protective properties — adiponectin (Khan M. & Joseph F., 2014).

Adiponectin is a hormone, a polypeptide consisting of 244 amino acids, synthesized and secreted by white adipose tissue, mainly adipocytes (Liu Y. et al., 2015; Qiao L. et al., 2012).

It is one of the most studied adipokines to date. First described in the mid-1990s, analysis of its regulation and physiological effects has proven to be extremely important and has complemented the understanding of the mechanisms involved in systemic metabolic homeostasis (Wang B. et al., 2018).

The main functions of adiponectin are classified as insulin-sensitising, anti-fibrotic (found in many tissues, especially the kidneys, liver and adipose tissue), anti-apoptotic and anti-inflammatory, and it also positively modulates the endocrine system (Nguyen T. M. D., 2020). At the systemic level, adiponectin is capable of regenerating tissues (Zhang L. et al., 2019).

This hormone exists in the body in various forms, such as monomers, trimers, and hexamers. It acts through its receptors, adipoR1 and adipoR2, to influence multiple metabolic processes. AdipoR1 activation mainly promotes mitochondrial biogenesis and glucose uptake through AMPK (adenosine monophosphate-dependent kinase) and p38MAPK pathways. AdipoR2 activation is involved in fatty acid oxidation via the PPARα pathway and provides cytoprotective and anti-inflammatory effects through NF κB modulation. Together, these pathways contribute to the regulation of energy metabolism and inflammatory responses in various tissues, including muscle, liver, kidney, brain, and bone, and increase insulin sensitivity (Krause M. P. et al., 2008). Weight loss increases the level of adiponectin in the body. A decrease in adiponectin is primarily associated with insulin resistance, dyslipidaemia, and the development of laminitis and atherosclerosis (Yadav A. et al., 2013).

The next major adipokine is leptin. It should be noted that leptin and adiponectin have opposite effects on inflammation and insulin resistance.

Leptin is a peptide hormone consisting of 167 amino acids that regulates energy metabolism and is mainly produced by fat cells and enterocytes in the small intestine (Wannamethee S. G. et al., 2007). Leptin was discovered in 1994 as a product of the OB gene in laboratory mice.

The hormone is responsible for regulating metabolic, neuroendocrine and energy processes in the body.

It is considered an independent risk factor for cardiovascular disease (CVD) and a key link between obesity and increased cardiovascular risk (Wannamethee S. G. et al., 2007; Reilly M. P. et al., 2004).

Leptin may also play a role in the immune response by stimulating the proliferation of T helper cells and the production of pro-inflammatory cytokines such as IL 6, which in turn stimulates the synthesis of C-reactive protein (CRP) in the liver. In addition, leptin produced by adipocytes can directly induce IL-6 production, leading to a further increase in CRP synthesis in the liver (Kamei N. et al., 2006).

In horses, leptin concentration increases proportionally to adipose tissue mass, making it a critical biomarker and potential mediator in equine metabolic syndrome (Buff P. R. et al., 2002).

Leptin also interacts closely with insulin metabolism. This hormone increases insulin sensitivity, promoting glucose regulation in the liver and lipid oxidation (Esteghamati A. et al., 2009). However, the literature shows that insulin-resistant horses have elevated blood leptin concentrations, indicating their possible resistance to leptin (Zhao S. et al., 2020).

In addition, leptin receptors have been detected in the lamellar tissue of horses, and hyperleptinaemia is thought to contribute to endothelial dysfunction, oxidative stress and pro-inflammatory conditions in the lamellae, potentially exacerbating laminitis pathology (Correia M. L. & Rahmouni K., 2006).

Based on this, an increase in fat mass results in impaired regulation of adipokines, including leptin and adiponectin, as well as inflammatory mediators, which can affect glycaemic control, inflammation and cardiovascular function (Radin M. J., Sharkey L. C. & Holycross B. J., 2009).

Thus, the determination of leptin and adiponectin in horses are objective, biologically significant indicators of obesity and metabolic health. Their integration with clinical assessment and insulin diagnostics improves the identification of animals with metabolic disorders and directs treatment strategies towards reducing morbidity.

Future research should focus on determining breed- and season-specific reference values for leptin and adiponectin and elucidating their epigenetic modulation to improve the management of equine metabolic health.

Objective. To evaluate the levels of adipocytokines (adiponectin and leptin), their ratio and correlation with the development of obesity in horses.

Materials and methods. The study examined horses, mainly of the Ukrainian riding breed, kept in state research farms in the Poltava region. The animals were divided into two groups: 9 clinically healthy horses and 9 horses diagnosed with obesity, with a total of 18 animals examined. Experimental studies were conducted at the National Scientific Centre ‘Institute of Experimental and Clinical Veterinary Medicine’.

The feeding and housing conditions met the physiological needs of the animals: the diet was balanced in terms of the main nutritional components, the animals had constant access to water and the opportunity for active grazing. All animals underwent a general clinical examination in accordance with standard procedures. The physical condition and body condition scoring (BCS) were assessed by two independent veterinary experts. Blood was collected from the jugular vein on an empty stomach into 10 ml Vacuette vacuum tubes for further serum extraction in accordance with biochemical testing methods.

Glucose levels were determined using the hexokinase test, in which glucose was oxidised to glucose 6 phosphate, and the resulting NADH was determined spectrophotometrically. Electrochemiluminescence immunoassay (ECLIA) was used for insulin analysis.

The calculation of integral indices, which are relevant in the study of insulin resistance, was performed according to the literature data (Melnik A. A. et al., 2024; Gutch M. et al., 2015).

Adiponectin levels were determined by ELISA using the EA2500 1, Human Adiponectin ELISA kit; leptin levels were determined by ELISA using the Human Leptin (LEP) ELISA Kit (Cloud-Clone Corp., USA). The ELISA was performed, the reaction was recorded, and the results were interpreted in accordance with the instructions of the test system manufacturers and using the Stat Fax 4700 immunoenzymatic analyser.

When conducting the experimental studies described in this paper, all manipulations with the horses involved in the studies were carried out in accordance with the basic principles of bioethics, in accordance with Article 26 of the Law of Ukraine 'On the Protection of Animals from Cruel Treatment', the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (1986) and the 'General Ethical Principles for Animal Experiments' adopted by the First National Congress on Bioethics (2012).

Statistical analysis of the data was performed using Minitab 19, Minitab Inc, in a free trial version. Based on the results of statistical processing, the tables show non-parametric indicators such as: mean value (M) and arithmetic mean error (m); a significant difference between groups was established based on the Mann Whitney criterion ($p < 0.05$).

Results. Based on the results of the studies, the relationship and level of influence of adipokines, in particular adiponectin and leptin, and carbohydrate metabolism in horses with normal weight and obese horses were studied (Table).

Table

Biochemical blood parameters in horses (M ± m; n = 9)

Indicators	Clinically healthy horses	Obese horses
Leptin, ng/ml	4,24 ± 0,16	16,42 ± 0,40*
Adiponectin, ng/ml	16,81 ± 0,22	6,32 ± 0,14*
Leptin/adiponectin ratio (LAR)	0,25 ± 0,011	2,65 ± 0,08**
Glucose, mmol/L	4,81 ± 0,41	7,52 ± 0,62**
Insulin, mU/ml	16,21 ± 2,12	38,88 ± 4,05*
HOMA-IR index	3,0 ± 0,15	9,6 ± 0,34**
HOMA-β index	88,5 ± 0,48	73,8 ± 0,52**

*Note: * — $p \leq 0,05$; ** — $p \leq 0,01$.*

A comparative analysis of metabolic indicators in clinically healthy horses and obese animals revealed significant differences, indicating the development of insulin resistance and metabolic imbalance in horses with excessive body weight.

In the group of obese horses, a significant increase in leptin levels was observed, 3.9 times higher ($p < 0.05$) compared to healthy animals. Since leptin is involved in the regulation of energy homeostasis and transmits signals to the brain about fat reserves in the body, an increase in its level indicates a disruption of this function (Zhou Y. & Rui L., 2013). In conditions of obesity, the transmission of the hormonal signal from leptin to the receptor in the hypothalamus is disrupted, leading to impaired leptin transport.

Adipocytes receive information that leptin is not working and begin to synthesise new portions of it (Wang Y. et al., 2014), which provokes the development of leptin resistance.

It should be noted that leptin resistance is not uniform: the concept of selective leptin resistance explains that some actions of leptin, such as sympathetic activation, which contributes to cardiovascular effects, may persist even when metabolic satiety signalling is impaired. This selective resistance may partially explain the higher cardiovascular and laminitis risks in horses compared to metabolically healthy obese horses (Mark A. L. et al., 2002; Correia M. L. & Rahmouni K., 2006).

In turn, leptin resistance also plays an important role in the development of insulin resistance (Zhou Y. & Rui L., 2013). Leptin promotes insulin secretion and increases the sensitivity of peripheral tissue receptors to insulin, which increases glucose utilisation. This fact is reflected in studies that have shown that leptin levels were significantly higher in patients with diabetes mellitus and metabolic syndrome and had a significant positive correlation with plasma insulin (Moonishaa T. et al., 2017; Beyazıt F. & Ünsal M. A., 2017). Our data on the direct relationship between the HOMA index, insulin levels and leptin concentration are consistent with these findings.

It should also be noted that the development of leptin resistance, which develops as a result of obesity, provokes the formation of an excessive amount of free radicals, the development of oxidative stress and inflammation (de Git K. C. G. et al., 2018). Numerous studies in horses emphasise the link between leptin and metabolically active fat deposits and the associated risk of disease (Esteghamati A. et al., 2009).

At the same time, the level of adiponectin was significantly lower by 2.7 times ($p < 0.05$) compared to healthy animals and had a negative correlation with the HOMA index. Calculation of the HOMA IR index showed its significant increase in the obese group by 3.2 times ($p < 0.01$), which is consistent with the literature data on the presence of insulin resistance in animals with excessive body weight. The HOMA β index, which reflects the functional activity of pancreatic β cells, was moderately reduced in obese horses by 1.2 times, indicating compensatory changes in β cell function and mass in response to increased insulin demand.

According to the literature, this fact is associated with an increased risk of developing atherosclerosis, myocardial infarction, diabetes mellitus, metabolic syndrome and obesity (Gairolla J. et al., 2017; Kang Y. et al., 2013).

Other studies indicate a correlation between adiponectin levels and insulin levels and adipose tissue mass (Gauff F., Patan-Zugaj B. & Licka T. F., 2013).

Current literature indicates that if serum adiponectin levels are low in the body, pro-inflammatory cytokine levels are elevated (Cornier M. A. et al., 2008). This imbalance in the inflammatory state leads to endothelial cell dysfunction, contributing to the loss of their vasodilatory, antithrombotic and antiatherogenic properties (Frühbeck G. et al., 2017), which is probably a very common biological response. Adiponectin has also been shown to reduce the expression of adhesion molecules in endothelial cells, inhibit the proliferation of vascular smooth muscle cells, inhibits the differentiation of monocytes into macrophages, the formation of foam cells and the secretion of TNF α by macrophages, promotes the differentiation of preadipocytes into mature adipocytes, and its deficiency negatively affects the development of these functions (Tian F. et al., 2010).

Discussion. Thus, our results indicate that obesity is accompanied by an imbalance of adipokines, which is reflected in the literature (Rasouli N. & Kern P. A., 2008).

The main marker of the pathophysiological function of both adipokines, which indicates an imbalance between anti-inflammatory and pro-inflammatory states and

adipose tissue dysfunction, is the leptin/adiponectin ratio (LAR) (Frühbeck G. et al., 2018).

Under normal conditions, the ratio of leptin to adiponectin is 1:2, which means a LAR value of 0.5; thus, higher values are associated with an increase in cardiovascular risk, metabolic risk, and insulin resistance (Han S. K. et al., 2024). Our research showed that the leptin/adiponectin ratio (LAR) was particularly informative, exceeding the similar indicator in clinically healthy horses by more than 10 times in obese animals (2.6 ± 0.08 vs. 0.25 ± 0.011, $p < 0.01$), indicating adipose tissue dysfunction and the development of related pathologies. These results show that LAR may be a useful index for insulin resistance in clinical practice and a good indicator for assessing the effectiveness of antidiabetic therapy. Indeed, it has been reported that both the calculated HOMA IR index and LAR can be used to determine insulin resistance (Rueda-Clausen C. F. et al., 2010; Oda N. et al., 2008).

Biochemical analysis of other indicators, which are primarily assessed when determining insulin resistance and obesity, also showed a significant increase in blood plasma glucose concentration in obese horses by 56.7% ($p < 0.01$), indicating a disturbance in carbohydrate metabolism. In response to the increase in glucose levels, a 2.4-fold increase in insulin levels was observed ($p < 0.05$), indicating a compensatory response of the body to reduced tissue sensitivity to insulin and consistent with data on increased leptin levels and decreased adiponectin (Marycz K. et al., 2018).

The results obtained are consistent with current understanding of the pathogenesis of metabolic syndrome in animals and confirm that obesity in horses is accompanied by complex disorders of hormonal and carbohydrate regulation, requiring early diagnosis and correction.

Conclusions. Glucose concentration, insulin level, and the HOMA IR and HOMA β indices calculated on their basis remain the most important markers of insulin resistance in horses, as together they allow the pathogenesis of this condition to be identified, assessed, monitored, and supplemented.

In summary, serum leptin, adiponectin, and LAR can be used as an integrated marker of obesity, insulin resistance, and vascular dysfunction and are an integral part of the pathophysiology of these conditions, making them useful for accurate diagnosis and treatment guidance.

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SEASONAL AND SEX-BASED VARIATION IN MUSCLE METABOLISM MARKERS IN HORSES BEFORE AND AFTER EXERCISE

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Key modulators of muscle metabolism in equines include seasonal environmental changes, biological sex and physical exertion. Indicators such as lactate dehydrogenase (LDH), lactate and pyruvate offer valuable insights into physiological adaptations and metabolic stress during exercise. The present study aimed to evaluate the influence of seasonality, sex and exercise on LDH activity and lactate and pyruvate concentrations in Shetland ponies. Blood samples were collected from 21 clinically healthy ponies (11 mares and 10 stallions) before and after standardised exercise sessions conducted in spring, summer, autumn and winter. LDH was assayed in serum, while lactate and pyruvate were analysed in whole blood. Paired t-tests, ANOVA and post hoc Tukey HSD tests were performed to evaluate intra- and intergroup differences. Pearson correlations and effect size analyses were applied to assess seasonal and physiological associations. Exercise led to significant increases in lactate and LDH levels, particularly in spring and autumn. Pyruvate showed mild but consistent post-exercise elevations. There was a pronounced seasonal influence: winter stallions had the highest LDH values, while summer mares exhibited elevated lactate levels, suggesting heat-related stress. Sex differences were modest yet significant, with stallions displaying higher mean LDH and pyruvate levels overall. LDH, lactate and pyruvate are sensitive biomarkers of muscular activity and seasonal adaptation. Their variation across seasons and between sexes reflects physiological stress responses and could inform training strategies, veterinary assessments and breeding decisions in equine practice.

Keywords: Shetland ponies, exercise physiology, lactate dehydrogenase (LDH), lactate, pyruvate, seasonal variation, sex differences, equine metabolism, biomarkers

СЕЗОННІ ТА СТАТЕВО-ЗУМОВЛЕНІ ЗМІНИ БІОМАРКЕРІВ М'ЯЗОВОГО МЕТАБОЛІЗМУ У КОНЕЙ ДО І ПІСЛЯ ФІЗИЧНОГО НАВАНТАЖЕННЯ

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Ключовими модифікаторами м'язового метаболізму у коней є сезонні зміни навколишнього середовища, статеві відмінності та фізичне навантаження. Показники, такі як лактатдегідрогеназа (ЛДГ), лактат і піруват, надають цінну інформацію про фізіологічну адаптацію та метаболічний стрес під час фізичних тренувань. Метою даного дослідження було оцінити вплив сезонності, статі та фізичного навантаження на активність ЛДГ і концентрацію лактату та пірувату у шетландських поні. Зразки крові було відібрано у 21 клінічно здорових поні (11 кобил і 10 жеребців) до і після стандартизованих тренувань, проведених навесні, влітку, восени та взимку. Активність ЛДГ визначалася у сироватці, тоді як лактат і піруват — у цільній крові. Для оцінки внутрішньо- та міжгрупових відмінностей застосовували парні t-тести, ANOVA та Tukey HSD тести. Кореляційний аналіз Пірсона та аналіз розміру ефекту використовувалися для визначення сезонних і фізіологічних взаємозв'язків. Фізичне навантаження призводило до істотного підвищення рівнів лактату і активності ЛДГ, особливо навесні та восени. Піруват демонстрував помірне, але стабільне зростання після тренування. Виявлено виражений сезонний вплив: взимку жеребці мали найвищу активність ЛДГ, а влітку у кобил спостерігалося підвищення рівня лактату, що може свідчити про тепловий стрес. Статеві відмінності були помірними, але значущими: у жеребців спостерігались вища середня активність ЛДГ і вміст пірувату. ЛДГ, лактат і піруват – чутливі біомаркери м'язової активності та сезонної адаптації. Їх зміна протягом року та між статями відображає фізіологічну реакцію на навантаження та може бути корисною для формування тренувальних стратегій, ветеринарної діагностики й племінної роботи у конярстві.

Ключові слова: шетландські поні, фізіологія навантажень, лактатдегідрогеназа (ЛДГ), лактат, піруват, сезонні зміни, статеві відмінності, метаболізм коней, біомаркери

Introduction. The metabolism of muscles in horses is a dynamic and multifaceted process influenced by intrinsic factors such as age, sex and genetic predisposition (Ronéus M. et al., 1991; Kim J. S. et al., 2005; Stefaniuk-Szmukier M. et al., 2023), as well as extrinsic variables such as environmental temperature, photoperiod and physical workload (Bryan K. et al., 2017; Kurhaluk N. et al., 2022; Vidal Moreno de Vega, C. et al., 2024). A horse's capacity for athletic performance, endurance and recovery is closely linked to the biochemical state of its muscles (Votion D. M. et al., 2012). In this context, specific enzymatic and metabolic markers are reliable indicators of physiological adaptation and tolerance to exertion (Larsson J. et al., 2013; Zhang X. et al., 2025).

The most informative biochemical markers include lactate dehydrogenase (LDH), lactate, and pyruvate (Klein R. et al., 2020; Satué K. et al., 2022). LDH reflects cellular stress, membrane permeability, and the shift towards anaerobic metabolism, particularly during periods of intense muscular activity (Melkonian E.A. and Schury M.P., 2023). Lactate, a by-product of glycolysis, accumulates in conditions where oxygen is limited and is an indicator of metabolic strain (Rogatzki M. J. et al., 2015). Pyruvate, which is formed at the intersection of anaerobic and aerobic metabolism, provides information about mitochondrial activity and the utilisation of energy substrates (Casanova A. et al., 2023).

Seasonal variation plays a pivotal role in regulating metabolic pathways as horses adapt physiologically to changes in ambient temperature, daylight duration and exercise frequency (Arnold W. et al., 2006; Refinetti R., 2020; Lisboa B. R. F. et al., 2023). For example, colder months may prompt thermogenic responses and altered muscular workloads, while warmer seasons can lead to issues such as heat stress, dehydration, and altered enzymatic turnover rates (Cymbaluk N. F. and Christison G. I., 1990; Verdegaal E. J. M. M. et al., 2023). These environmental changes can lead to noticeable shifts in biochemical parameters, such as LDH activity and lactate accumulation.

Furthermore, sex-based physiological differences can affect metabolic output and enzyme kinetics, thereby influencing athletic potential, recovery rate and muscle fibre composition (Haizlip K. M. et al., 2015; Vidal Moreno de Vega, C. et al., 2024). Stallions and mares may respond differently to exercise stimuli due to their different hormonal profiles, cardiovascular regulation and muscle mass. While several studies have examined metabolic changes in horses after exercise, the specific contributions of sex to these enzymatic profiles are not fully understood (Ferlazzo, A. et al., 2020; de Meeûs d'Argenteuil C. et al., 2021).

Exercise itself is a primary modulator of muscle metabolism (Thyfault J. P. and Bergouignan A., 2020). The transition from rest to physical activity triggers a series of biochemical reactions, including increased anaerobic glycolysis, heightened oxidative phosphorylation and accelerated energy substrate turnover (Smith J. A. B. et al., 2023). These changes are reflected in elevated concentrations of LDH, lactate and pyruvate (Bartoloni B. et al., 2024). Understanding how these responses vary depending on season and sex could provide valuable insights into optimising performance and monitoring veterinary health.

Despite the growing body of literature on exercise-induced metabolic changes in horses, few studies have examined the combined impact of season, sex, and physical exertion on core biochemical markers (Ono T. et al., 2021; Tkaczenko H. et al., 2024; Mehrazin H. et al., 2025). This study aims to address this by examining LDH, lactate and pyruvate levels in stallions and mares throughout spring, summer, autumn and winter, both before and after standardised exercise. By establishing reference patterns and revealing interactive dynamics, this research aims to contribute to a deeper understanding

of equine physiological adaptation, with applications in training, selection, and clinical practice.

This study aimed to analyse and compare LDH, lactate and pyruvate levels in stallions and mares across four seasons (spring, summer, autumn and winter), both before and after standardised physical activity. The specific aims were: i) To determine the effect of season on resting and post-exercise metabolic profiles; ii) To assess sex-linked differences in LDH, lactate, and pyruvate concentrations; iii) to evaluate the impact of exercise on these biochemical markers and explore interactive patterns between sex, season and activity. The results of this study provide new insights into seasonal adaptation, muscular efficiency and potential training strategies, and could improve performance assessment and veterinary monitoring protocols in equine sports.

Materials and methods.

Horses. The study was conducted in accordance with current European Union legislation and ethical standards, as set out in Council Directive 2010/63/EU on the protection of animals used for scientific purposes. Ethical approval was obtained from the Local Ethics Committee for Animal Experimentation in Gdansk University, Poland and the T. H. Shevchenko National University "Chernihiv Colehium", Chernihiv, Ukraine.

Twenty-one healthy adult Shetland ponies (11 mares and 10 stallions) from the Central Pomeranian region of Poland (Strzelinko, coordinates N54°30'48.0" E16°57'44.9") were included in the study. The ponies were aged 6.5 ± 1.4 years. All animals were involved in recreational riding and were kept under consistent management conditions. Each pony was housed individually in a box stall and fed a standard diet of hay and oats twice daily at 08:00 and 18:00, with unrestricted access to clean drinking water.

Prior to inclusion in the study, all ponies underwent a comprehensive clinical evaluation to confirm physiological health, including assessment of vital signs and complete haematological and biochemical profiles. The mares were confirmed to be non-pregnant and not in oestrus during the sampling period.

Training protocol. All exercise sessions began at 10:00 and lasted one hour. They followed a standardised sequence designed to simulate moderate workload conditions. Walking (5 minutes), trotting (15 minutes), walking (10 minutes), trotting (10 minutes), walking (5 minutes), galloping (5 minutes), walking (10 minutes). This protocol was applied consistently across seasons and subjects to ensure a consistent workload and enable valid comparisons of seasonal and post-exercise metabolic changes.

Blood sample collection. Blood samples were drawn from the jugular vein while the ponies were at rest. Pre-exercise samples were collected between 8:30 and 10:00 am, approximately 90 minutes after the ponies had been fed in the morning, while they were at rest in their stalls. Post-exercise samples were obtained immediately after physical activity, between 11:00 and 12:00. Each horse was sampled once per season (spring, summer, autumn and winter) over the course of one year to ensure seasonal representativeness and control for intra-individual variation.

Sample processing and biochemical analysis. Blood was collected into VACUETTE® CAT Serum Clot Activator tubes for serum-based assays and into tubes containing 3.8% sodium citrate as an anticoagulant for whole blood analysis. For LDH testing, serum was obtained by allowing the blood to clot for 30 minutes at room temperature, followed by centrifugation at 3,000 rpm for 10 minutes. The resulting supernatant was then divided into smaller portions and stored at −80°C until analysis.

LDH activity was assessed using a standard colourimetric method with the Randox Lactate Dehydrogenase P-L (UV) Kit (Cat. No. LLD3818) on the RX Monza

Clinical Chemistry Analyser. Measurements were taken at 37 °C in a 1 cm light path cuvette with a working range of 42.3–1191 U/L. Within-run precision for the assay was reported at <4.0%.

Lactate and pyruvate assays. The concentrations of lactate and pyruvate in whole blood, which are key substrates in energy metabolism, were determined using the spectrophotometric method described by Herasimov and Plaksina (2000). Lactate absorbance was measured at 420 nm using a blank mixture containing 0.5% p-dimethylaminobenzaldehyde dissolved in 25% NaOH. For the pyruvate assay, the samples were processed with 10% copper(II) sulphate, concentrated H_2SO_4 (4 ml) and 20% hydroquinone in ethanol (0.1 ml), and then incubated at 95 °C in a water bath for 15 minutes. Final absorbance was read at 430 nm. Calibration curves ranging from 0.1–5.0 mM for both substrates were used and the results were expressed in mmol/L. Additionally, the lactate-to-pyruvate ratio was calculated as an indicator of the efficiency of energy exchange.

Statistical analysis. All statistical analyses were performed using Statistica 13.3 (TIBCO Software Inc., Palo Alto, California, USA). Data are presented as the mean ± standard deviation (mean ± SD). Prior to analysis, normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test.

Two-way ANOVA was used to examine the effects of season (spring, summer, autumn, winter), sex (mare, stallion) and exercise (pre-exercise, post-exercise) on lactate dehydrogenase (LDH) activity, lactate concentration and pyruvate concentration. When significant main or interaction effects were detected, Tukey's HSD post hoc test was applied for multiple comparisons.

Additionally, paired Student's t-tests were used to compare pre- and post-exercise values within each sex and season. Effect sizes were calculated using Cohen's d and interpreted as small (0.2–0.49), moderate (0.5–0.79) or large (≥0.8). The coefficient of variation (CV%) was computed to evaluate inter-individual variability.

To explore the associations between the biochemical variables and the environmental conditions, Pearson's correlation coefficients were calculated. Statistical significance was set at $p < 0.05$ for all tests (Stanisz A., 2006, 2007).

Results. We investigated lactate dehydrogenase (LDH) activity in the blood of Shetland ponies in relation to three factors: photoperiod, sex, and exercise. Figure 1 shows LDH activity in the serum of Shetland pony mares and stallions, measured before and after exercise in spring, summer, autumn and winter.

Notable seasonal and physiological differences were revealed in the biochemical parameters measured – lactate dehydrogenase (LDH), lactate and pyruvate – between mares and stallions, both before and after exercise. LDH activity varied significantly across seasons and between groups. LDH activity varied significantly across seasons and between groups. In general, LDH activity increased after exercise in all groups. The highest post-exercise LDH values were observed in stallions in spring (mean ± S.D.: 868.47 ± 126.68 $U \cdot L^{-1}$) and winter (904.81 ± 179.65 $U \cdot L^{-1}$). Mares also exhibited increased LDH activity following exercise, particularly in summer (905.28 ± 132.42 $U \cdot L^{-1}$) and winter (896.77 ± 172.51 $U \cdot L^{-1}$). Relatively high LDH levels were also observed before exercise, with the highest values recorded in winter in stallions (982.74 ± 156.50 $U \cdot L^{-1}$).

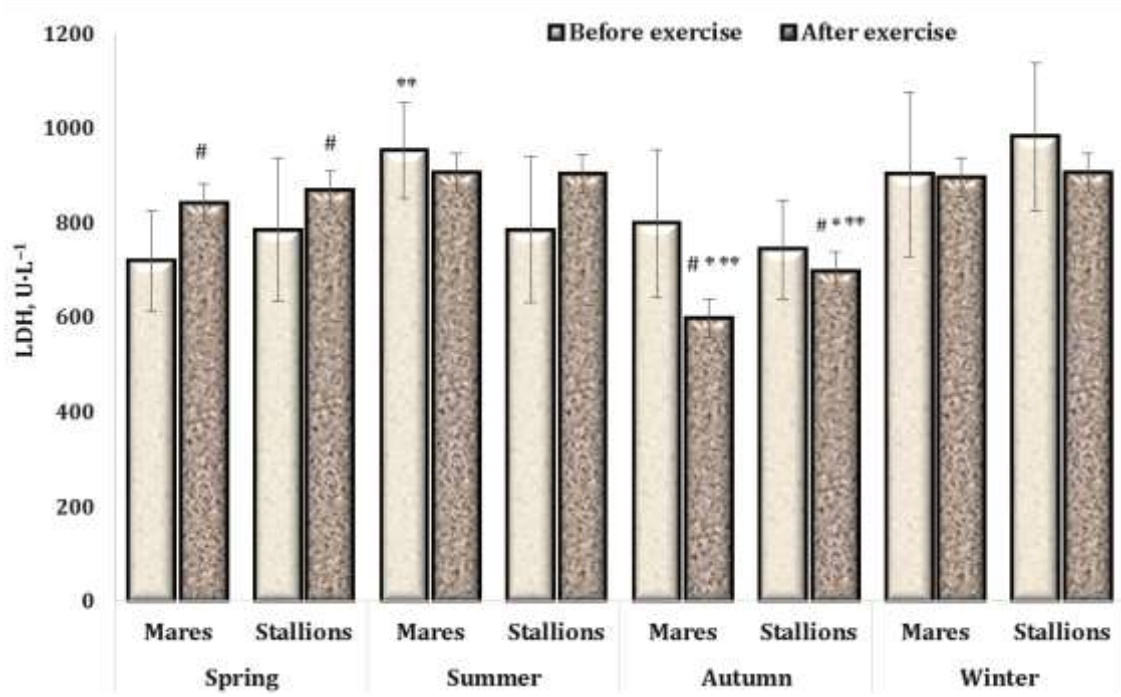

Fig. 1. The lactate dehydrogenase (LDH) activity in the serum of 11 Shetland pony mares and 10 Shetland pony stallions was measured before and after exercise in spring, summer, autumn and winter.

Statistically significant differences ($p < 0.05$) were identified in the following comparison groups using ANOVA, followed by a Tukey's HSD post hoc test:

 # – significant difference between pre- and post-exercise values;

**– significant difference between mares and stallions;*

*** – significant difference between seasons.*

Results are expressed as mean ± standard deviation (mean ± S.D.).

Figure 2 illustrates the lactate levels in the blood of Shetland pony mares and stallions before and after exercise in spring, summer, autumn and winter.

Exercise led to the expected increase in blood lactate levels. The highest post-exercise lactate concentrations were recorded in stallions in summer (1.47 ± 1.27 mmol·L^{-1}) and in mares in the same season (1.45 ± 1.20 mmol·L^{-1}). Before exercise, lactate values were consistently lower across all seasons, with the lowest values observed in spring in stallions (0.85 ± 0.09 mmol·L^{-1}) and mares (0.90 ± 0.14 mmol·L^{-1}).

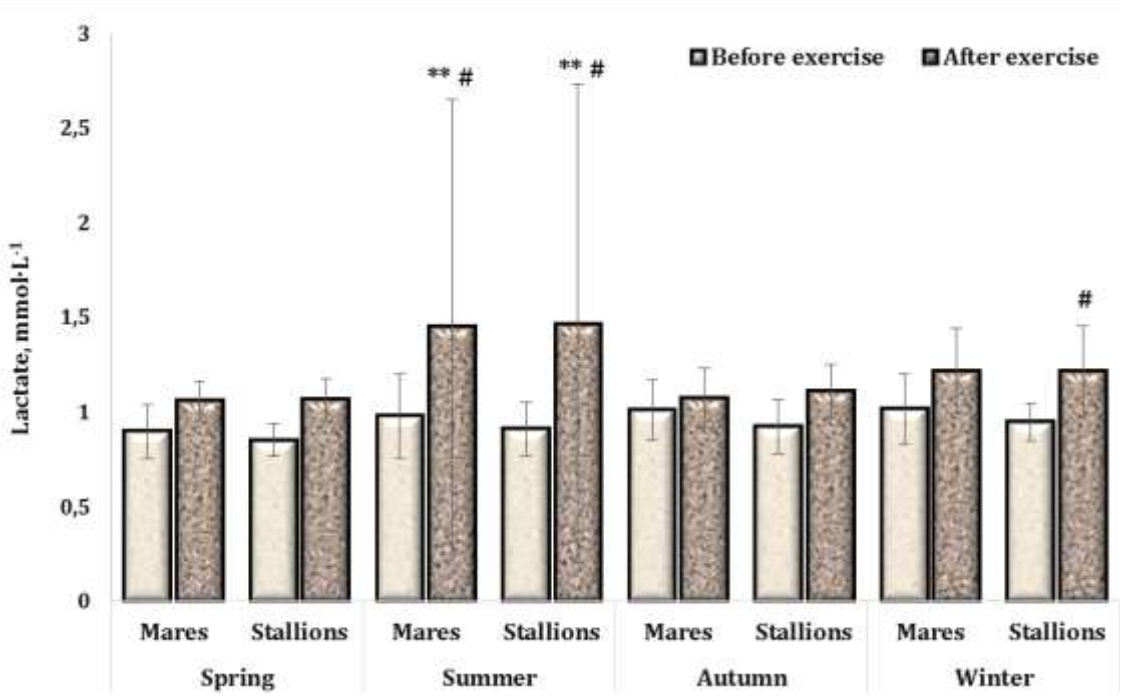

Fig. 2. The lactate levels in the serum of 11 Shetland pony mares and 10 Shetland pony stallions was measured before and after exercise in spring, summer, autumn and winter.

Statistically significant differences ($p < 0.05$) were identified in the following comparison groups using ANOVA, followed by a Tukey's HSD post hoc test:

 # – significant difference between pre- and post-exercise values;

*** – significant difference between seasons.*

Results are expressed as mean ± standard deviation (mean ± S.D.).

Figure 3 shows the seasonal variation in pyruvate levels in the blood of Shetland pony mares and stallions, as measured before and after standardised exercise sessions in spring, summer, autumn and winter.

Compared to LDH and lactate, pyruvate levels demonstrated smaller seasonal fluctuations. Following exercise, concentrations of pyruvate remained relatively stable, typically ranging from 0.50 to 0.61 μmol·L^{-1} across all groups. The lowest post-exercise value was found in autumn in mares (0.50 ± 0.12 μmol·L^{-1}), while the highest value was recorded in autumn in stallions (0.61 ± 0.21 μmol·L^{-1}). Pre-exercise values were also consistent, with most falling between 0.53 and 0.62 μmol·L^{-1}.

In summary, LDH activity and lactate concentration were both markedly elevated following exercise, particularly in summer and winter, highlighting the seasonal impact on metabolic responses. In contrast, pyruvate levels were more stable, suggesting a less pronounced role in the acute exercise response under the studied conditions.

To further elucidate these physiological responses, a two-way ANOVA revealed significant main effects of season ($p < 0.01$) and sex ($p < 0.05$) on lactate dehydrogenase (LDH) and lactate concentrations. This indicates that both variables meaningfully contribute to metabolic variation in equines. Notably, an interaction effect between season and sex was observed for LDH ($p < 0.05$), suggesting that the metabolic activity of mares and stallions differs seasonally, possibly due to differences in thermoregulation or conditioning.

Post hoc Tukey's HSD comparisons showed that LDH activity in stallions was significantly higher in winter and spring than in summer and autumn ($p < 0.01$), whereas

mares had their highest LDH levels post-exercise in summer (mean = 999.2 $U \cdot L^{-1}$). This seasonal elevation in mares could be attributed to increased muscular fatigue or heat stress during exercise.

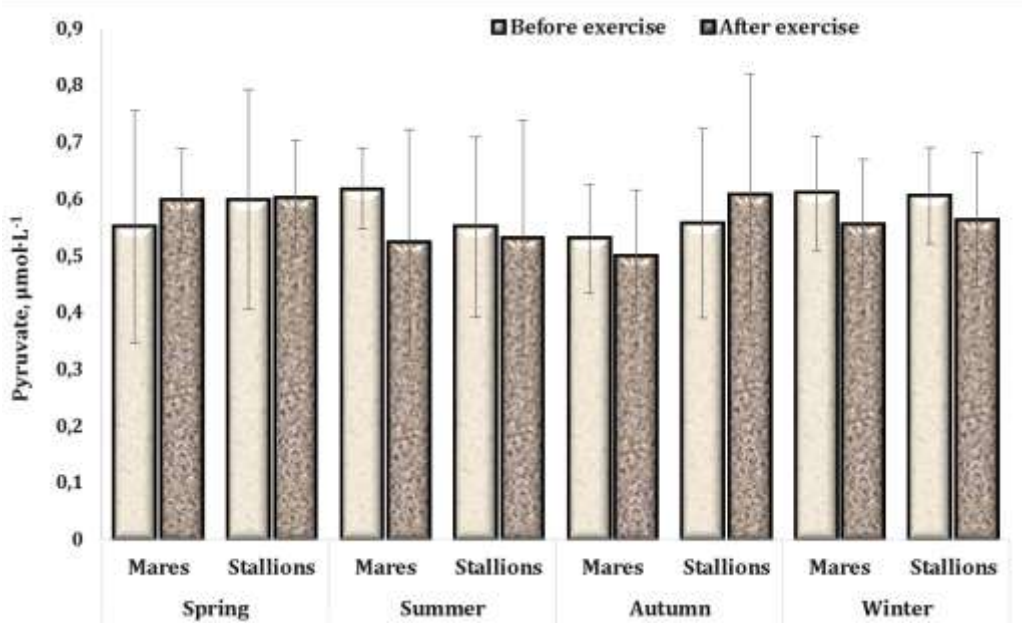

Fig. 3. The pyruvate levels in the serum of 11 Shetland pony mares and 10 Shetland pony stallions was measured before and after exercise in spring, summer, autumn and winter.

Results are expressed as mean ± standard deviation (mean ± S.D.).

Paired t-tests revealed significant differences in LDH and lactate values between pre- and post-exercise conditions across all seasons. In spring and winter, post-exercise LDH values increased markedly in both mares ($t = 3.54$, $p = 0.006$) and stallions ($t = 4.12$, $p = 0.002$), indicating strong anaerobic responses. In contrast, summer lactate values exhibited greater variability, with some mares achieving notably high post-exercise concentrations (up to 5.05 $mmol \cdot L^{-1}$), suggesting potential susceptibility to thermal stress or dehydration at the individual level.

Pyruvate levels also increased significantly after exercise, albeit to a lesser extent (paired t-test, $p < 0.05$). Stallions consistently exhibited higher pyruvate values than mares, particularly in winter and spring, suggesting greater glycolytic flux or mitochondrial capacity.

Effect size analysis confirmed robust seasonal and sex-related patterns. Cohen's d for LDH changes post-exercise ranged from 0.78 (moderate) in summer to 1.42 (large) in winter, indicating stronger anaerobic activation in the colder months. ANOVA revealed that season explained 34% of the variance in LDH levels, while sex accounted for 18%. The coefficient of variation (CV%) was highest for lactate in summer (21.3%), which is consistent with the observed differences in individual exercise tolerance.

Pearson's correlation analysis revealed a significant positive correlation between ambient temperature and post-exercise lactate levels ($r = 0.68$, $p = 0.007$), supporting the hypothesis that thermal stress exacerbates lactate accumulation. Furthermore, a moderate positive correlation was observed between pyruvate levels and LDH post-exercise ($r = 0.61$, $p = 0.014$), suggesting a coordinated metabolic response.

Discussion. This study investigated changes in key metabolic markers (LDH, lactate and pyruvate) in horses over the course of a year, and in relation to sex and

exercise. Statistical analysis revealed several significant trends and interactions that provide insight into equine muscular physiology and its responsiveness to intrinsic and extrinsic factors.

Exercise-induced metabolic shifts. The consistent and significant elevation in LDH and lactate concentrations after exercise across all seasons and sexes confirms the metabolic stress response and anaerobic energy utilisation associated with physical exertion. LDH activity is a marker of muscle membrane permeability and anaerobic glycolysis, and an increase in LDH activity indicates muscle workload intensity (Smith J. A. B. et al., 2023). Post-exercise LDH levels were highest in winter and in stallions, suggesting a robust anaerobic response possibly linked to muscle conditioning or thermoregulatory adaptations in colder environments (Fig. 1). Lactate levels, particularly the high value observed in summer and in mares (approximately 5.05 $mmol \cdot L^{-1}$), may indicate acute muscular fatigue, subclinical myopathy or increased thermogenic strain in hot conditions (Wan J. J. et al., 2017; Siquier-Coll J. et al., 2024). Although rare, this outlier is consistent with literature describing heat-related increases in lactatemia in equines (Ebisuda Y. et al., 2023, 2024).

Seasonal variation and physiological adaptation. Animals in winter, especially stallions, demonstrated higher baseline LDH levels, suggesting a potential metabolic shift – such as an increased reliance on anaerobic processes due to lower ambient temperatures. While pyruvate levels were generally stable, they tended to increase post-exercise in both sexes, suggesting enhanced glycolytic flux and mitochondrial processing efficiency under stress (Gray L. R. et al., 2014). These observations are consistent with previous studies indicating that winter conditioning can alter mitochondrial density or shift fibre type composition towards more oxidative phenotypes (Yan Z. et al., 2011; Jacobs R. A. and Lundby C., 2013; Latham C. M. et al., 2021, 2022).

Sex-linked metabolic profiles. Stallions consistently exhibited higher levels of LDH and pyruvate than mares, both before and after exercise. This may be due to differences in muscle mass, hormonal influences (e.g. testosterone-driven anabolic activity) or behavioural factors, such as exercise intensity and reactivity (Kraemer W. J. and Ratamess N. A.; de Graaf-Roelfsema E. et al., 2007). Although lactate elevation was observed in both sexes, stallions exhibited more consistent lactate profiles, suggesting tighter regulation of glycolytic pathways. It is important to note that, while sex-related metabolic distinctions exist, their magnitude is relatively modest and there is substantial variation within groups.

The data confirm that LDH, lactate and pyruvate are sensitive biomarkers of equine physical stress and seasonal adaptation. Stallions appear to be more metabolically responsive, particularly in the colder months, whereas seasonal heat may exacerbate lactate accumulation in mares. These findings have implications for the management of performance horses, training schedules and even veterinary screening protocols during seasonal transitions (Coelho C. S. et al., 2022; Annan R. et al., 2023; Ramos G. V. et al., 2024).

The physiological implications of LDH and lactate dynamics. A significant increase in LDH and lactate levels after exercise indicates a shift towards anaerobic energy metabolism, which is characteristic of short-term, high-intensity muscular activity (Bartoloni B. et al., 2024). As a proxy for membrane permeability and tissue stress, LDH highlights the muscle workload imposed during trials (Callegari G. A. et al., 2017). The substantial increase in LDH levels observed in stallions during winter suggests greater anaerobic capacity or muscular recruitment in response to cold conditions, a phenomenon supported by thermogenic activation and altered cardiovascular dynamics during exercise in lower ambient temperatures (Hodgson D. R. et al., 1994; Geor R. J. and

McCutcheon L. J., 1998; Barreto, I. V. P. D. S. et al., 2023).

While lactate accumulation was expected, it presented with noteworthy variability, particularly in mares exposed to summer conditions. This heightened response may reflect thermoregulatory limitations or an electrolyte imbalance, given that heat stress has been shown to impair lactate clearance and amplify peripheral fatigue (Art T. et al., 1994; Lindinger M. I., 1999; Kang H. et al., 2023). The exceptionally high lactate values recorded in summer and mares warrant further investigation into hydration status, environmental factors and individual fitness profiles.

Pyruvate response and oxidative metabolic activity. Although changes in pyruvate concentration were modest compared to LDH and lactate, they remained statistically significant. This suggests nuanced shifts in glycolytic throughput and mitochondrial efficiency post-exercise (Glancy B. et al., 2021). Stallions consistently exhibited higher pyruvate levels, particularly in spring and winter, indicating greater oxidative potential or faster substrate conversion. This may be linked to fibre type distribution, as stallions have been reported to possess a higher proportion of type IIa fibres, which are capable of both anaerobic and aerobic function. This facilitates more efficient energy metabolism during intermediate-duration exertion (Curry J. W. et al., 2012; Mo M. et al., 2023).

The positive correlation between pyruvate and LDH supports the idea of a tightly coordinated metabolic cascade triggered by physical stress, which could reflect enhanced NAD^+ regeneration and sustained ATP turnover (Luengo A. et al., 2021).

Seasonal adaptation and individual variability. Seasonal differences in enzyme activity and metabolic response likely reflect adaptation to environmental stressors, such as temperature, humidity and photoperiod. Higher levels of LDH and lactate in colder months may indicate an increased metabolic demand for heat generation, whereas variability in summer could be due to fluid-electrolyte imbalances affecting muscular efficiency (Klein R. et al., 2020). The effect size and variability indices – particularly the coefficient of variation (CV%) for lactate in summer – highlight substantial divergence in individual responses. This emphasises the importance of personalised conditioning and monitoring strategies in equine sports, particularly during periods of environmental extremes (Geor R. J. et al., 1996; Marlin D. J. et al., 1996; Klous L. et al., 2020).

The observed increase in lactate and LDH levels after exercise, particularly in the colder seasons, suggests that horses may benefit from tailored warm-up strategies aimed at reducing anaerobic strain during the initial stages of exercise (Anderson M. G., 1976; Titotto A. C. et al., 2023). For stallions, whose LDH response was particularly pronounced in winter, incorporating longer aerobic warm-ups could promote more efficient oxygen utilisation and reduce cellular stress. Furthermore, the variability in lactate response among mares in summer highlights the importance of heat-adapted training schedules. Exercising during cooler hours, optimising hydration and gradually acclimatising to heat may reduce excessive lactate build-up and improve recovery rates (Lorenzo S. et al., 2010; De Maré L. et al., 2022).

Given the strong correlation between temperature and post-exercise lactate levels, seasonal biomarkers such as LDH and pyruvate could be valuable indicators in pre-competition veterinary examinations (Tennent-Brown B. S., 2011; Li G. et al., 2012; Satué K. et al., 2022). Horses exhibiting unusually high post-exercise values may require follow-up testing for subclinical muscular injury, metabolic syndrome or dehydration (Stefaniuk-Szmukier M. et al., 2023). Stallions with consistently high levels of pyruvate and LDH may also exhibit symptoms of overtraining (Dzięgielewska A. and Dunislawska A., 2022; Davie A. et al., 2023). Periodic blood screening across seasons could facilitate the early detection of exercise-induced stress, enabling more informed decisions regarding workload progression (Ferlazzo A. et al., 2020; Aragona F. et al., 2025).

Sex-related metabolic distinctions could indicate potential selection markers for performance horses (Andriichuk A. and Tkachenko H., 2017). Stallions with elevated oxidative and anaerobic responses may exhibit favourable traits for disciplines requiring high power output, while mares' thermoregulation and endurance in warmer seasons could be advantageous in events demanding sustained effort in hot conditions (Fonseca R. G. et al., 2013; Zhang X. et al., 2025). These insights could inform breeding decisions and encourage genetic studies on muscle fibre composition, enzymatic variability and heat tolerance. Such adjustments could promote peak performance while safeguarding metabolic health.

Conclusions. This study highlights the complex interplay between seasonal conditions, sex and physical activity in influencing metabolic responses in horses. The data clearly demonstrate that exercise significantly increases LDH, lactate and pyruvate levels in both sexes and at all times of year, confirming the reliance on anaerobic and glycolytic pathways during muscular exertion. There were pronounced seasonal effects, with winter stallions exhibiting the highest LDH levels post-exercise and summer mares showing substantial lactate concentration variability, including a notable outlier likely linked to heat stress. Sex differences were moderate but consistent: stallions had higher LDH and pyruvate levels overall, indicating greater muscle mass or glycolytic activity. Pyruvate levels increased modestly after exercise, indicating enhanced mitochondrial turnover and energy substrate utilisation.

Statistical analyses, including two-way ANOVA and post hoc tests, confirmed the main effects of season and sex, as well as a significant season × sex interaction for LDH, reflecting nuanced patterns of physiological adaptation. Effect size calculations and correlation analyses further emphasised the influence of ambient temperature on lactate dynamics and the coordinated increase in LDH and pyruvate levels following exercise.

The practical implications of these findings include: 1) optimising seasonal training and recovery strategies, 2) making better-informed breeding and selection decisions based on metabolic resilience, and 3) developing enhanced veterinary screening tools that utilise LDH and lactate as biomarkers.

In summary, LDH, lactate and pyruvate are reliable indicators of equine metabolic activity that are sensitive to environmental context and individual traits. These markers can inform performance assessments, conditioning protocols and clinical evaluations, thereby supporting the safe and effective athletic development of horses.

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TEMPORAL MODULATION OF OXIDATIVE STRESS AND ANTIOXIDANT CAPACITY IN RAINBOW TROUT (*ONCORHYNCHUS MYKISS* WALBAUM) FOLLOWING *YERSINIA RUCKERI* VACCINATION

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This study investigated the temporal effects of Yersinia ruckeri vaccination on markers of oxidative stress and antioxidant capacity in the livers of rainbow trout (Oncorhynchus mykiss Walbaum). Oxidative stress was assessed using 2-thiobarbituric acid-reactive substances (TBARS), oxidatively modified protein (OMP) derivatives and total antioxidant capacity (TAC) at three time points: baseline and one and two months post-vaccination. TBARS levels exhibited a transient peak one month after vaccination, suggesting a short-term increase in lipid peroxidation associated with immune activation. In contrast, TAC increased progressively over the experimental period, reaching significantly higher levels in vaccinated fish after two months, which is indicative of enhanced systemic antioxidant defences. OMP derivatives exhibited moderate variability: aldehydic forms peaked in the control group at one month, while ketonic forms were highest at baseline. However, no significant vaccination effect was observed. Correlation analysis revealed a strong negative association between TBARS and TAC ($r = -0.58$), supporting the role of antioxidant capacity in mitigating oxidative damage. Effect size and variability analyses confirmed substantial time- and treatment-related changes, particularly with regard to TBARS reduction and TAC enhancement in vaccinated fish. Overall, the results demonstrate a biphasic oxidative response to vaccination characterised by an initial oxidative challenge followed by adaptive antioxidant upregulation, highlighting the importance of modulation of redox balance in immune protection and aquaculture health management.

Keywords: liver, rainbow trout, *Yersinia ruckeri*, vaccination, 2-thiobarbituric acid-reactive substances (TBARS), oxidatively modified protein (OMP) derivatives, total antioxidant capacity (TAC)

ЧАСОВА МОДУЛЯЦІЯ ОКСИДАТИВНОГО СТРЕСУ ТА АНТИОКСИДАНТНОЇ АКТИВНОСТІ У РАЙДУЖНОЇ ФОРЕЛІ (*ONCORHYNCHUS MYKISS* WALBAUM) ПІСЛЯ ВАКЦИНАЦІЇ ПРОТИ *YERSINIA RUCKERI*

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У цьому дослідженні вивчали часовий вплив вакцинації щодо Yersinia ruckeri на показники оксидативного стресу та антиоксидантної активності у печінці райдужної форелі (Oncorhynchus mykiss Walbaum). Оксидативний стрес оцінювали за допомогою продуктів, які реагують з 2-тіобарбітуровою кислотою (TBARS), похідних окиснювально модифікованих білків (OMP) та загальної антиоксидантної активності (TAC) у трьох часових точках: на початковому етапі, через один та два місяці після вакцинації. Рівні TBARS демонстрували тимчасовий пік через місяць після вакцинації, що свідчить про короткочасне підвищення пероксидації ліпідів, пов'язане з активацією імунної відповіді. Натомість TAC поступово зростала протягом усього експерименту, досягаючи значно вищих рівнів у вакцинованих риб через два місяці, що вказує на посилення системного антиоксидантного захисту. Похідні OMP проявляли помірну варіабельність: альдегідні форми досягали максимуму у контрольній групі через місяць, тоді як кетонові форми були найвищими на початковому етапі. Проте значного впливу вакцинації на рівні похідних OMP не виявлено. Кореляційний аналіз показав істотну негативну кореляцію між TBARS і TAC (r = −0,58), що підтверджує роль антиоксидантної активності у зменшенні оксидативного ушкодження. Аналіз ефекту та варіабельності підтвердив суттєві зміни, пов'язані з часом і впливом обробки, особливо щодо зниження TBARS та підвищення TAC у вакцинованих риб. Загалом результати демонструють біфазну оксидативну реакцію на вакцинацію, що характеризується початковим оксидативним стресом, за яким слідує адаптивне підвищення антиоксидантного захисту, підкреслюючи важливість модуляції редокс-балансу для імунного захисту та роль терапевтичних і профілактичних процедур в аквакультурі.

Ключові слова: печінка, райдужна форель, *Yersinia ruckeri*, вакцинація, продукти, які реагують з 2-тіобарбітуровою кислотою (TBARS), похідні окиснювально модифікованих білків (OMP), загальна антиоксидантна активність (TAC)

Introduction. Vaccination is a key part of preventing disease in aquaculture, as it reduces the morbidity and mortality caused by infectious pathogens (Mondal H. and Thomas J., 2022; Kumar A. et al., 2024). *Yersinia ruckeri*, the causative agent of enteric redmouth disease (ERM), is a significant bacterial pathogen affecting salmonids worldwide and causing substantial economic losses in freshwater aquaculture (Kumar G.

et al., 2015). Although effective vaccines against *Y. ruckeri* have been developed and are widely used, the physiological consequences of vaccination beyond immune protection are not well understood.

One area of emerging interest is the interaction between vaccination and oxidative stress. Activation of the immune system often triggers the production of reactive oxygen species (ROS) as part of the host's defence mechanisms (Andrés C. M. C. et al., 2022; Afzal S. et al., 2023). While ROS play a crucial role in clearing pathogens, excessive or prolonged ROS generation can damage cellular macromolecules, including lipids, proteins and nucleic acids (Schieber M. and Chandel N. S., 2014; Juan C. A. et al., 2021). An organism's ability to maintain redox homeostasis depends on balancing pro-oxidant processes with antioxidant defences, which can be either enzymatic or non-enzymatic (Rahal A. et al., 2014).

In fish, markers of oxidative stress such as 2-thiobarbituric acid reactive substances (TBARS) and oxidatively modified proteins (OMPs), alongside measures of total antioxidant capacity (TAC), have been used to evaluate the physiological response to environmental, nutritional and immunological challenges (Schumann S. et al., 2023; Oliveira J. et al., 2024; Grădinariu L. et al., 2025). However, few studies have investigated how these redox biomarkers change over time following vaccination (Tkachenko H. et al., 2014; Kurhaluk N. et al., 2024; Grădinariu L. et al., 2025), particularly in economically important species such as the rainbow trout (*Oncorhynchus mykiss* Walbaum) (D'Agaro E. et al., 2022).

Furthermore, given its central role in metabolic regulation and detoxification, the liver is a critical organ for assessing systemic oxidative stress (Li S. et al., 2015; Allameh A. et al., 2023). Due to its high metabolic activity and exposure to circulating immune mediators, hepatic tissue is particularly sensitive to fluctuations in redox balance (Smith R. L. et al., 2018). By focusing on liver-specific responses, this study provides an insight into how vaccination may influence oxidative processes at an organ level.

The timing of sample collection after vaccination is crucial for capturing the dynamic nature of redox changes. Acute responses may differ significantly from longer-term adaptations, and distinguishing between these phases can help to establish whether the oxidative stress is transient or sustained (Pickering A. M. et al., 2013). In this study, fish were sampled at multiple time points following immunisation to capture both immediate and delayed effects on oxidative biomarkers.

This study aimed to evaluate the temporal dynamics of oxidative stress markers and antioxidant capacity in the livers of rainbow trout following vaccination against *Yersinia ruckeri*. Through the integration of biochemical analyses and statistical modelling, we sought to clarify the relationships between lipid peroxidation, protein oxidation and antioxidant status, as well as determining the extent to which vaccination influences these parameters. Understanding these interactions could provide valuable insights into fish physiology and contribute to the development of health management strategies in aquaculture.

Ultimately, integrating oxidative stress profiling into vaccine evaluation protocols could provide a more comprehensive understanding of fish health. If vaccination induces measurable oxidative shifts, these could serve as early indicators of physiological strain or adaptation. Such insights could inform the formulation of vaccines, dosing schedules and post-vaccination monitoring practices, thereby contributing to more sustainable and welfare-conscious aquaculture systems.

Materials and methods.

Fish. The experiments used rainbow trout (*Oncorhynchus mykiss* Walbaum) weighing 105-135 g. Prior to the commencement of the experiment, all individuals were

acclimated to laboratory conditions for 14 days, with the same water quality parameters being employed as during the trial.

The study was conducted at the Department of Salmonid Research at the Stanisław Sakowicz Inland Fisheries Institute in Olsztyn, Poland. Experiments were conducted at a water temperature of 14.5 ± 0.5 °C and a pH of 7.5. Dissolved oxygen levels were maintained at approximately 12 ppm with supplemental oxygen provided by a continuous water flow of 25 litres per minute and a photoperiod of 12 hours of light followed by 12 hours of darkness. The fish were fed a commercial pelleted diet at optimum levels using 12-hour automatic belt feeders. Daily dietary allowances were calculated in accordance with current nutritional guidelines for salmonids.

All biochemical assays were performed at the Department of Zoology and the Department of Animal Physiology at the Institute of Biology, Pomeranian University in Słupsk, Poland. All procedures involving animals were conducted in accordance with national and EU regulations for the protection of animals used for scientific purposes. The experimental protocol was approved by the Local Ethical Committee for Animal Experiments in Olsztyn.

Experimental design. The rainbow trout were acclimated to laboratory conditions for 14 days prior to the experiment. The fish were randomly assigned to two groups: (1) an untreated control group and (2) a group vaccinated against *Yersinia ruckeri*. Each group was held in a separate 1,000-litre square tank (150 fish per tank) under identical environmental conditions.

The vaccine was produced at the Department of Fish Diseases at the National Veterinary Research Institute in Puławy, Poland, according to a procedure covered by patent no. P.428259. The prepared vaccine, at a concentration of 1×10^9 cells ml^{-1}, was administered orally. It was mixed with commercial fish feed and given to the fish three times at one-day intervals. Following vaccination, the fish were kept at a temperature of 14.5 ± 0.5 °C, a pH level of 7.5, a dissolved oxygen level of ~12 ppm, and a photoperiod of 12 hours of light followed by 12 hours of darkness. In the present study, 15 untreated control trout and 15 vaccinated trout were sampled at three time points: baseline (0), one month and two months after vaccination.

Tissue collection and sample preparation. Thirty-one and sixty-one days after vaccination, the rainbow trout were humanely euthanised by decapitation. Immediately afterwards, the liver was excised in situ. The organs were perfused via the hepatic portal vein with an ice-cold isolation buffer to remove any remaining blood. This buffer solution consisted of 100 mM Tris-HCl with a pH of 7.2.

The liver tissue was then homogenised using a glass H500 homogeniser with a motor-driven pestle and immersed in an ice–water bath to obtain a 1:9 (weight/volume) homogenate. The homogenates were then centrifuged at 3,000 rpm (approximately 1,000×g) for 15 minutes at 4°C. After centrifugation, the supernatant was collected and stored at −25 °C until analysis.

The protein content of the supernatant was determined using the Bradford method (Bradford, M.M., 1976) with bovine serum albumin (BSA) as the standard. Absorbance was measured at 595 nm using a UV–Vis spectrophotometer (Spekol 11, Carl Zeiss, Jena, Germany). All assays were performed in duplicate at 22 ± 0.5 °C and biochemical reactions were initiated by adding tissue supernatant to the reaction mixture.

Specific assay conditions for each parameter are described in the following subsections.

2-Thiobarbituric acid reactive substances (TBARS) assay. Lipid peroxidation levels were assessed by measuring the concentration of 2-thiobarbituric acid reactive substances (TBARS) according to the method of Buege J.A. and Aust S.D. (1978), with

minor modifications. This assay is based on the reaction between 2-thiobarbituric acid (TBA; Sigma-Aldrich, St. Louis, MO, USA) and malondialdehyde (MDA) or similar aldehydic products of lipid peroxidation. Under high temperature and acidic conditions, TBA reacts with MDA to form a pink chromogen with a maximal absorbance at 532 nm.

Briefly, 0.5 ml of supernatant was mixed with 2.5 ml of TBA reagent (0.375% TBA, 15% trichloroacetic acid, and 0.25 N HCl) and heated in a boiling water bath for 15 min. After cooling on ice, samples were centrifuged at 3,000 × g for 10 min to remove precipitated proteins. The absorbance of the supernatant was measured at 532 nm against reagent blanks using a UV–Vis spectrophotometer (Spekol 11, Carl Zeiss, Jena, Germany).

The TBARS concentration was calculated using the molar extinction coefficient for the MDA–TBA complex ($\varepsilon = 1.56 \times 10^5$ $M^{-1} \cdot cm^{-1}$) and expressed as nanomoles of MDA equivalents per milligram of protein.

Assay for carbonyl groups in oxidatively modified proteins. Carbonyl groups were determined as a marker of protein oxidation using the method of Levine R. L. et al. (1990) with some modifications. Briefly, liver homogenate supernatant aliquots were incubated with 10 mM 2,4-dinitrophenylhydrazine (DNPH; Sigma-Aldrich, St. Louis, Missouri, USA) in 2 M hydrochloric acid (HCl) for one hour at room temperature and in the dark. Blank samples were prepared under identical conditions, but without DNPH.

The proteins were then precipitated using 20% trichloroacetic acid (TCA), after which the mixture was centrifuged at 3,000 g for 20 minutes at 4 °C. The protein pellet was washed three times with a mixture of ethanol and ethyl acetate (1:1, v/v) to remove any remaining reagents or lipids. The pellet was then incubated at 37 °C in an 8 M urea solution until completely resuspended. The carbonyl content was measured spectrophotometrically at 370 nm for aldehydic derivatives (OMP_{370}) and at 430 nm for ketonic derivatives (OMP_{430}), using a molar extinction coefficient of 22,000 $M^{-1} \cdot cm^{-1}$. The results were expressed as nmol of carbonyl groups per mg of protein (Levine et al., 1990).

Total antioxidant capacity (TAC) assay. TAC was determined spectrophotometrically using the Tween 80 oxidation method (Galaktionova L. P. et al., 1998). Absorbance was measured at 532 nm and TAC values were expressed as a percentage relative to the control oxidation value.

Statistical analysis. Statistical analyses were performed to evaluate the effects of anty-*Yersinia* vaccination and sampling time on oxidative stress markers and total antioxidant capacity (TAC) in liver tissue. Six experimental groups were included: three control groups that were not treated and three groups that received the anti-*Yersinia* vaccine at 0, 1 and 2 months after vaccination. Four biochemical parameters were assessed: 2-thiobarbituric acid reactive substances (TBARS; nmol per mg of protein) as a marker of lipid peroxidation, and aldehydic and ketonic derivatives of oxidatively modified proteins (nmol per mg of protein), as well as TAC (%).

Data were analysed using two-way ANOVA to assess the main effects of time and vaccination status, as well as their interaction. When significant effects were detected, post hoc pairwise comparisons were performed using the Tukey–Kramer honest significance test (HSD). Effect sizes were calculated using Cohen's d and partial eta squared (η^2). Pearson's correlation coefficients (r) were determined to assess the associations between the oxidative stress markers and TAC. Multiple linear regression analysis was used to identify the strongest predictors of TBARS levels, including TAC, vaccination status and time. Variability in the data was expressed as the coefficient of variation (CV%) (Stanisz A., 2006, 2007).

Normality and homogeneity of variances were verified using Shapiro–Wilk and

Levene's tests, respectively. All tests were two-tailed and differences were considered statistically significant at $p < 0.05$. The statistical analyses were conducted using Statistica 13.3 (TIBCO Software Inc., Palo Alto, USA).

Results. Figure 1 shows the levels of TBARS (a key indicator of lipid peroxidation), aldehydic and ketonic derivatives of oxidatively modified proteins, and total antioxidant capacity in the hepatic tissues of rainbow trout that were orally immunised against *Y. ruckeri* at 0, 1 and 2 months post-vaccination.

A statistical analysis was performed to evaluate the effects of anti-*Yersinia* vaccination and time on oxidative stress markers and antioxidant capacity in liver tissue. The study included six groups: three control groups that received no treatment and three groups that received the anti-*Yersinia* vaccine (at 0, 1 and 2 months after vaccination). Four biochemical parameters were assessed: TBARS as a marker of lipid peroxidation (nmol·mg^{-1} protein); aldehydic and ketonic derivatives of oxidatively modified proteins (nmol·mg^{-1} protein); and total antioxidant capacity (TAC, %).

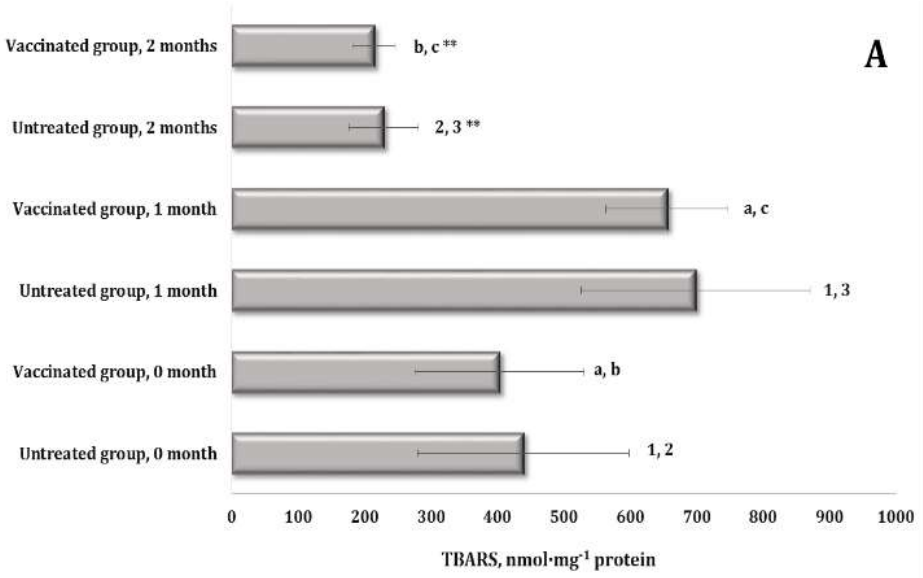
TBARS levels varied significantly across groups and time points. One-way ANOVA revealed significant main effects of time ($F_{2.78} = 14.62$, $p < 0.001$) and group ($F_{1.78} = 6.87$, $p = 0.011$), as well as a significant interaction effect ($F_{2.78} = 4.23$, $p = 0.018$). Post hoc Tukey HSD tests showed that TBARS levels peaked at one month in both the control group (698.30 ± 172.43 nmol·mg^{-1} protein) and the vaccinated group (655.67 ± 91.95 nmol·mg^{-1} protein), followed by a significant decrease at two months (control group: 228.64 ± 51.89 nmol·mg^{-1} protein; vaccinated group: 214.18 ± 32.20 nmol·mg^{-1} protein; $p < 0.01$) (Fig. 1A).

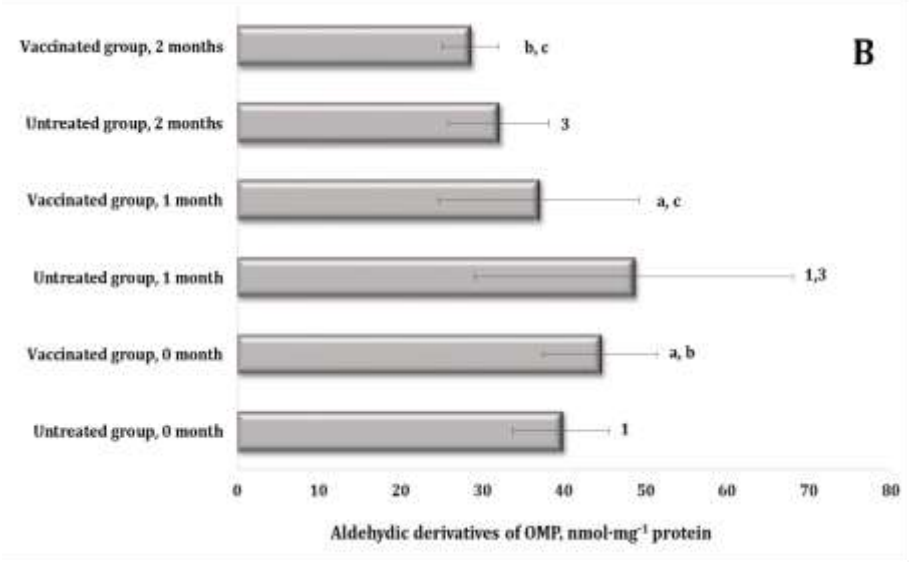
Levels of aldehydic and ketonic derivatives of oxidatively modified proteins exhibited moderate variability (Fig. 1B, 1C). Aldehydic derivative levels peaked at 1 month in the control group (48.57 ± 19.50 nmol·mg^{-1} protein) compared to the vaccinated group (36.91 ± 12.25 nmol·mg^{-1} protein) (Fig. 1B), while ketonic derivative levels peaked at 0 months in the control group (58.49 ± 6.13 nmol·mg^{-1} protein) compared to the vaccinated group (57.34 ± 4.59 nmol·mg^{-1} protein) (Fig. 1C). ANOVA revealed a significant time effect for ketonic derivatives ($F_{2.78} = 4.76$, $p = 0.012$), but no significant group effect.

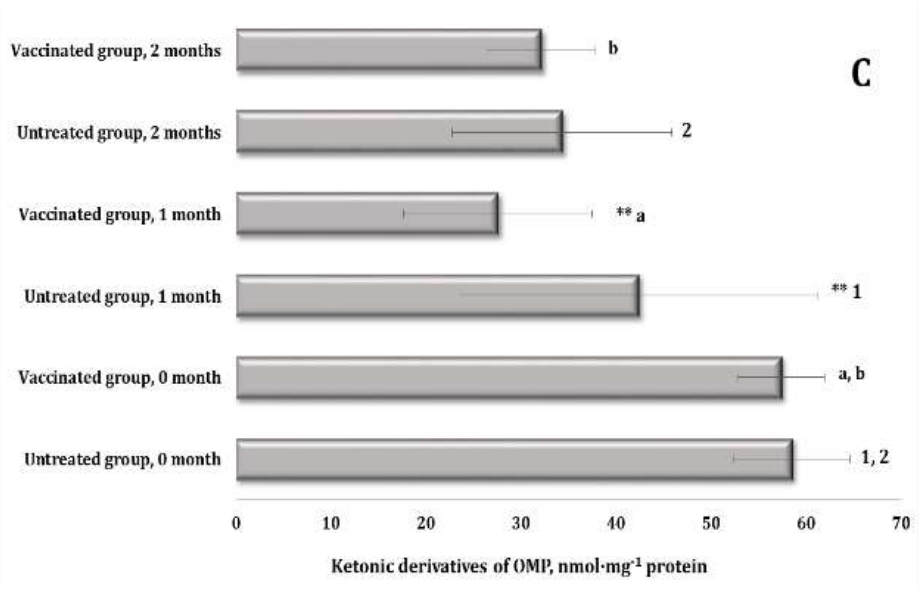
TAC values increased over time, reaching their highest levels after two months. A two-way ANOVA revealed significant effects of both time ($F_{2.78} = 21.34$, $p < 0.001$) and group ($F_{1.78} = 9.45$, $p = 0.003$). At 2 months, the vaccinated group showed significantly higher TAC levels (54.62 ± 12.84%) than the control group (49.41 ± 13.45%) ($p < 0.01$) (Fig. 1D).

Pearson's correlation analysis revealed a moderate positive correlation between TBARS and aldehydic derivatives of oxidatively modified proteins ($r = 0.42$, $p < 0.01$), a weaker correlation with ketonic derivatives of oxidatively modified proteins ($r = 0.35$, $p = 0.03$) and a strong negative correlation between TBARS and TAC ($r = −0.58$, $p < 0.001$). Multiple linear regression identified TAC as the strongest predictor of TBARS levels ($\beta = −5.2$, $p < 0.001$). Vaccination status was also a significant factor ($\beta = −45.6$, $p = 0.017$), indicating reduced oxidative stress in vaccinated animals. Time had a non-linear effect, with the highest TBARS values occurring at one month.

For TBARS changes between 1 and 2 months, Cohen's d ranged from 1.12 (large) in the control group to 1.35 (very large) in the vaccinated group, indicating a substantial reduction in oxidative stress over time. For TAC, Cohen's d between 0 and 2 months was 1.48 in the vaccinated group, reflecting a significant increase in antioxidant capacity after immunisation.


A
Vaccinated group, 2 months
b, c **
Untreated group, 2 months
2, 3 **
Vaccinated group, 1 month
a, c
Untreated group, 1 month
1, 3
Vaccinated group, 0 month
a, b
Untreated group, 0 month
1, 2
0 100 200 300 400 500 600 700 800 900 1000
TBARS, nmol·mg-1 protein


B
Vaccinated group, 2 months
b, c
Untreated group, 2 months
3
Vaccinated group, 1 month
a, c
Untreated group, 1 month
1,3
Vaccinated group, 0 month
a, b
Untreated group, 0 month
1
0 10 20 30 40 50 60 70 80
Aldehydic derivatives of OMP, nmol·mg-1 protein


C
Vaccinated group, 2 months
b
Untreated group, 2 months
2
Vaccinated group, 1 month
** a
Untreated group, 1 month
** 1
Vaccinated group, 0 month
a, b
Untreated group, 0 month
1, 2
0 10 20 30 40 50 60 70
Ketonic derivatives of OMP, nmol·mg-1 protein

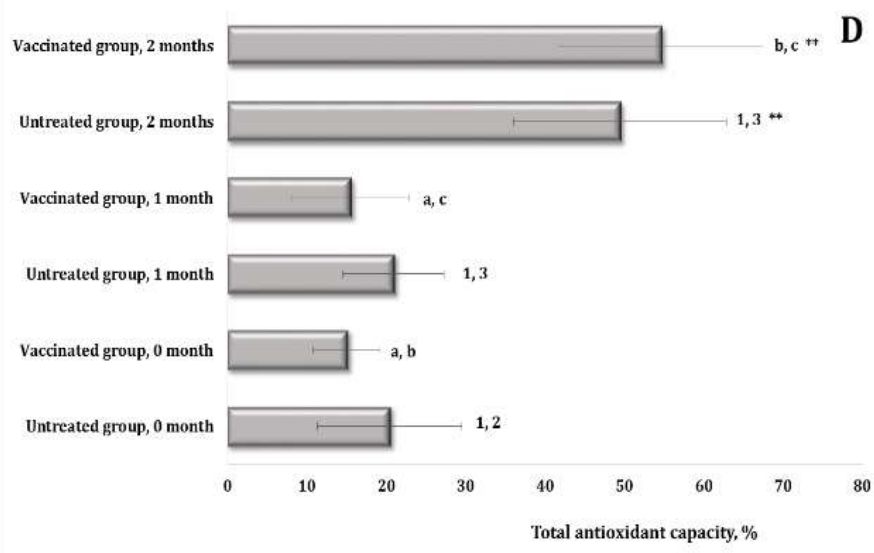


Fig. 1. The levels of TBARS levels, a key indicator of lipid peroxidation (A), aldehydic and ketonic derivatives of oxidatively modified proteins (B, C), and total antioxidant capacity (D) in the hepatic tissues of rainbow trout that were orally immunised against *Y. ruckeri* at 0, 1, and 2 months after vaccination.

Data are presented as means ± S.D. (n = 10).

*** Significant differences (p < 0.05) between the untreated control group and the group vaccinated against Y. ruckeri;*

[1] Significant differences (p < 0.05) between the untreated control group at 0 and 1 months after vaccination against Y. ruckeri;

[2] Significant differences (p < 0.05) between the untreated control group at 0 and 2 months after vaccination against Y. ruckeri;

[3] Significant differences (p < 0.05) between the untreated control group at 1 and 2 months after vaccination against Y. ruckeri;

[a] Significant differences (p < 0.05) between the group vaccinated against Y. ruckeri at 0 and 1 months after vaccination;

[b] Significant differences (p < 0.05) between the group vaccinated against Y. ruckeri at 0 and 2 months after vaccination;

[c] Significant differences (p < 0.05) between the group vaccinated against Y. ruckeri at 1 and 2 months after vaccination.

Two-way ANOVA revealed that time accounted for 41% of the variance in TBARS levels (partial $\eta^2 = 0.41$), while vaccination status accounted for 17% (partial $\eta^2 = 0.17$). For TAC, time accounted for 38% of the variance and group differences accounted for 22%, suggesting a meaningful physiological impact of the vaccine. The coefficient of variation (CV%) was highest for TBARS at 1 month (24.6%), which is consistent with elevated oxidative stress and variability in the response to Yersinia exposure between individuals. In contrast, TAC showed the lowest CV% (12.3%) at 2 months in the vaccinated group, indicating a more uniform antioxidant response post-vaccination.

Overall, these findings emphasise the robust protective effect of anti-*Yersinia* vaccination, characterised by reduced lipid peroxidation and enhanced antioxidant defences over time.

Discussion. This study investigated the temporal and immunological effects of *Yersinia ruckeri* vaccination on oxidative stress markers and antioxidant capacity in the livers of rainbow trout. The results showed clear time-dependent patterns of biochemical modulation, indicating that vaccination measurably affects the redox balance in fish.

TBARS levels, a key indicator of lipid peroxidation, varied significantly between time points and treatment groups. The peak observed one month after vaccination suggests a transient increase in oxidative stress, which is likely to be linked to immune activation and metabolic adaptation during the post-vaccination phase (Fig. 1A). Similar transient increases in TBARS have been reported in teleosts following immunostimulation or pathogen exposure, reflecting the increased production of reactive oxygen species (ROS) during the innate immune response (Torrealba D. et al., 2019; Yu Y. et al., 2020; Usman S. et al., 2021; Hissen K. L. et al., 2023). The subsequent decline in TBARS levels at two months, which was particularly pronounced in vaccinated fish, indicates the activation of compensatory antioxidant mechanisms, which may involve the upregulation of antioxidant enzymes such as superoxide dismutase, catalase and glutathione peroxidase (Tkachenko H. et al., 2014; Shastak Y. and Pelletier W., 2023). The reduction in TBARS in vaccinated fish (214.18 ± 32.20 nmol·mg^{-1} protein) compared to controls (228.64 ± 51.89 nmol·mg^{-1} protein) suggests that immunisation protects against sustained lipid oxidative damage.

The variability of oxidatively modified protein (OMP) derivatives was moderate. Aldehydic derivatives peaked at one month in the control group, while ketonic derivatives were at their highest level at baseline (Fig. 1B, 1C). This pattern suggests that the kinetics of protein oxidation may differ from those of lipid peroxidation: aldehydic forms may reflect ongoing damage, while ketonic forms may represent earlier oxidative events (Pizzimenti S. et al., 2013; Frijhoff J. et al., 2015). Although ANOVA indicated a significant time effect for ketonic derivatives, no significant group effect was observed. This suggests that vaccination has a stronger impact on lipid oxidation and antioxidant capacity than on protein oxidation. Previous studies in fish have also found that markers of protein oxidation are generally less responsive than TBARS to immunological or environmental stressors (Dinardo F. R. et al., 2021).

Total antioxidant capacity (TAC) increased progressively over the experimental period, reaching its highest levels at two months post-vaccination. This increase was statistically significant for both time and group, with TAC values being higher in vaccinated fish (54.62% ± 12.84%) than in controls (49.41% ± 13.45%) (Fig. 1D). This aligns with the hypothesis that immunisation triggers systemic antioxidant defences, possibly via the transcriptional activation of antioxidant genes in response to ROS signalling (Birben E. et al., 2012; Hong Y. et al., 2024). The enhancement of TAC in vaccinated animals may represent an adaptive, protective mechanism aimed at restoring redox homeostasis after the initial oxidative challenge (Kurutas E. B., 2016; Liu S. et al., 2025).

Correlation analysis revealed moderate correlation between TBARS and aldehydic OMP ($r = 0.42$), weak correlation between TBARS and ketonic OMP ($r = 0.35$), and strong negative correlation between TBARS and TAC ($r = -0.58$). These findings emphasise the interconnected nature of oxidative stress pathways and suggest that higher antioxidant capacity is associated with lower lipid peroxidation. Multiple regression analysis identified TAC as the strongest predictor of TBARS, emphasising the central role of antioxidant defences in controlling oxidative damage.

Effect size analysis confirmed significant time- and treatment-related changes, particularly for TBARS and TAC shifts, with large Cohen's d values. For TBARS, the decrease between one and two months corresponded to a large-to-very-large effect size in both groups, with vaccinated fish demonstrating greater improvement. Changes in TAC between 0 and 2 months in vaccinated fish yielded a Cohen’s d of 1.48, indicating a substantial enhancement of systemic antioxidant defences. Coefficient of variation (CV%) analysis revealed the greatest variability in TBARS at one month (24.6%),

consistent with inter-individual differences in oxidative responses, and the lowest CV% for TAC in vaccinated fish at two months (12.3%). This suggests a more uniform antioxidant adaptation post-vaccination.

Importantly, these redox-related changes are consistent with the immunological observations reported by Raida M. K. et al. (2011). They demonstrated that immersion vaccination of rainbow trout against *Y. ruckeri* significantly increased plasma IgM titres and provided complete protection at 8 and 26 weeks post-vaccination. Antibody levels correlated with reduced bacteraemia and enhanced bactericidal activity of plasma *in vitro*. Integrating these findings with our data suggests that the biphasic oxidative response – initial oxidative stress followed by enhanced antioxidant capacity – may support the development of robust humoral immunity by limiting oxidative damage to immune cells and plasma proteins involved in pathogen neutralisation.

The proposed link between redox modulation and humoral immunity is further supported by the work of Rømer Villumsen K. et al. (2012), who investigated protection against *Aeromonas salmonicida* induced by vaccination in rainbow trout. They found that both commercial and experimental vaccines significantly improved survival following bacterial challenge, inducing sustained increases in specific antibody levels during the 18-week post-vaccination period. Notably, antibody titres prior to infection were positively correlated with survival, while a rapid decline in antibodies was observed within three days post-challenge. This indicates the active utilisation of these immune effectors in defending against pathogens. These findings reinforce the idea that the efficacy of vaccination in salmonids depends not only on the generation of strong antibody responses, but also on preserving the functional capacity of these antibodies during infection. In this context, the enhanced antioxidant capacity observed in our study could play a critical role in maintaining antibody stability and effectiveness, thereby supporting long-term protection in aquaculture settings.

Taken together, these findings suggest that vaccination against *Y. ruckeri* induces a biphasic oxidative stress response in rainbow trout. This is characterised by an initial increase in lipid peroxidation, followed by a significant increase in antioxidant capacity. These adaptive changes may represent an important physiological mechanism that supports the development of effective immune protection while limiting oxidative damage. These results are consistent with reports in other fish species, in which vaccination or immune stimulation has been shown to modulate redox balance (Zhang C. et al., 2021; Nadarajapillai K. et al., 2023; Dagoudo M. et al., 2023; Khansari A. R. et al., 2025), and could inform future strategies aimed at optimising fish health and vaccine efficacy in aquaculture.

In summary, the data demonstrate that anti-*Yersinia* vaccination influences oxidative stress dynamics in a time-dependent manner. The transient increase in TBARS followed by enhanced TAC indicates a coordinated physiological response to an immunological challenge. These findings provide insight into the redox-modulatory effects of vaccination and highlight the usefulness of TBARS, protein oxidation markers and TAC as sensitive indicators of hepatic oxidative status.

Conclusions. This study provides evidence that vaccination against Yersinia ruckeri modulates oxidative stress and antioxidant capacity in the livers of rainbow trout over time. The observed biphasic response – an initial, transient increase in lipid peroxidation, followed by a pronounced rise in total antioxidant capacity – suggests a coordinated physiological adjustment to the immunological challenge. Lipid peroxidation markers (TBARS) were found to be more sensitive to the effects of vaccination than indicators of protein oxidation, while antioxidant capacity was found to be a strong negative predictor of oxidative damage. These findings emphasise fish's ability to activate

compensatory antioxidant mechanisms following vaccination and highlight the importance of oxidative stress biomarkers as tools for monitoring fish health and vaccine efficacy in aquaculture systems.

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MECHANISMS OF ACTION OF ESSENTIAL OILS IN PIGS AND THEIR IMPACT ON PORK QUALITY

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The growing demand for high-quality pork and consumers' preference for natural additives has sparked interest in using plant essential oils (EOs) as an alternative to synthetic preservatives, antibiotics and antioxidants in pig farming. This review summarises the current knowledge on the chemical composition, biological properties and mechanisms of action of EOs, and highlights their effects on gut microbiota, nutrient absorption, oxidative status, immune function and meat quality. Comparative studies suggest that EOs can match or complement conventional feed additives, enhancing growth performance, carcass characteristics and shelf life while providing additional advantages such as antimicrobial and antioxidant properties. EO efficacy depends on factors including plant source, purity, dosage, supplementation duration, pig genotype, age, diet composition, and potential interactions with other additives. Limitations include variability in EO composition, palatability issues at high inclusion levels, and potential toxicity. Future research directions include novel delivery systems (e.g. microencapsulation and nanoemulsions), combination strategies involving probiotics, prebiotics or enzymes, and omics-based approaches to elucidate the molecular mechanisms involved. Overall, EOs represent a promising natural tool for improving pork quality and sustainability in swine production. However, standardised application protocols and safety considerations are essential for their practical implementation.

Keywords: essential oils, pigs, meat quality, antioxidants, antimicrobials, gut health, phytogenic feed additives, oxidative status, swine nutrition, shelf life

МЕХАНІЗМИ ДІЇ ЕФІРНИХ ОЛІЙ ТА ЇХ ВПЛИВ НА ЯКІСТЬ СВИНИНИ

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Зростаючий попит на високоякісну свинину, поєднаний із зростанням зацікавленості споживачів у натуральних добавках, зумовив підвищений інтерес до використання рослинних ефірних олій (ЕО) як альтернативи синтетичним консервантам, антибіотикам та антиоксидантам у свинарстві. У цьому огляді узагальнено сучасні знання про хімічний склад, біологічні властивості та механізми дії ЕО, а також детально розглянуто їхній вплив на мікробіоту кишечника, засвоєння поживних речовин, окиснювальний статус, імунну функцію та якість м'яса. Результати порівняльних досліджень свідчать, що ЕО можуть не лише замінювати, а й доповнювати традиційні кормові добавки, підвищуючи продуктивність росту, покращуючи характеристики туші та подовжуючи термін зберігання продукції. При цьому вони забезпечують додаткові переваги, зокрема антимікробні та антиоксидантні властивості. Ефективність їх застосування залежить від багатьох факторів, серед яких джерело рослинної сировини, чистота та дозування олій, тривалість згодовування, генотип і вік свиней, склад раціону, а також можливі взаємодії з іншими кормовими добавками. Водночас існують певні обмеження, зокрема мінливість складу ЕО, зниження поїдання корму при високих рівнях їх включення та потенційна токсичність. У зв'язку з цим напрями майбутніх досліджень передбачають розробку нових систем доставки (наприклад, мікроінкапсуляції та наноемульсій), застосування комбінованих стратегій із пробіотиками, пребіотиками чи ферментами, а також використання омікс-підходів для глибшого розуміння молекулярних механізмів їх дії. Отже, ЕО є перспективним природним інструментом для підвищення якості свинини та забезпечення сталості свинарської галузі. Проте для їх широкого та безпечного впровадження необхідна розробка стандартизованих протоколів застосування та чітке дотримання вимог безпеки.

Ключові слова: ефірні олії, свині, якість м'яса, антиоксиданти, антимікробні засоби, здоров'я кишечника, фітогенні кормові добавки, окиснювальний статус, годівля свиней, термін зберігання.

Introduction. The quality of pork is critical to its market value and consumer acceptance. It encompasses sensory attributes such as colour, flavour, tenderness and juiciness, as well as nutritional composition and technological properties (Rodrigues S. S. Q. et al., 2024). In recent decades, consumer demand for 'clean-label' products, stricter food safety regulations, and growing concerns about antimicrobial resistance have put increasing pressure on the livestock industry to replace synthetic growth promoters and antimicrobial agents with natural, sustainable alternatives (Zhou Y. et al., 2025). Of the

natural feed additives that have been investigated, plant essential oils (EOs) have attracted a great deal of attention thanks to their wide range of bioactive properties, including antimicrobial, antioxidant, anti-inflammatory and digestive-modulatory effects (Stevanović, Z. D. et al., 2018; Nehme R. et al., 2021).

EOs are complex mixtures of volatile secondary metabolites, primarily terpenes, terpenoids, and phenylpropanoids, derived from aromatic plants (Bassolé I. H. and Juliani H. R., 2012). Their inclusion in pig diets has been studied for various purposes, such as improving growth performance (Peng X. et al., 2021), modulating gut microbiota (Ruzauskas M. et al., 2020), enhancing immune responses (Su G. et al., 2018), and reducing oxidative stress (Tan C. et al., 2015; Peng X. et al., 2021). Importantly, these biological activities can translate into measurable improvements in meat quality, such as better oxidative stability, enhanced sensory properties, and a prolonged shelf life (Omonijo F. A. et al., 2018).

The mechanisms by which EOs influence meat quality are multifactorial. These mechanisms may involve the modulation of oxidative processes in muscle tissue, the alteration of lipid composition, the reduction of microbial spoilage and the effects on post-mortem proteolysis (Ojeda-Piedra S. A. et al., 2022). However, the extent of these effects depends on various factors, such as the type and chemical composition of the EO, the dosage, the duration of supplementation and interactions with other dietary components (Ji J. et al., 2023).

This review aims to summarise and critically analyse the current knowledge regarding the impact of plant-derived essential oils on pork quality, particularly in relation to their potential as natural dietary supplements for sustainable pork production. By integrating findings from animal nutrition, meat science, and food technology, this review provides an overview of the applicability, advantages, and limitations of using EOs to improve pork quality.

Chemical Composition and Biological Properties of Essential Oils

EOs are complex mixtures of volatile, aromatic, and bioactive secondary metabolites that give plants their characteristic aroma and flavour. Since ancient times, herbs and their EOs have been used to mask odours, enhance the sensory qualities of food, and in medicine, cosmetics, and perfumery (Bolouri P. et al., 2022). Due to their antioxidant, antimicrobial, and anti-inflammatory properties, EOs are widely used in the pharmaceutical, food, agriculture, cosmetics, and health industries.

EOs are produced by over 17,500 plant species, primarily within the *Lamiaceae*, *Rutaceae*, *Myrtaceae*, *Zingiberaceae*, and *Asteraceae* families, although only around 300 species are used commercially (Wińska K. et al., 2019). They mostly consist of lipophilic, volatile metabolites, including mono- and sesquiterpenes, phenolic compounds, aldehydes, ketones, and esters (Masyita A. et al., 2022). Major classes include:

- Terpenes (e.g. α-pinene, myrcene and limonene), which are hydrocarbons with antimicrobial activity through membrane disruption and the inhibition of protein and DNA synthesis (Álvarez-Martínez et al., 2021);
- Terpenoids are oxygenated derivatives of terpenes that play a role in plant defence and food preservation (Perricone M. et al., 2015).
- Phenylpropanoids are aromatic compounds with antioxidant activity via radical scavenging and metal chelation (Dai J. and Mumper R. J., 2010).

These compounds are synthesised via the malonic, mevalonic and MEP pathways, and are stored in glands, cavities or ducts. Typically, two to three dominant constituents (20–70%) are present alongside many minor components (Bergman M. E. et al., 2019).

Extraction strongly affects EO yield and composition. Conventional methods include hydrodistillation, steam distillation and cold pressing, while the Clevenger

apparatus is used on a laboratory scale (Pandey V. K. et al., 2023). Modern techniques, such as microwave-assisted extraction and supercritical fluid extraction, improve efficiency and preserve thermolabile compounds (Sousa V. I. et al., 2022).

EO bioactivity arises from the synergistic interaction of its constituents. These constituents display broad antimicrobial effects against bacteria, fungi, viruses, parasites and insects (Bakkali et al., 2008), acting through mechanisms such as increasing membrane permeability and interfering with nutrient uptake (Gonelimali et al., 2018). Phenylpropanoids and terpenoids also act as antioxidants, stabilising free radicals and quenching singlet oxygen (Dai and Mumper, 2010).

The rising demand for natural preservatives in foodstuffs has led to increased use of EOs in the meat industry. Their antimicrobial and antioxidant properties enhance microbial safety, oxidative stability and shelf life, providing a natural alternative to synthetic additives (Bassolé and Juliani, 2012; Ojeda-Piedra et al., 2022). This dual preservative role is the focus of research into the effects of EOs on improving pork quality, which will be discussed later in this review.

Mechanisms of Action of Essential Oils in Pigs

Improving pork quality requires optimal genetic selection and husbandry practices, as well as targeted nutritional strategies to modulate pigs' physiological processes. One such strategy that has attracted considerable attention is the use of plant-derived EOs, which have antimicrobial, antioxidant and anti-inflammatory properties that can translate into measurable benefits for meat quality (Nhara R. B. et al., 2024).

Effects on gut microbiota and nutrient absorption. The gut microbiota plays a central role in the digestion and absorption of nutrients, as well as the overall health of pigs, thereby influencing their growth performance and meat quality (Szabó C. et al., 2023). EOs have been shown to modulate the composition and metabolic activity of intestinal microbiota, inhibiting pathogenic bacteria such as *Escherichia coli* and *Clostridium perfringens*, while promoting beneficial species such as *Lactobacillus* and *Bifidobacterium* (He Y. et al., 2022). These shifts in microbial balance can enhance nutrient digestibility, reduce intestinal inflammation and improve feed conversion efficiency (He Y. et al., 2022; Luise D. et al., 2023). The improved absorption of amino acids and fatty acids contributes to optimal muscle growth and reduced fat deposition, thereby supporting favourable carcass traits (Zhao B. C. et al., 2023) (Fig. 1).

Choi J. et al. (2020) demonstrated that the combination of microencapsulated organic acids and EOs enhanced the intestinal morphology of weaned piglets challenged with enterotoxigenic *E. coli* F4. This resulted in reduced diarrhoea, decreased gut permeability and increased villus height in the jejunum, thereby enhancing nutrient absorption. Similar effects were reported by Chen et al. (2023), who found that *Litsea cubeba* EO improved antioxidant status, nutrient digestibility and growth performance. Together, these findings highlight the potential of EOs, either alone or in combination with organic acids, as an alternative to antibiotic growth promoters, as they improve gut integrity, immunity, and nutrient utilisation.

Garavito-Duarte et al. (2025) demonstrated that both herb-based (HP) and EO-based phytobiotics mitigated the effects of *E. coli* F18+ in nursery pigs. Both treatments reduced faecal scores, supported jejunal enterocyte maturation and modulated mucosa-associated microbiota with antimicrobial-like effects. HP also exhibited antioxidant properties. These results are consistent with those of Choi J. et al. (2020) and confirm that phytogenic additives enhance gut barrier function, reduce diarrhoea and increase resilience to enteric pathogens. This supports their potential as an alternative to antibiotics.

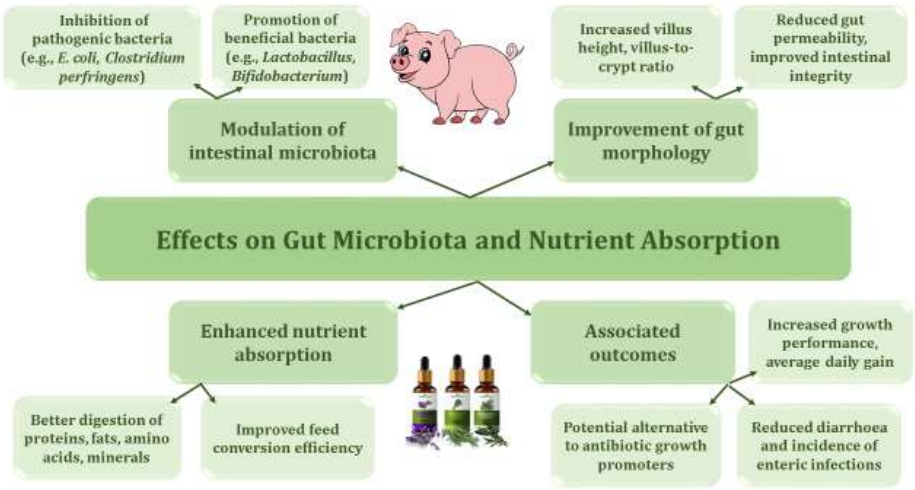

Fig. 1. **The effects of essential oils on gut microbiota and nutrient absorption in pigs**

Building on these findings, Zhao B. C. et al. (2023) discovered that dietary supplementation with cinnamaldehyde and carvacrol enhanced piglet growth, appetite, and intestinal health. EOs increased body weight and average daily gain (ADG), reduced diarrhoea, improved intestinal morphology, up-regulated tight junction proteins and digestive enzymes, and enhanced microbial diversity, promoting the growth of beneficial bacteria. These changes supported better feed utilisation and appetite regulation. Taken together, these studies confirm that phytogenic additives, particularly EOs, can enhance gut integrity, balance the microbiota, and improve growth performance, offering a viable alternative to antibiotics in nursery pigs.

Modulation of oxidative status and immune function. Oxidative stress is a key factor affecting pork quality, particularly under intensive farming conditions when animals are exposed to stressors such as high stocking density, transportation, and pre-slaughter handling (Hao Y. et al., 2021). Excessive reactive oxygen species (ROS) can accelerate the oxidation of lipids and proteins in muscle tissue, resulting in undesirable changes to colour, flavour, tenderness and shelf life (Domínguez R. et al., 2019). Essential oils rich in phenolic compounds, such as thymol, carvacrol and eugenol, possess strong antioxidant properties. They can neutralise ROS and stimulate the production of endogenous antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx) (Frankič T. et al., 2010). Furthermore, EOs can modulate immune responses by reducing pro-inflammatory cytokine production and enhancing humoral immunity. This lowers the risk of disease outbreaks and associated carcass downgrading (Grazul M. et al., 2023) (Fig. 2).

Forte et al. (2017) reported that oregano EO improved growth and oxidative stability in outdoor-reared pigs, but not in those reared indoors. The greater benefits outdoors were attributed to higher levels of oxidative and physiological stress, in which the phenolic compounds carvacrol and thymol exhibit stronger antioxidant and antimicrobial properties. These results highlight the potential of oregano EO to counteract performance losses in challenging environments.

Similar findings have been observed with other essential oils. For example, Chen F. et al. (2023) demonstrated that *Litsea cubeba* oil (LCO) increased antioxidant capacity, improved nutrient digestibility and enhanced growth performance in fattening pigs while also modulating faecal microbiota. A 500 mg/kg dose increased serum catalase activity, while lower doses improved the digestibility of protein, ash, calcium and fat. LCO also

reduced specific bacterial taxa (e.g. SMB53 and L7A_E11), suggesting that improvements in nutrient utilisation and antioxidant status are mediated by the microbiota. Notably, measurable physiological benefits were observed at a dose of just 250 mg/kg, supporting the use of LCO as an alternative to antibiotics.

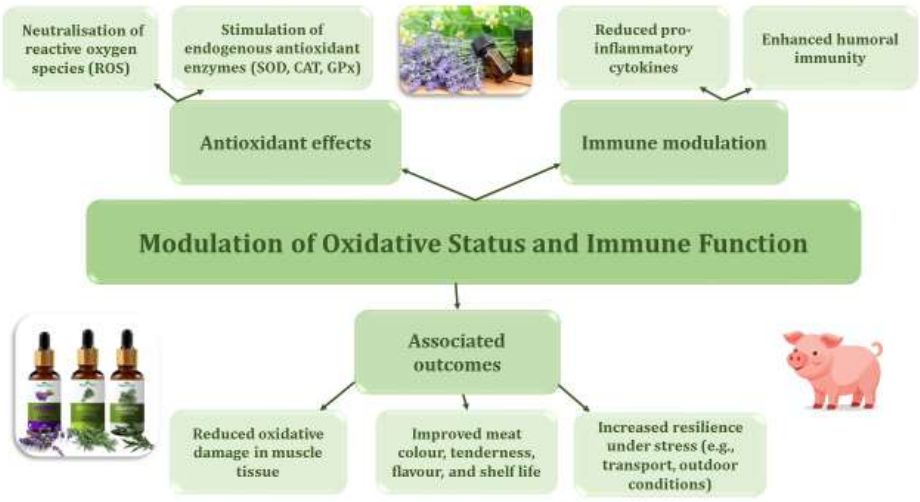

Fig. 2. **Essential oils and modulation of oxidative status and immune function in pigs**

Chen et al. (2024) found that *Alpinia oxyphylla* oil (AEO) improved immune and antioxidant functions, as well as altering the gut microbiota of pigs, though it had no effect on growth performance. AEO increased serum IgG, glutathione (GSH) activity, and the digestibility of ash and calcium in a dose-dependent manner. It also promoted beneficial bacteria such as *Blautia*, *Butyricicoccus* and *Lactobacillus*, while reducing *Clostridium* and *Turicibacter*. The strongest benefits were observed at a dose of 1,000 mg/kg, suggesting that higher doses may be required to achieve significant effects and offering an alternative to conventional antibiotics such as CTC.

Taken together, the studies by Forte (2017) and Chen (2023, 2024) demonstrate that EOs can enhance oxidative stability, immunity, nutrient utilisation and gut microbiota composition in pigs. While growth responses vary depending on the conditions and type of oil, phytogenic additives offer a promising approach to reducing antibiotic use, particularly in situations of stress or immune challenges.

Influence on metabolism relevant to muscle and meat quality. Nutritional modulation through EOs can influence metabolic pathways related to muscle fibre composition, energy utilisation and fat deposition in pigs (Yan E. et al., 2023). Certain EOs have been reported to promote lean muscle growth by increasing protein synthesis and reducing intramuscular fat accumulation (Janz J. A. et al., 2007). This is particularly important for achieving the desired pH value and colour stability of meat after slaughter, since the energy status at slaughter determines the rate at which glycogen is depleted and the pH value declines during rigor mortis (Towers L., 2016). Furthermore, EOs may help to maintain the integrity of muscle cell membranes, thereby reducing drip loss and improving water-holding capacity – critical parameters for consumer acceptance and processing yield (Omonijo F. A. et al., 2018).

Cheng C. et al. (2017) found that supplementing a low-protein, amino acid-balanced diet with oregano EO and benzoic acid improved the oxidative stability and antioxidant enzyme activity of pig muscle, but reduced its intramuscular fat (IMF) content, which could affect its flavour. This highlights the trade-off between extending

shelf life and maintaining sensory quality, and emphasises the importance of balancing feed strategies.

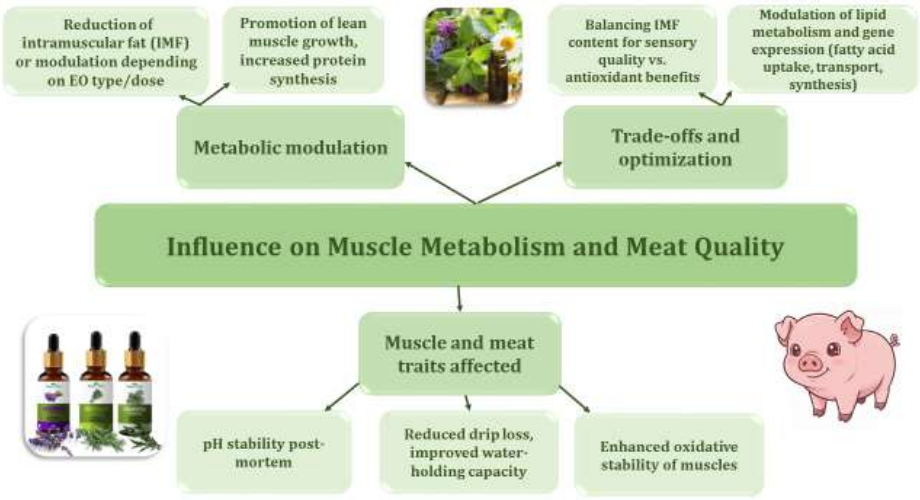

Fig. 3. **The influence of essential oils on muscle metabolism and meat quality**

Huang C. et al. (2022) reported that administering 200 mg/kg of plant essential oils to finishing pigs improved growth, nutrient digestibility, antioxidant capacity and IMF content while reducing shear force. By modulating lipid metabolism and oxidative balance, EOs can enhance both efficiency and meat quality, thus aligning with consumer demand for premium, functional products.

EOs may also mitigate the effects of acute stress. Zou Y. et al. (2017) demonstrated that 25 mg/kg of oregano EO reduced transport stress in pigs more effectively than vitamin E, resulting in higher post-mortem muscle pH, reduced drip loss, lower serum cortisol and creatine kinase levels, and improved intestinal morphology in supplemented pigs. EO also down-regulated stress-related heat shock proteins, suggesting enhanced resilience and meat quality under stress.

The long-term effects were examined by Hofmann H. H. et al. (2022), who found that high doses of omega-3 fatty acids caused minimal changes in carcass traits, but modulated the expression of genes related to the gut barrier and immune system (e.g. tight junction proteins and interferons). These findings suggest that the benefits may be more evident at the molecular level than in performance traits.

Nannoni E. et al. (2023) explored the effects of inhaling lavender EO. While it had little impact on carcass traits or meat quality, once-daily inhalation reduced tail lesions, whereas twice-daily inhalation increased body lesions. No residues were detected in edible tissues, indicating its suitability for Parma ham production. However, the welfare benefits remain inconclusive and require optimisation of the dosage.

In summary, EOs influence pigs at multiple physiological levels, enhancing antioxidant defences, modulating the microbiota and supporting immune resilience and improving meat quality traits. Their multifunctional effects make them a promising natural alternative to synthetic additives and meet the demand for cleaner, more sustainable pork production.

The effects of plant essential oils on pig meat quality

The spoilage of pork is primarily driven by microbial growth, lipid oxidation and enzymatic autolysis (Zhu et al., 2024). The lipid oxidation of minced pork depends on the fatty acid composition, the presence of radicals, oxygen levels, the balance of antioxidants and pro-oxidants, additives such as spices and herbs, processing methods such as

irradiation, cooking, grinding and cutting, packaging methods such as vacuum packing and modified or active atmospheres, and storage conditions (Huang X. and Ahn D.U., 2019). Microbial contamination also plays a significant role, with pork acting as a reservoir for *E. coli*, *Staphylococcus aureus*, *Salmonella* spp. and *Listeria* spp. (Zhu Y. et al., 2022).

The quality of pork – defined by tenderness, juiciness, flavour, colour and shelf life – is influenced by the animal's diet, metabolism and well-being (Lebret and Čandek-Potokar, 2022a, b). EOs can enhance these characteristics through their antioxidant and antimicrobial properties, improving flavour by modulating fatty acid composition and oxidative stability, reducing the microbial load and extending the shelf life. Their natural origin also meets consumer demand for alternatives to synthetic preservatives (Zhai H. et al., 2018). Meat quality can be improved by either dietary EO supplementation, which alters fatty acid profiles and stability, or by direct application to meat products (Wenk, 2003). However, at high concentrations, some EOs can act as pro-oxidants with cytotoxic effects, damaging DNA and proteins (Bakkali F. et al., 2008).

Meat quality. Plant-derived compounds such as EOs and oleoresins are attracting increasing interest in the meat industry due to their ability to enhance animal performance and meat quality, as well as extending shelf life through natural preservation. These bioactive substances are typically obtained from herbs such as oregano, rosemary, thyme, garlic, and ginger, and exhibit antimicrobial, antioxidant, and flavour-modulating properties. Incorporating them into diets, marinades, or surface applications therefore represents a promising strategy for meeting consumer demand for clean-label, minimally processed meat products.

Janz J. A. et al. (2007) provided an example of dietary supplementation, testing a low inclusion level (0.05%) of rosemary, garlic, oregano, and ginger extracts in finishing pigs. The study showed that garlic supplementation increased feed intake and daily weight gain, while oregano supplementation reduced lipid oxidation. However, carcass traits and sensory quality were not significantly affected, suggesting that higher doses or longer supplementation periods may be required to achieve measurable improvements.

As dietary inclusion produced only modest effects, further research shifted towards marination as a direct method of improving pork quality. Siroli L. et al. (2020) demonstrated that marination using a mixture of oil, beer and lemon enriched with oregano, rosemary and juniper EOs improved both tenderness and water-holding capacity, as well as enhancing sensory scores. Notably, microbiological analyses revealed reduced spoilage organisms and complete inhibition of major pathogens, suggesting that combining marination with essential oils can improve technological, sensory, and safety attributes simultaneously.

Similar findings were reported by Boskovic M. et al. (2019), who investigated the impact of thyme and oregano EOs on minced pork stored in vacuum or modified atmosphere packaging (MAP). Both EOs reduced lipid oxidation and lipolysis in a dose-dependent manner, with oregano EO demonstrating superior antioxidant properties. Furthermore, vacuum packaging was found to enhance stability even more, highlighting the potential for essential oils and packaging technologies to work together to extend pork shelf life.

Building on this, Zduńczyk W. et al. (2023) explored the effect of applying oregano EO superficially to pork loins stored in MAP. While a 1.0% dose modified the colour and imparted a distinct herbal aroma, the antimicrobial activity was marginal and only observed at later stages of storage. At 0.5%, the effects were negligible, suggesting that surface treatment may be better suited to creating value-added products with unique sensory attributes than to extending shelf life.

Taken together, these studies emphasise that the effectiveness of EOs and oleoresins depends largely on the mode of application. While low dietary levels primarily affect feed preference and growth, strategies involving marination and packaging provide more substantial enhancements to sensory appeal, microbial safety, and oxidative stability. Overall, integrating EOs into pork production emerges as a versatile, natural approach to improving product quality, extending shelf life and meeting consumer expectations for safe, minimally processed foods.

Microbiological analysis. Due to its susceptibility to microbial and oxidative spoilage, preserving fresh pork is a major challenge for the meat industry (Zhu Y. et al., 2022). *Pseudomonas* spp. predominate under aerobic storage conditions, while lactic acid bacteria (*Lactobacillus*, *Leuconostoc* and *Carnobacterium* spp.) and *Brochothrix thermosphacta* dominate under anaerobic conditions. Spoilage manifests as off-flavours, discolouration, and acidification (Zhao F. et al., 2015). Microbiological quality is routinely assessed using mesophilic and psychrotrophic counts, with an upper acceptability limit of 7.0 log CFU/g (Ercolini D. et al., 2009).

To address these issues, plant-derived bioactive compounds, especially EOs and extracts, are being explored increasingly as natural preservatives. When applied through marination, coatings or packaging, these compounds offer clean-label alternatives to synthetic additives (Aguiar Campolina G. et al., 2023). Siroli L. et al. (2020) demonstrated that marination, particularly with EOs, can suppress the growth of *Pseudomonas* spp., coliforms, *Listeria monocytogenes* and *Salmonella enteritidis*, thereby improving microbial safety. The addition of organic acids, ethanol and sodium chloride further enhances preservation (Friedman M. et al., 2007).

Building on this, Mantzourani I. et al. (2023) tested the effect of wine-based marinades containing pomegranate extract and thyme/oregano EOs on pork fillets. These treatments were highly effective in inhibiting *Enterobacteriaceae, Staphylococcus* spp., lactic acid bacteria, and yeasts/moulds, thereby extending the shelf life of the pork fillets by up to four days. Importantly, tenderness, colour and flavour were also preserved. Similar results were obtained with cranberry and pomegranate extracts in pork meatballs, where the strong antimicrobial effects were attributed to the presence of phenolic acids, terpenes and organic acids (Mantzourani I. et al., 2022).

Other EO-based strategies have also shown promise. For example, Hernández-Hernández E. et al. (2017) demonstrated that oregano EO, particularly when used in microencapsulated coatings, can effectively inhibit spoilage bacteria, slow down lipid oxidation, and preserve colour for up to 15 days. Similarly, Zhang J. et al. (2016) found that black pepper EO reduced lipid oxidation and microbial growth in pork while improving its appearance.

Further innovation comes from combining natural antimicrobials with advanced technologies. Xu Y. et al. (2022) reported that cinnamon EO nanoemulsions containing ε-polylysine effectively suppressed spoilage and pathogens in pork during storage and radio frequency cooking, thereby maintaining freshness and improving textural attributes.

Overall, these findings emphasise that plant-derived extracts and EOs, when applied through marination, coatings, or nanoemulsion systems, can inhibit the growth of spoilage and pathogenic microorganisms, delay oxidation, and preserve sensory qualities. Novel approaches, such as micro- and nanoencapsulation or their combination with compounds like ε-polylysine, can further enhance efficacy. Overall, these natural strategies demonstrate significant potential for extending the shelf life of pork while meeting consumer expectations for safe, high-quality, minimally processed meat.

An approach to improving pig health. The voluntary feed intake of pigs is strongly influenced by the characteristics of their diet. EOs, with their intense aroma, can increase

consumption by 3–19% compared to control diets (Kiarie E. G. and Mills A., 2019; Peng X. et al., 2021). Their flavour and odour enhance palatability, and their antioxidant properties preserve feed quality, ensuring it remains attractive to animals (Moyo P. et al., 2019; Nhara R. B. et al., 2024).

Beyond influencing feed intake, EOs improve nutrient utilisation. Supplementation enhances the apparent digestibility of crude protein and dry matter by modulating gene expression in the ileum and stimulating digestive secretions (Moyo P. et al., 2019; Hofmann H. H. et al., 2022). Morphological benefits have also been observed, including increased jejunal villus height, a higher villus-to-crypt ratio, fewer intraepithelial lymphocytes and improved intestinal integrity. These effects are closely linked to favourable modulation of the gut microbiota, which decreases pathogens while promoting lactobacilli and other beneficial microbes (Liu Y. et al., 2018; Tariq S. et al., 2019).

In parallel, EOs contribute to immune modulation and the control of oxidative stress. Extracts containing carvacrol, capsicum oleoresin and cinnamaldehyde have been shown to reduce DNA damage in lymphocytes, thus demonstrating their antioxidant and immunoprotective properties (Frankič T. et al., 2010). Similarly, preferred EO flavours were found to increase voluntary feed intake, resulting in higher average daily gain without compromising carcass quality (Janz J. A. et al., 2007).

Taken together, these findings suggest that EOs can enhance pig nutrition and performance through various mechanisms. They do this by improving palatability and feed quality, supporting nutrient digestibility, optimising gut morphology and microbiota, and protecting against oxidative damage. Consequently, they contribute to better growth rates, feed efficiency, and potentially improved meat quality. This highlights their value as functional feed additives with broad benefits for animal health and production outcomes.

Comparative studies: Essential Oils vs. Conventional Additives

The growing demand for natural alternatives in pig farming has prompted research into using EOs instead of conventional feed additives, such as antibiotics and synthetic antioxidants. Although antibiotics promote growth and prevent disease and antioxidants such as BHT and BHA limit lipid oxidation in meat, there are concerns about antimicrobial resistance, chemical residues and potential health risks (Oswell N. J. et al., 2018).

EOs offer multifunctional benefits: they act as antimicrobials against pathogens such as Escherichia coli, Salmonella spp., Listeria monocytogenes and Staphylococcus aureus, and they also serve as natural antioxidants, preventing lipid and protein oxidation in pork (Bakkali F. et al., 2008; Siroli L. et al., 2020). They can also modulate gut microbiota, enhance nutrient digestibility and support immune function — effects that synthetic antioxidants alone cannot provide (Moyo P. et al., 2019; Hofmann H. H. et al., 2022; Nhara R. B. et al., 2024).

Comparative studies with other phytobiotics, such as plant extracts and oleoresins, further highlight the potential of EOs. Janz J.A. et al. (2007) found that EOs or oleoresins from rosemary, garlic, oregano or ginger improved feed intake and growth performance without adversely affecting carcass or meat quality. This multi-targeted action, which combines flavour enhancement, antioxidant protection and antimicrobial activity, could reduce the need for multiple additives.

The cost-effectiveness of EOs depends on concentration, formulation, and application. Despite their higher per-unit cost, their multifunctionality may reduce overall supplementation expenses by addressing several production challenges simultaneously (Wenk C., 2003; Zhai H. et al., 2018). Furthermore, consumer preference for natural and

clean-label products can increase market acceptance and add economic value (Ojeda-Piedra S.A. et al., 2022).

However, variability in EO composition, influenced by plant species, harvest conditions and extraction methods, can affect efficacy and stability (Wińska K. et al., 2019). Careful selection of the type and dosage of EOs, as well as standardised extraction, is essential for achieving consistent benefits in terms of meat quality and animal health.

In summary, EOs represent a promising, multifunctional alternative to antibiotics, synthetic antioxidants, and other phytobiotics. Their ability to improve gut health, enhance meat quality and reduce oxidative and microbial spoilage makes them valuable for sustainable pig production, provided that practical considerations such as cost, dosage and variability are taken into account.

Factors Influencing the Efficacy of Essential Oils

The effectiveness of EOs in improving the health and growth performance of pigs, and the quality of their meat, is influenced by various factors. These include the oils' chemical composition and purity, the dosage and duration of supplementation, host-specific characteristics such as age, genetics and gut microbiota composition, and diet-related variables that may interact with EO bioactivity.

EO type and purity. The biological activity of EOs largely depends on the specific plant species, chemotype and extraction method. EOs are complex mixtures of terpenes, terpenoids, phenylpropanoids, aldehydes, and other minor compounds which can vary in concentration depending on harvest conditions, the part of the plant used and processing techniques (Wińska K. et al., 2019). High-purity EOs with consistent chemical profiles tend to be more effective, whereas variability in composition can result in inconsistent antioxidant, antimicrobial and immune-modulating activities (Bolouri P. et al., 2022; Masyita A. et al., 2022).

Dosage and duration of supplementation. The optimal effects of EOs depend on the concentration and duration of feeding. Low levels may be insufficient to elicit significant biological responses, whereas excessive doses can have cytotoxic effects, act as pro-oxidants, or reduce feed intake due to their strong odours and flavours (Bakkali F. et al., 2008; Janz J. A. et al., 2007). While long-term supplementation can enhance gut health and immune responses, intermittent or strategic administration may be more cost-effective in avoiding the development of tolerance in the gastrointestinal microbiota (Kiarie E. G. and Mills A., 2019; Peng X. et al., 2021).

The pig's genotype, age and diet composition. The efficacy of EOs can be modulated by the host animal's genetic background, developmental stage and nutritional composition of its diet. Different pig breeds or lines may exhibit variable sensitivity to phytogenic compounds, which influences feed intake, nutrient absorption, and metabolic responses (Lebret B. and Čandek-Potokar M., 2022a, b). Similarly, the age of pigs affects gut morphology and microbiota composition, thereby impacting the antimicrobial and digestive-stimulant properties of EOs (Liu Y. et al., 2018). The composition of the diet, including the type of basal feed, fibre content, and presence of other bioactive compounds, can interact with EOs, thereby enhancing or reducing their overall effectiveness (Nhara R. B. et al., 2024).

EOs can interact synergistically or antagonistically with other additives. The presence of multiple feed additives, such as organic acids, probiotics or vitamins, can affect the biological activity of EOs. Synergistic effects can improve antioxidant protection, gut health and meat quality, whereas antagonistic interactions may reduce bioavailability or interfere with microbial modulation (Bassolé I. H. and Juliani H. R., 2012; Siroli L. et al., 2020). Understanding these interactions is crucial for designing dietary strategies that maximise the benefits of EOs while minimising negative effects.

In conclusion, the efficacy of essential oils in enhancing pig nutrition and meat quality is not consistent and depends on a combination of essential oil-related, host-related, and dietary factors. Careful selection of the type of essential oil, standardised extraction procedures, optimal dosing strategies, consideration of the genotype and age of the pig, and evaluation of potential interactions with other feed additives are all essential for achieving consistent, beneficial outcomes in commercial pig production systems.

Potential limitations and safety considerations

EOs are increasingly recognised as multifunctional pig feed additives, with demonstrated effects on growth performance, gut health, immune modulation, mitigation of oxidative stress, and meat quality (Zhai H. et al., 2018; Ruzauskas M. et al., 2020; Luise D. et al., 2023). The bioactive compounds found in EOs, such as monoterpenes, phenolic acids, and aldehydes, contribute to their antioxidant, antimicrobial, and immunomodulatory activities (Su G. et al., 2018; Peng X. et al., 2021). This makes EOs an attractive alternative to synthetic additives (Liu Y. et al., 2018). However, despite these benefits, their practical application in pig diets requires careful consideration of potential limitations. Variability in EO composition, strong sensory characteristics and the risk of toxicity at high inclusion levels can affect both the response of the animals and the quality of the meat (Stevanović Z. D. et al., 2018). Therefore, understanding these limitations is crucial for optimising EOs in pig diets, ensuring safety, and achieving consistent and beneficial results.

Variability in EO composition and standardisation challenges. The chemical composition of EOs can vary depending on plant species, cultivar, harvest time, geographic origin and extraction method (Wińska K. et al., 2019; Masyita A. et al., 2022). This variability makes standardisation challenging and can lead to inconsistent effects on animal performance, gut health and meat quality. Therefore, establishing standardised profiles and quality control measures is essential for reproducible outcomes.

Risk of reduced feed intake due to strong odours or flavours. EOs have intense odours and flavours, which can negatively affect feed palatability at higher inclusion levels. Studies have shown that pigs may reduce their voluntary feed intake when their diets are supplemented with EOs at concentrations that exceed the optimal level, which could limit growth performance and nutrient utilisation (Janz J. A. et al., 2007; Kiarie E. G. and Mills A., 2019). Careful formulation and inclusion strategies are therefore necessary to balance bioactivity and palatability.

Toxicity at high doses. Certain EO components can be cytotoxic when administered at high concentrations. Excessive supplementation may induce oxidative stress, impair digestive or metabolic functions, or cause cellular damage (Bakkali F. et al., 2008). Therefore, adhering to established safe dosage ranges and monitoring animal health is critical when incorporating EOs into pig diets.

In conclusion, while essential oils have the potential to significantly improve pig nutrition and meat quality, their use must be carefully managed. Standardising EO composition and implementing quality control is essential to ensure consistent results. Optimising inclusion levels is key to balancing bioactivity with palatability and avoiding reductions in voluntary feed intake. Furthermore, adhering to safe dosage ranges is essential to prevent cytotoxic effects and maintain animal health. Addressing these considerations enables EOs to serve as effective, natural feed additives that can improve growth performance, gut integrity, immune function and meat quality, thereby supporting the development of sustainable, high-quality pork production.

Future perspectives and research directions. Future research on EOs in pig production should focus on improving their efficacy, safety and practical application in

commercial settings. One key approach is the development of novel delivery systems, such as microencapsulation and nanoemulsions. These systems protect EO compounds from degradation during feed processing, enhance bioavailability and enable controlled release in the gastrointestinal tract (Stevanović Z. D. et al., 2018; Moyo P. et al., 2019; Sousa V. I. et al., 2022). These technologies can also mitigate the strong odours and flavours that can reduce feed palatability at higher inclusion levels.

Combining EOs with probiotics, prebiotics, or digestive enzymes is another promising strategy. Such synergistic approaches can support gut microbiota balance, enhance nutrient absorption, modulate immune responses and ultimately improve growth performance and meat quality (Nhara R. B. et al., 2024; Tariq S. et al., 2019). Investigating these interactions could help to identify the most effective supplementation regimes for optimal animal health and productivity.

Omics-based methods, including genomics, transcriptomics, metabolomics and microbiomics, offer valuable insights into the molecular mechanisms of EO action. These mechanisms include the effects of EOs on gut microbiota, metabolic pathways, oxidative stress and immune function (Frankič T. et al., 2010; Hofmann H. H. et al., 2022). Linking molecular changes to phenotypic outcomes can inform precision nutrition strategies and guide the tailored supplementation of EOs adapted to specific production goals, breeds, or environmental conditions.

Future studies should prioritise long-term feeding trials, dose-response assessments and evaluations under commercial farm conditions, in order to validate laboratory findings. Addressing these aspects will bridge the gap between experimental research and practical application, ensuring that EOs can be safely and effectively incorporated into pig diets to enhance performance, welfare, and meat quality.

Conclusions. Essential oils are increasingly recognised as a promising natural alternative to conventional feed additives in pig farming. They offer potential benefits for gut health, oxidative status, immune function and meat quality. Research has shown that essential oils can modulate lipid oxidation, inhibit the growth of spoilage and pathogenic microorganisms, and influence sensory attributes such as flavour, aroma, colour, tenderness and juiciness. This contributes to improved meat quality and an extended shelf life.

However, the efficacy of EOs depends on a number of factors. These include the chemical composition and bioactive profile of the oil; the dosage and duration of supplementation; host-specific factors, such as age, genetic line and gut microbiota composition; and interactions with other dietary components, including macronutrients, probiotics and prebiotics. Careful consideration of these factors is essential to achieve consistent and reproducible improvements in pig performance, health and product quality.

The practical application of essential oils also requires the consideration of safety and standardisation. Variability in the composition of EOs due to plant species, harvest conditions or extraction methods can affect the consistency and predictability of results. Additionally, the strong aroma and flavour of EOs can reduce the palatability of feed at high inclusion levels, and certain EO constituents can have cytotoxic effects if overdosed. Therefore, optimised formulations, dosing strategies and quality control measures are essential for the safe and effective use of EOs in commercial pig production.

Incorporating EOs into pig diets enables the swine industry to reduce its reliance on synthetic antioxidants and antibiotics, thereby aligning with consumer demand for natural, clean-label products while maintaining or enhancing pork quality. Future research should focus on developing standardised EO formulations and advanced delivery systems, such as microencapsulation or nanoemulsions. Other areas of research should include synergistic combinations with other feed additives and mechanistic studies

employing omics technologies. These efforts will enable the design of optimised, evidence-based essential oil interventions that promote sustainable, safe and high-quality pork production.

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ЗМІСТ

Технології утримання, годівля, селекція тварин та переробка продукції тваринництва

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Авторські дані	Не більше 5-ти авторів. Ім’я та прізвище (повністю), науковий ступінь, звання, код ORCID, e-mail. (Якщо автор не зареєстрований в ORCID, потрібно створити обліковий запис за посиланням http://orcid.org.).
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	В анотації лаконічно та інформативно описуються дані щодо місця проведення дослідження, основні результати та їх практична цінність, НЕ вказується мета та методи роботи. Не можна в анотацію копіювати речення та абзаци з розділів статті.
Ключові слова	Курсивом, 12 pt, 5-7 слів або словосполучень.
Вступ	Виключка по ширині, 12 pt 1-2 стор. У розділі висвітлюється сучасний стан розглянутої проблеми, наукова новизна роботи, аналізуються дослідження та публікації за останні 5 років, обґрунтовується актуальність, напівжирним виділяється **мета дослідження.** В кожному посиланні коротко розкрити суть та результати досліджень автора (-ів), які цитуються. Посилання на літературу необхідно подавати у круглих дужках (…), наприклад: (Ivanov A. V., 2023; Zlobin S. E. et al., 2022a). Якщо потрібно зазначити посилання всередині рядка, варто вказувати тільки рік у (), наприклад: Тимошин М. (2023) у своїй роботі ....". В одному посиланні не варто цитувати більше 3-ох джерел.
Матеріали та методи досліджень	Зазначається об’єкт дослідження та експериментальна база. Викладена методологія повинна дати можливість повністю відтворити Ваші дослідження.
Результати досліджень	Розділ експериментальної статті повинен складати не менше 70 % від обсягу статті (не враховуючи анотацій та бібліографії) з повним обґрунтуванням отриманих наукових результатів. Таблиці, рисунки та формули повинні бути пронумеровані та подані після посилання на них у тексті. Слово “*Таблиця* __” писати справа курсивом з номером арабськими цифрами. **Заголовок таблиці** – напівжирним, виключка по центру. Посилання на таблицю у тексті вказують скорочено перед розміщенням таблиці. Примітки до таблиці – курсивом, шрифт 10 pt, без абзацного відступу. Формули – створювати у редакторі формул, виключка по центру. За наявності у тексті посилання на формулу, її нумерують арабською цифрою у круглих дужках з правого краю в межах форматування сторінки. Заголовок рисунка (Приклад: *Рис. 1.* **Назва**.) – напівжирним, виключка по ширині, без абзацного відступу. На кожен рисунок потрібно робити в тексті посилання – (рис. __). Умовні позначення та підписи на рисунку – шрифт 10 pt.

Обговорення	У цьому розділі необхідно зіставити результати власних досліджень з результатами робіт інших авторів, яких цитували у вступній частині, що найбільш близькі до теми дослідження.
Висновки	Рекомендується наводити пронумеровані висновки.
Подяки	Розділ не є обов'язковим, у ньому висловлюється подяка організаціям за посильну технічну допомогу; ідеї; фінансову підтримку, завдяки якому дослідження стало можливим.
Бібліографічний список	Джерела розташовувати в алфавітному порядку, без нумерації. В експериментальній статті повинно бути не менше 20 джерел, в оглядовій – не менше 40, переважно з наукових видань, які індексуються в наукометричних базах Scopus та Web of Science за останні 5 років, 90% джерел повинні мати DOI або електронні посилання. Не можна посилатись на ненаукову літературу (національні стандарти, технічні умови, конспекти лекцій тощо). За потреби посилань на патенти, стандарти, технічну документацію, їх робити як зноски внизу сторінки, але НЕ включати в список літератури. Слід уникати посилань на свої роботи - не більше 10 %. Вказуються прізвище та ініціали всіх (!) авторів. Ініціали пишуться після прізвища. Список літератури оформлюється лише латиницею. Англомовні посилання оформлюються згідно з зарубіжними бібліографічними стандартами, стиль APA https://apastyle.apa.org/ Елементи списку українською та російською мовою потрібно транслітерувати. Для транслітерації з української мови використовується Паспортний (КМУ 2010), а з російської – стандарт: BGN. Слід уникати посилань на літературу країни-агресора.

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