



Influences of Genetic, Feed, and Technological Factors on the Productivity and Reproductive Capacity in Farm Animals

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ABSTRACT

Productive and reproductive performance in farm animals is shaped by the combined effects of genetic potential, nutritional conditions, and technological management, although the relative importance of these factors differs among species. The present study aimed to identify the main genetic, nutritional, and technological factors influencing the productive and reproductive performance of farm animals and to assess their relative contributions and interactions. A 12-month controlled comparative study included 480 clinically healthy animals, including 120 cattle, 160 pigs, and 200 laying hens of the selected breeds. Within each species and breed, eligible animals were grouped according to age, sex, physiological status, and body condition score. Animals with similar values for these variables were then matched and non-randomly allocated to control and experimental groups to minimize pre-intervention differences between the groups. In cattle, the assessed parameters included milk yield, milk fat and protein content, liveweight gain, pregnancy rate after first insemination, calf birth weight, and calf survival to weaning. In pigs, average daily gain, slaughter yield, intramuscular fat content, litter size, piglet birth weight, and pre-weaning survival were evaluated. In laying hens, egg production, egg weight, the proportion of eggs with shell or shape defects, hatchability, and chick survival were assessed. Measurements were obtained from July 2024 to June 2025 from production records, electronic weighing, infrared milk analysis, ultrasonography, Soxhlet extraction, and automated egg analysis. In cattle, genetic factors, particularly breed and breeding improvement, had the greatest influence in increasing milk yield by 5.8-9.3% and milk protein content by 0.08-0.12 percentage points. In pigs, nutritional factors made the greatest contribution, including optimization of the dietary protein-to-energy ratio, which increased average daily gain by 7.0%, litter size by 4.5%, and intramuscular fat content by 16.7%. In laying hens, combined nutritional and genetic factors increased egg production by 3.9-6.0% and reduced the proportion of non-standard eggs by 31.1%. Technological optimization of microclimate, stocking density, reproductive management, and stress reduction stabilized performance and increased piglet survival by 1.5-2.8%. The findings support species-specific integration of breeding, nutritional, and management strategies.

Keywords: Breeding, Microclimatic condition, Optimization of feeding, Product quality, Reproduction indicator

INTRODUCTION

Improving the productive and reproductive efficiency of farm animals is essential for maintaining the economic sustainability of livestock production and meeting the growing demand for animal-derived food products. These outcomes are determined by the combined effects of genetic potential, nutritional management, and production technologies, yet the relative contribution and interaction of these factors remain insufficiently understood across different animal species (Tsvihun et al., 2025). The intensification of livestock production requires the integrated application of selective breeding, nutritionally balanced feeding strategies, advanced housing and management technologies, and biotechnological methods. Rising demand for livestock products coincides with increasing pressure on natural and economic resources, while climate-related changes further undermine the stability of production systems (Szöllösi et al., 2021; Nurgaliyev et al., 2024).

Kramarenko et al. (2023) examined the factors associated with an increased risk of stillbirth in Ukrainian Meat breed sows. Their findings demonstrated that deviations from recommended indoor microclimatic parameters and non-compliance with prescribed housing and management practices were associated with higher reproductive losses. They noted that optimizing temperature, humidity, and ventilation in sow housing is a key measure for reducing reproductive losses during and immediately after farrowing. Kramarenko et al. (2025) examined the effect of lactation duration on dairy animal productivity and found that even minor deviations from the optimal lactation period were associated with fluctuations in annual milk yield and, consequently, production profitability. The authors substantiated the feasibility of systematic monitoring and planning of lactation duration as a factor in improving the overall efficiency of the herd.

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Dayoub et al. (2024) reviewed the application of smart agriculture technologies in animal husbandry, including sensor-based monitoring systems, automated feeding equipment, environmental control technologies, and artificial intelligence tools for data analysis and management decision-making. It was noted that sensor-based animal monitoring, automated feeding systems, and artificial intelligence combined with data analytics can improve the accuracy of management decisions and reduce farm operating costs associated with labour, feeding, routine monitoring, and resource use (Sychoy et al., 2024). A complex of agronomic and breeding methods for increasing the nutritional value of forage crops is considered in the study of Chand et al. (2022). The authors emphasized that improving the protein and mineral balance of feed was associated with higher animal productivity and better physiological condition. Mueller and Van Eenennaam (2022) examined the combined use of genomic selection, assisted reproductive technologies, and gene editing to accelerate genetic improvement in cattle. According to the authors, combining these methods can speed up genetic improvement in cattle and help breeders introduce desirable productive and adaptive traits more quickly. A review by Akintan et al. (2024) highlighted the latest approaches to the development of diets that combine environmental sustainability and high nutritional value. Innovative technologies for processing and selecting feed ingredients can improve nutrient digestibility, optimize the balance of protein, energy, and minerals, and reduce feed losses (Nurgul et al., 2025). As a result, animals use nutrients more efficiently, productivity increases, and the environmental burden of livestock production is reduced through lower feed consumption, nutrient excretion, and waste generation.

Menchaca (2021) reviewed the prospects of gene editing in cattle, pigs, sheep, and goats, particularly its potential to improve productivity and product quality, increase resistance to infectious diseases and environmental stress, and enhance animal welfare by reducing the need for invasive husbandry procedures. Gene editing is regarded as an important component of future strategies for strengthening food security. Melak et al. (2024) analyzed the use of machine-learning and computer-vision systems, sensor-based monitoring tools, robots, and drones for managing animal health, behavior, feeding, and welfare on livestock farms. Automated forecasting and monitoring systems enable farm managers to detect changes in animal health, behavior, and feeding patterns at an early stage, allowing timely intervention before these changes lead to reduced productivity. Davis and White (2020) showed that improving reproductive efficiency in cattle can reduce the number of breeding cows required to produce a given quantity of beef, thereby lowering resource use and environmental costs, while reproductive technologies can accelerate genetic improvement in fertility, productivity, and adaptation. The integration of selective breeding, reproductive biotechnologies, and effective reproductive management can improve fertility, accelerate genetic progress, and increase both the quantity and quality of livestock products. Taken together, these studies indicate that the current study increasingly supports the integration of genetic improvement, reproductive biotechnologies, precision feeding, and advanced management systems to enhance animal productivity and reproductive performance while maintaining animal welfare and production efficiency.

Under these conditions, there was a need for a systematic study of the factors that determine the level of productivity and reproductive capacity of different types of farm animals and to establish relationships between them to optimize production parameters. The study novelty lies in the comparative cross-species evaluation of these factors within a single analytical framework, which allowed the leading factor and the most effective combinations to be identified for each animal species. Therefore, the present study aimed to assess the effects of genetic, nutritional, and technological factors on the productive and reproductive performance of cattle, pigs, and laying hens.

MATERIALS AND METHODS

Ethical approval

All experimental procedures were performed in accordance with Directive 2010/63/EU of the European Parliament and of the Council on the protection of animals used for scientific purposes (European Parliament and Council of the European Union, 2010).

Study location and timing

The 12-month study was conducted from July 2024 to June 2025 under commercial production conditions at the Agro-Oven (2025) agricultural enterprise in Mahdalynivka, Dnipropetrovsk Oblast, Ukraine, which operated cattle, pig, and poultry production units (Figure 1).

Study design

A prospective, non-randomized controlled field study was conducted at a single agricultural enterprise selected purposively because it maintained cattle, pigs, and laying hens under commercial production conditions, thereby allowing genetic, nutritional, and technological factors to be assessed within the same production setting. Animals were

recruited from the available farm population using purposive non-probability sampling. Only clinically healthy animals that met the predefined criteria for breed, age, sex, physiological status, and body condition were eligible for inclusion.

The sample size was determined pragmatically by the number of eligible animals available during the study period and the need to obtain equal representation of the selected breeds within each animal category (Lakens, 2022). The final sample comprised 480 animals, including 120 cattle, including 30 Holstein, 30 Ukrainian Black-and-White Dairy, 30 Aberdeen Angus, and 30 Limousine cattle; 160 pigs, including 80 Large White and 80 Landrace pigs; and 200 laying hens, including 100 Hy-Line Brown and 100 Leghorn hens.

The breeds were selected because they were available at the study enterprise, represented distinct dairy, beef, pig, and egg-production types, and had established commercial relevance. Holstein and Ukrainian Black-and-White Dairy cattle are widely represented in high-producing Ukrainian dairy herds, while Hy-Line Brown hens are characterized by high egg production under commercial production systems.



Figure 1. Location of the Agro-Oven agricultural enterprise in Mahdalynivka, Dnipropetrovsk Oblast, Ukraine. Source: Agro-Oven (2025).

Animals and grouping

For cattle and pigs, four groups were formed for each species, including one control group and three experimental groups differing in the genetic, nutritional, or technological factor under evaluation. For laying hens, three groups were formed, including one control group and two experimental groups. Thus, the study comprised 11 groups in total, with animals within each species matched for age, sex, breed, physiological status, and body condition. Animals were eligible for inclusion if they were clinically healthy, belonged to the selected breed and predefined age, sex, and physiological categories, and had a body condition score of 3.0-3.5 on a 5-point scale.

Animals were excluded if, at the time of screening, they had acute or chronic disorders capable of affecting productive or reproductive performance, or if they had received antibiotic treatment within the 30 days preceding enrolment. The experimental conditions were organized according to three categories of factors. Genetic factors included breed and membership in breeding-improved lines; nutritional factors included the dietary protein-to-energy ratio, feeding frequency, and feed supplementation; and technological factors included microclimatic conditions, stocking density, reproductive procedures, and exposure to transport, noise, or heat stress. Animals in the control groups were fed twice daily at fixed times according to the standard feeding schedule used at the farm. The control groups were maintained under the farm's standard housing conditions, with an ambient temperature of 22-24°C and relative humidity of 60-65%. Stocking density was set at 10 cattle per 10 m², 8 pigs per 10 m², and 6 laying hens per 1 m². In the nutritional experimental groups, the diets were adjusted according to animal species; the feed for laying hens contained 16.5% crude protein, and animals were fed three times daily, compared with twice-daily feeding in the control groups. In the technological experimental groups, stocking density and microclimatic conditions were adjusted to a temperature of

18-20°C and relative humidity of 55-60%, while ventilation for pigs was maintained at 0.2 m³/h per animal. For each animal species, the study included a control group maintained under the farm's standard production conditions and separate experimental groups in which one predefined nutritional or technological factor, such as the protein-to-energy ratio, feeding frequency, or stocking density, was modified.

The allocation of animals to the control and experimental groups is described below. Productive and reproductive outcomes were compared between the control group and each experimental group. Three control-versus-treatment comparisons were conducted for cattle and pigs, covering genetic improvement, nutritional optimization, and technological management, whereas two comparisons were conducted for laying hens, covering nutritional and technological interventions. For each animal species, productive and reproductive outcomes were compared between a control group and experimental groups exposed to predefined genetic, nutritional, or technological conditions. The control groups were maintained according to the farm's standard production protocol, which included twice-daily feeding; an ambient temperature of 22-24°C; relative humidity of 60-65%; standard stocking densities of 10 cattle per 10 m², 8 pigs per 10 m², and 6 laying hens per 1 m²; and conventional reproductive management. The experimental groups differed from the control group in one principal factor, including breeding improvement, optimization of the diet and feeding frequency, or modification of microclimatic, stocking-density, and reproductive-management conditions. The exact number of animals allocated to each control and experimental group is presented in Tables 1-4.

Control and breeding-improved groups

The control group comprised animals from standard farm lines that had not been included in targeted selection programmed based on pedigree and productivity records. These animals were maintained under the farm's conventional feeding, housing, and reproductive-management conditions. The breeding-improved group included animals from lines selected over several generations for superior productive and reproductive traits, including milk yield in dairy cattle, live-weight gain in pigs, and egg production in laying hens. Animals in the breeding-improved group belonged to high-performing lines selected on the basis of productive and reproductive records. Optimized diets with a balanced protein-to-energy ratio were provided to the nutritional experimental groups and were evaluated separately from the effect of genetic selection. Female cattle and sows in the breeding-improved groups were artificially inseminated using commercial semen doses obtained from breeding males selected on the basis of documented pedigree, performance records, and estimated breeding values provided by the semen supplier.

Experimental factors and conditions

The influence of three groups of factors was studied, including genetic factors, nutritional factors, and technological factors related to animal housing and management. Two main breeds of cattle were selected for genetic factors, including Holstein and Ukrainian Black-and-white Dairy, meat pigs (Large White and Landrace), and egg-laying hens (Hy-Line Brown and Leghorn). Breeding-improved groups were selected from within each breed based on documented participation in productivity improvement programmed conducted during the preceding 5-7 years. The selection of breeding-improved groups within each breed was based on official breeding records and documented productivity data collected over several generations. Breeding improvement was assessed in terms of milk yield, weight gain in pigs, and egg production in hens. For feed factors, rations were formed in accordance with farm standards and the protein-energy ratio was optimized. For example, for cattle, the diet contained 16% protein per digestible protein and 14.0 MJ/kg of metabolic energy. For pigs and hens, the feed contained 20% protein and 15.0 MJ/kg of energy for pigs, 16.5% protein and 12.0 MJ/kg of energy for hens, respectively (Table 1).

For the technological experimental groups of cattle, pigs, and laying hens, the housing microclimate was maintained at 18-20°C and 55-60% relative humidity, with air velocity not exceeding 0.2 m/s. In the control groups, conditions were standard for the farm, with a temperature of 22-24°C and humidity of 60-65%. For insemination, high-quality sperm from the manufacturer Genus Public Limited Company (GPLC; United Kingdom) was used, which provided a high concentration of spermatozoa. Stress factors included four-hour transportation of cattle and pigs, continuous elevated environmental noise in the pig housing facility, and exposure of laying hens to ambient temperatures above 30°C. Noise exposure was assessed in the pig technological group. Sound pressure levels were measured in dB(A) using a calibrated integrating sound-level meter conforming to IEC 61672-1, with measurements taken at approximately animal-head height at several locations within the housing area. The equivalent continuous A-weighted sound level, LAeq, was recorded during the six-hour observation period. Noise exposure was defined as a continuous sound level of approximately 85 dB(A), whereas the control group remained under the ordinary background-noise conditions of the facility. The selected threshold was based on Council Directive 2008/120/EC (European Union, 2008), according to which continuous noise levels of 85 dB(A) or higher and constant or sudden noise should be avoided in pig housing. Animal responses were evaluated through serum cortisol concentrations and behavioral indicators before and after

exposure.

Table 1. Dietary composition, and feeding management in the control and experimental farm animals

Animal species	Group	Crude protein content	Metabolizable energy	Main feed additives	Feeding frequency	Feeding equipment
Cattle	Control	Farm-standard level (National Academies of Sciences, Engineering, and Medicine, 2021)	Farm-standard level (National Academies of Sciences, Engineering, and Medicine, 2021)	Standard mineral and vitamin supplementation used at the farm (National Academies of Sciences, Engineering, and Medicine, 2021)	Twice daily	Trioliet Solomix feed dispenser
Cattle	Experimental nutritional group	16.0%	14.0 MJ/kg	Calcium phosphate, copper, zinc, and selenium, mineral and vitamin permix	Three times daily	Trioliet Solomix feed dispenser
Pigs	Control	Reduced or farm-standard protein level (National Academies of Sciences, Engineering, and Medicine, 2021)	Farm-standard level (National Academies of Sciences, Engineering, and Medicine, 2021)	Standard supplementation used at the farm (National Academies of Sciences, Engineering, and Medicine, 2021)	Twice daily	Big Dutchman automated feeder
Pigs	Experimental nutritional group	20.0%	15.0 MJ/kg	Lysine 98% manufactured by Adisseo, methionine, calcium phosphate, copper, zinc, and selenium	Three times daily	Big Dutchman automated feeder
Laying hens	Control	14.0%	Farm-standard level (National Academies of Sciences, Engineering, and Medicine, 2021)	Standard vitamin and mineral supplementation used at the farm (National Academies of Sciences, Engineering, and Medicine, 2021)	Twice daily	Big Dutchman automated feeder
Laying hens	Experimental nutritional group	16.5%	12.0 MJ/kg	Poultry Boost TM manufactured by DSM company, methionine, calcium phosphate, copper, zinc, and selenium, vitamins A, D, and E	Three times daily at fixed intervals	Big Dutchman automated feeder

All feed additives were administered according to the manufacturers' recommendations. The control diets followed the farm's standard feeding practices, whereas the experimental diets were formulated by optimizing the protein-to-energy ratio, supplementation, and feeding frequency. The manuscript does not provide the proportions of individual feed ingredients; therefore, the table presents the available nutrient specifications and feeding conditions rather than a complete ingredient formulation.

Productivity and reproductive outcome measures

Milk yield was recorded from individual production records, while milk fat and protein contents were determined using a MilkoScan FT 120 infrared analyzer. Pregnancy rate after first insemination was confirmed by ultrasonography on day 30, calf birth weight was measured using electronic scales, and survival to weaning was determined from individual farm records in accordance with ICAR guidelines. Pregnancy after first insemination was diagnosed by transrectal ultrasonography on day 30 and reconfirmed on day 60 by repeat ultrasonography or rectal palpation. Milk yield and milk composition were recorded monthly throughout the 12-month study, whereas pregnancy status, calf birth weight, and survival to weaning were assessed at the relevant physiological stages. Average daily weight gain, slaughter yield, multiparity, and offspring survival were determined in pigs. Average daily increments were measured monthly using electronic scales. At the end of the study, slaughter yield was calculated from preslaughter live weight and carcass weight, while intramuscular fat content was determined using Soxhlet extraction (Melak et al., 2024). Extraction was performed with n-hexane at 70°C for 4 hours. The measurements were performed at the end of 12 months of the study. Multiparity was determined at the time of farrowing, and offspring survival was determined before weaning. Egg production was measured monthly by counting the number of eggs per laying hen for 30 days. Egg weight was

determined using an EggAnalyzer™ automatic analyser (Orka Food Technology, Israel). Egg hatching was evaluated on day 21 of incubation by counting the number of hatched chicks compared to the number of incubated eggs.

Measurement equipment

Milk fat and protein contents were determined using a MilkoScan FT 120 infrared analyser (FOSS, Denmark). Cattle and pigs were weighed using an AXIS BDU1500 electronic scale (AXIS, Poland). Microclimate parameters were monitored using Testo 635-2 thermohygrometers and Testo 416 anemometers (Testo, Germany). Egg quality was determined by an automatic EggAnalyzer™ analyser (Orka Food Technology, Israel). Trioliet Solomix feed mixers (Trioliet, the Netherlands) were used to mix and distribute cattle rations, while Big Dutchman automatic feeders (Big Dutchman, Germany) were used to dispense feed to pigs and laying hens. The proportion of eggs with visible shell defects, cracks, or abnormal shape was determined by visual inspection in accordance with the [State Consumer Standard of Ukraine \(2008\)](#).

Statistical analysis

Statistical analyses were performed using Statistica 10.0 (StatSoft, USA) and IBM SPSS Statistics 25 (IBM, USA). The student's t-criterion was used to compare the two groups, and the univariate or multivariate analysis of variance (ANOVA) was used for three or more groups. For a multivariate ANOVA, interactions between major factors such as genetics × feed, genetics × technology, feed × technology, and between all three factors (genetics × feed × technology) were analyzed. This allowed identification of the influence of each factor separately, in addition to their combined interaction on the productivity and reproductive indicators of animals. For qualitative indicators, the chi-square (χ^2) test was used. The statistical significance level was taken as $p < 0.05$, and the confidence intervals were calculated with $\alpha=0.05$. Quantitative data were presented as mean ± standard deviation (SD), together with absolute and percentage changes between groups.

RESULTS AND DISCUSSION

The analysis revealed statistically significant differences in productive performance among cattle, pigs, and laying hens according to breed and breeding-improvement status ($p < 0.05$). In cattle, breeding improvement increased milk yield from 5,800 to 8,200 kg per cow per year and milk protein content from 3.1% to 3.5% ($p < 0.05$). In meat cattle, average daily weight gain increased from 1.05 to 1.25 kg/day ($p < 0.05$). In pigs, breeding improvement increased average daily liveweight gain from 730 to 820 g and multiparity from 10.8 to 12.5 piglets per farrowing ($p < 0.05$). In laying hens, breeding improvement increased annual egg production from 305 to 314 eggs per hen and egg weight from 60.5 to 61.4 g ($p < 0.05$). The findings were consistent with [Yang et al. \(2023\)](#), who identified significant genetic associations among key reproductive traits in pigs.

Reproductive performance differed according to genotype, including pregnancy rate and calf survival in cattle, litter size and piglet survival in pigs, and hatchability and chick survival in laying hens. The average birth weight of calves ranged from 34.5 to 38.0 kg ($p < 0.05$), and the survival rate of young animals before weaning was 96-98% ($p < 0.05$). The findings were consistent with [Carvalho et al. \(2023\)](#), who reported genetic associations between semen-quality traits and reproductive performance in cows. The results similarly demonstrated an association between reproductive traits and productive performance in cattle.

Large White and Landrace sows had litter size ranging from 10.8 to 12.5 piglets per farrowing, with the difference between genotypes reaching 15.7% ($p < 0.01$). The survival rate of newborn piglets ranged from 88% to 94% ($p < 0.05$), while their average birth weight ranged from 1.25 to 1.40 kg ($p < 0.05$). These findings were consistent with [Alam et al. \(2021\)](#), who reported breed-related variation in productive and reproductive traits in pigs. In the present study, Large White and Landrace pigs differed significantly in litter size ($p < 0.01$), piglet survival, and birth weight ($p < 0.05$).

In Hy-Line Brown and Leghorn hens, egg hatchability ranged from 80% to 86% and differed significantly between the two breeds ($p < 0.05$). Chick survival to 8 weeks of age ranged from 94% to 97%, with a significant difference between the breeds ($p < 0.05$). The duration of the productive period ranged from 68 to 74 weeks ($p < 0.05$). These differences in egg hatchability and chick survival support the conclusion of [Chebo et al. \(2022\)](#) that targeted breeding strategies can improve reproductive performance in laying hens. Consistent with [Chebo et al. \(2022\)](#), the results indicated that systematic selection and performance evaluation improved reproductive traits, particularly egg hatchability and chick survival. Epigenetic mechanisms were not examined in the present study; therefore, the observed differences in reproductive performance cannot be attributed to DNA methylation or histone modifications. Their potential role should be investigated in future molecular studies, as suggested by [Wang and Ibeagha-Awemu \(2021\)](#).

Across cattle, pigs, and laying hens, breeding-improved groups showed significantly better productive and reproductive performance than the corresponding control groups ($p < 0.05$). In dairy cattle, breeding improvement increased milk yield from 5,800 to 8,200 kg per cow per year, representing an increase of 2,400 kg ($p < 0.05$), while milk protein content increased from 3.1% to 3.5% ($p < 0.05$). In meat cattle, average daily weight gain increased from 1.05 to 1.25 kg/day in the breeding-improved groups ($p < 0.05$). In pigs, breeding improvement increased average daily liveweight gain from 730 to 820 g, multiparity from 10.8 to 12.5 piglets per farrowing, and survival rate of young animals from 88% to 94% ($p < 0.05$). In laying hens, breeding improvement increased annual egg production from 305 to 314 eggs per hen, egg weight from 60.5 to 61.4 g, and output from 83.2% to 85.3% ($p < 0.05$). These results were consistent with [Djermanovic et al. \(2021\)](#), who emphasised the importance of genetic factors and breeding strategies in improving reproductive performance. The effects of breeding improvement and their statistical significance are summarised in Table 2.

Table 2. Effects of breeding improvement on productive and reproductive performance of farm animals

Animal species	Breed	Parameters (units)	Control	Breeding-improved group	p-value
Cattle	Dairy	Milk yield (kg/year)	5800 ± 65.6	8200 ± 85.4	$p < 0.05$
Cattle	Dairy	Protein content in milk (%)	3.1 ± 0.05	3.5 ± 0.04	$p < 0.05$
Cattle	Meat	Weight gain (kg/day)	1.05 ± 0.02	1.25 ± 0.03	$p < 0.05$
Pigs	Meat	ADLWG (g)	730 ± 10.5	820 ± 12.3	$p < 0.05$
Pigs	Meat	Multiparity (head/farrowing)	10.8 ± 0.3	12.5 ± 0.2	$p < 0.05$
Pigs	Meat	Survival rate of young animals (%)	88 ± 1.2	94 ± 1.1	$p < 0.05$
Hens	Laying hen	Egg production (egg/year)	305 ± 5.3	314 ± 6.1	$p < 0.05$
Hens	Laying hen	Egg weight (g)	60.5 ± 0.3	61.4 ± 0.2	$p < 0.05$
Hens	Laying hen	Output (%)	83.2 ± 1.1	85.3 ± 1.2	$p < 0.05$

ADLWG: Average daily live weight gain, kg: Kilogram, g: Gram, p: Probability value

Breeding improvement significantly enhanced productive and reproductive performance in cattle, pigs, and laying hens ($p < 0.05$). The most pronounced numerical improvements were observed in dairy cattle milk yield and pig reproductive performance, whereas improvements in laying hens were smaller but remained statistically significant.

The dietary protein-to-energy ratio significantly affected both quantitative and qualitative productivity indicators ($p < 0.05$). Dairy cows receiving the optimal ratio of digestible protein to metabolizable energy (1:5.5) produced 8,050 kg of milk annually, compared with 7,460 kg in cows fed the lower-protein diet ($p < 0.05$). The fat content of milk at the optimal protein level was 4.05%, which exceeded the control by 0.12 percentage points ($p < 0.05$). Pigs fed the balanced diet had an average daily weight gain of 840 g, compared with 785 g in pigs receiving the lower-protein diet ($p < 0.01$). Intramuscular fat content was 2.8% in pigs receiving the optimised diet, compared with 2.4% in the control group ($p < 0.05$). In laying hens, a diet containing 16.5% protein increased annual egg production to 318 eggs per hen, compared with 306 eggs in hens receiving 14% protein ($p < 0.05$). These findings support [Cheng et al. \(2022\)](#), who emphasised that balanced diets help maintain livestock productivity under changing climatic conditions. Consistent with [Cheng et al. \(2022\)](#), the present results showed that optimising the dietary protein-to-energy balance improved milk yield, live-weight gain, and product quality. The findings were consistent with [Walmsley et al. \(2016\)](#), who emphasised the importance of adequate protein and energy supply for cattle productivity. In the present study, the balanced diet increased milk yield and improved milk composition, particularly fat and protein contents.

The feeding schedule, including feeding frequency and consistency of feed delivery times, significantly affected productive and reproductive performance. Dairy cows fed three times daily at evenly spaced intervals produced 8,100 kg of milk per year, compared with 7,750 kg in cows fed twice daily ($p < 0.05$). The pregnancy rate after first insemination was 67.4% in cows maintained on a consistent feeding schedule, compared with 63.2% in the control group ($p < 0.05$). In pigs, feeding three times daily increased average daily weight gain by 5.6% and pre-weaning survival by 2.3% compared with feeding twice daily (both $p < 0.05$). In laying hens, consistent feed delivery times reduced egg-weight variability, with the coefficient of variation declining from 4.2% to 2.9%, and increased hatchability from 84.1% to

85.9% (both $p < 0.05$). These findings were consistent with [Muro et al. \(2023\)](#), who showed that feeding frequency and regularity contributed to maintaining optimal body condition and reproductive performance in sows. They also agreed with [Theil et al. \(2023\)](#), who emphasised that modern sow-feeding systems should ensure a regular nutrient supply. Overall, a consistent feeding schedule improved both productive and reproductive performance.

Dietary interventions, including optimisation of the protein-to-energy ratio, adjustment of feeding frequency, and targeted supplementation with feed additives and premixes, significantly improved productive and reproductive indicators across the studied species ([Jonova et al., 2018](#)). Optimisation of the dietary protein-to-energy ratio increased milk yield in dairy cows from 7,460 to 8,050 kg/year and milk protein content from 3.93% to 4.05% ($p < 0.05$). In pigs, a balanced protein-to-energy ratio increased average daily growth from 785 to 840 g ($p < 0.01$) and intramuscular fat content from 2.4% to 2.8% ($p < 0.05$). In laying hens, a diet containing 16.5% protein increased egg production from 306 to 318 eggs/year and egg weight from 60.8 to 62.1 g ($p < 0.05$). Targeted supplementation also improved specific reproductive and quality indicators: a mineral and vitamin complex increased milk protein content in dairy cows from 3.94% to 4.03%, an amino acid premix increased multiparity in pigs from 11.2 to 11.7 piglets per farrowing, and supplementation with vitamins A, D, E, and trace elements reduced the proportion of non-standard eggs from 4.5% to 3.1% ($p < 0.05$). These findings were consistent with [Zhang et al. \(2021\)](#), who reported beneficial effects of biologically active feed components on poultry productivity and health, and with [Du et al. \(2020\)](#), who emphasised the role of balanced nutrition in maintaining reproductive performance in laying hens. The effects of the investigated nutritional factors are summarised in Table 3.

Table 3. Comparative indicators of productivity and reproduction under different feeding conditions of farm animals

Animal species	Feeding conditions	Indicator (units)	Control	Experimental group	P-value
Cattle	Optimal B/E ratio	Milk yield (kg/year)	7,460 ± 85.2	8,050 ± 90.1	$p < 0.05$
Cattle	Optimal B/E ratio	Protein content in milk (%)	3.93 ± 0.03	4.05 ± 0.02	$p < 0.05$
Pigs	Optimal B/E ratio	Average daily growth (g)	785 ± 10.5	840 ± 12.2	$p < 0.01$
Pigs	Optimal B/E ratio	Intramuscular fat content (%)	2.4 ± 0.1	2.8 ± 0.2	$p < 0.05$
Hens	Optimal protein 16.5%	Egg production (egg/year)	306 ± 5.6	318 ± 6.2	$p < 0.05$
Hens	Optimal protein 16.5%	Egg weight (g)	60.8 ± 0.3	62.1 ± 0.2	$p < 0.05$
Cattle	3-time feeding	Percentage of fertilization (%)	63.2 ± 1.0	67.4 ± 1.2	$p < 0.05$
Pigs	3-time feeding	Piglet survival rate (%)	90.1 ± 1.3	92.2 ± 1.1	$p < 0.05$
Hens	Stable feeding time	Output (%)	84.1 ± 0.8	85.9 ± 0.7	$p < 0.05$
Cattle	Mineral and vitamin complex	Protein content in milk (%)	3.94 ± 0.02	4.03 ± 0.02	$p < 0.05$
Pigs	Premix with amino acids	Multiparity (head/farrowing)	11.2 ± 0.3	11.7 ± 0.4	$p < 0.05$
Hens	Vitamins A, D, E + trace elements	Percentage of non-standard eggs (%)	4.5 ± 0.2	3.1 ± 0.2	$p < 0.05$

SD: Standard deviation, B/E ratio: Protein-to-energy ratio, kg: Kilogram, g: Gram, p: Probability value.

Optimizing the dietary protein-to-energy ratio, maintaining consistent feeding schedules, and applying targeted feed supplementation significantly improved productive and reproductive indicators across cattle, pigs, and laying hens ($p < 0.05$). The observed effects varied depending on the animal species and the nutritional intervention applied, with improvements detected in growth performance, product quality, reproductive indicators, and egg quality parameters.

Microclimatic conditions and stocking density significantly affected productive and reproductive performance across the studied animal species ($p < 0.05$). Dairy cows maintained at 18-20°C and 55-60% relative humidity produced 8,120 kg of milk annually, compared with 7,720 kg in cows exposed to 24-26°C and 75-80% relative humidity ($p < 0.05$). Pregnancy rate after first insemination was 68.1% under the predefined microclimatic conditions and 63.9% under the less favourable conditions ($p < 0.05$). In pigs, a ventilation rate of 0.15-0.20 m³/min per animal and a temperature of 18-20°C increased average daily weight gain to 845 g, which was 6.3% higher than in pigs maintained at a ventilation rate of 0.08-0.10 m³/min per animal and a temperature of 24-25°C ($p < 0.05$). Litter size also increased by 0.4 piglets per litter ($p < 0.05$). In laying hens, a stocking density of 6-7 hens/m² resulted in annual egg production of 320 eggs per hen, compared with 312 eggs at 9-10 hens/m² ($p < 0.05$). Hatchability increased from 83.5% to 85.7% ($p < 0.05$). These findings were consistent with [Raciewicz et al. \(2021\)](#), who emphasised the importance of appropriate housing conditions

for maintaining pig health and productivity, and with [Zhong et al. \(2022\)](#), who reported that improvements in housing and management conditions enhanced productivity in pig production. Overall, the predefined microclimatic conditions and lower stocking density improved productive and reproductive performance in cattle, pigs, and laying hens.

The insemination method significantly affected pregnancy rate and offspring survival. In the experimental group subjected to oestrus synchronisation followed by artificial insemination, the pregnancy rate after first insemination was 69.4%, which was 5.1 percentage points higher than in the control group inseminated without prior synchronisation ($p < 0.05$). In pigs, artificial insemination with diluted semen containing a high sperm concentration increased litter size by 0.5 piglets per litter and pre-weaning piglet survival by 2.0% (both $p < 0.05$). In laying hens, incubation with automatic egg turning increased hatchability by 2.4% and reduced the proportion of weak chicks from 5.8% to 4.1% (both $p < 0.05$). These findings were consistent with [Gordon \(2017\)](#), who reported that oestrus synchronisation and the use of high-quality semen improve pregnancy outcomes and offspring viability. Similarly, the application of these reproductive technologies in the present study enhanced reproductive performance. [Elliott et al. \(2013\)](#) similarly noted that the adoption of reproductive technologies in cattle production depends on whether improvements in pregnancy rate and calf output outweigh the associated costs. The results of this study confirmed the economic feasibility of introducing modern insemination technologies due to the improvement of productive and reproductive indicators.

Exposure to technological stressors affected productive and reproductive performance across the studied animal species. In cattle, transport stress reduced annual milk yield from 8,050 to 7,630 kg per cow ($p < 0.05$). In pigs, exposure to noise stress decreased average daily growth from 820 to 780 g ($p < 0.05$). In laying hens, temperature stress above 30°C reduced annual egg production from 315 to 296 eggs per hen ($p < 0.05$). In contrast, optimisation of technological conditions improved performance indicators: maintaining an optimal microclimate increased milk yield in cattle from 7,720 to 8,120 kg/year and improved fertilisation rate from 63.9% to 68.1% ($p < 0.05$); optimal ventilation increased average daily growth in pigs from 795 to 845 g and multiparity from 11.3 to 11.7 piglets per farrowing ($p < 0.05$); and optimal stocking density increased egg production in laying hens from 312 to 320 eggs/year and output from 83.5% to 85.7% ($p < 0.05$). Reproductive technologies, including cycle synchronisation, concentrated sperm insemination, and automatic egg turning, also improved reproductive indicators ($p < 0.05$). These findings were consistent with [Szöllősi et al. \(2021\)](#), who reported that stress-reducing technologies improved poultry productivity and reduced non-standard product rates. They also supported [Birhanu et al. \(2021\)](#), who emphasised the importance of reducing environmental stress to maintain production efficiency. The effects of the investigated technological factors are summarised in Table 4.

Table 4. Comparative productive and reproductive performance under different technological conditions

Animal species	Technological factor	Indicator (Units)	Control	Experimental group	p-value
Cattle	Optimal microclimate	Milk yield (kg/year)	7,720 ± 85.5	8,120 ± 90.2	$p < 0.05$
Cattle	Optimal microclimate	Percentage of fertilisation (%)	63.9 ± 1.1	68.1 ± 1.2	$p < 0.05$
Pigs	Optimal ventilation	Average daily growth (g)	795 ± 10.4	845 ± 12.5	$p < 0.05$
Pigs	Optimal ventilation	Multiparity (head/farrowin)	11.3 ± 0.3	11.7 ± 0.2	$p < 0.05$
Hens	Optimal density	Egg production (pcs/year)	312 ± 5.1	320 ± 5.3	$p < 0.05$
Hens	Optimal density	Output (%)	83.5 ± 0.9	85.7 ± 1.0	$p < 0.05$
Cattle	Cycle synchronisation	Percentage of fertilisation (%)	64.3 ± 1.0	69.4 ± 1.1	$p < 0.05$
Pigs	Insemination with concentrated sperm	Multiparity (head/farrowing)	11.4 ± 0.2	11.9 ± 0.3	$p < 0.05$
Hens	Automatic egg turning	Output (%)	84.2 ± 0.8	86.2 ± 0.9	$p < 0.05$
Cattle	Transport stress	Milk yield (kg/year)	8,050 ± 87.7	7,630 ± 62.4	$p < 0.05$
Pigs	Noise stress	Average daily growth (g)	820 ± 9.7	780 ± 11.3	$p < 0.05$
Hens	Temperature stress > 30°C	Egg production (egg/year)	315 ± 4.3	296 ± 5.1	$p < 0.05$

SD: Standard deviation, kg: Kilogram, g: Gram, pcs: Pieces, °C: Degrees Celsius, p: Probability value

Technological management practices, including optimisation of microclimatic conditions, ventilation, stocking density, and reproductive technologies, significantly affected productive and reproductive indicators across cattle, pigs, and laying hens ($p < 0.05$). Conversely, exposure to transport, noise, and heat stress was associated with reduced performance parameters, demonstrating the importance of appropriate environmental and management conditions in animal production systems.

Comparison of the three investigated factor groups showed that genetic, nutritional, and housing and management factors significantly affected productive and reproductive performance ($p < 0.05$), although their relative contribution differed among animal species. In dairy cattle, genetic factors, particularly breed and assignment to breeding-improved groups, had the strongest association with milk yield and milk composition. These factors increased milk yield by 5.8–9.3% ($p < 0.05$) and milk protein content by 0.08–0.12 percentage points ($p < 0.01$). Nutritional factors, particularly optimisation of the dietary protein-to-energy ratio, further increased milk yield by 7.9% and improved milk composition, particularly fat and protein contents ($p < 0.05$). Housing and management factors, particularly maintaining the prescribed temperature, relative humidity, and ventilation conditions, stabilised performance and reduced seasonal variation, increasing milk yield by 5.2% and pregnancy rate after first insemination by 6.6% ($p < 0.05$).

In pigs, nutritional factors, particularly a balanced dietary protein-to-energy ratio and adequate amino acid supply, had the strongest effect (Shahini et al., 2023; Balanchuk and Umanets, 2025). A balanced diet increased average daily weight gain by 7.0% ($p < 0.01$), litter size by 4.5% ($p < 0.05$), and intramuscular fat content by 16.7% ($p < 0.05$). Genetic factors, particularly assignment to breeding-improved groups, increased average daily weight gain by 5.1–7.4% ($p < 0.05$) and litter size by 0.4–0.6 piglets per litter ($p < 0.01$). In pigs, technological factors, especially optimal ventilation and temperature control, provided an additional increase in average daily increments of 6.3% ($p < 0.05$) and multiplicity of 3.5% ($p < 0.05$), in addition to reducing the negative impact of stress on reproduction rates. In laying hens, nutritional factors made the largest contribution to improved performance. An optimal dietary protein level increased egg production by 3.9%, while vitamin–mineral supplementation increased it by 3.4% and reduced the proportion of eggs with shell defects, cracks, or abnormal shape by 31.1% (all $p < 0.05$). Genetic improvement increased annual egg production by 6–10 eggs per hen and average egg weight by 0.7–1.1 g ($p < 0.05$). Housing and management factors, particularly appropriate stocking density and consistent feed delivery times, reduced the coefficient of variation in egg weight from 4.2% to 2.9% and increased hatchability by 2.1–2.6% ($p < 0.05$). Overall, genetic factors had the strongest effect in cattle, nutritional factors in pigs, and a combination of nutritional and genetic factors in laying hens. The improvements were achieved when genetic, nutritional, and housing and management factors were applied together rather than separately.

CONCLUSION

The study demonstrated that genetic, nutritional, and housing and management factors significantly influenced productive and reproductive performance, although their relative importance differed among species. In cattle, genetic improvement increased milk yield by 5.8–9.3% and milk protein content by 0.08–0.12 percentage points. In pigs, a balanced protein-to-energy ratio increased average daily weight gain by 7.0% and intramuscular fat content by 16.7%. In laying hens, nutritional optimization increased egg production by 3.9–6.0%, while genetic improvement increased egg weight by 0.7–1.1 g. Maintaining appropriate microclimatic conditions and reducing stress further improved milk yield, pregnancy rate, and piglet survival. Overall, the greatest improvements were achieved through the combined application of genetic, nutritional, and management interventions. The findings support breed-focused improvement in dairy cattle, precisely balanced diets in pigs, and combined genetic selection and vitamin–mineral supplementation in laying hens. The study was limited by its 12-month duration and the relative uniformity of the experimental groups. Further studies should examine long-term and epigenetic effects, develop predictive productivity models, and evaluate the economic feasibility of the proposed interventions.

DECLARATIONS

Authors' contributions

Serhii Luhovyi contributed to the study design, data analysis, and manuscript preparation. Tetiana Pidpala conducted the data collection and interpretation of the results. Halyna Danylchuk contributed to the literature review and methodological framework. Liudmyla Onyshchenko was responsible for editing and final approval of the manuscript. All authors read and approved the final edition of the manuscript.

Availability of data and materials

The authors confirmed that the data supporting the findings of this study are available in the article from corresponding author.

Competing interests

The authors declare no conflict of interest.

Ethical considerations

The authors declared that the manuscript is original, has not been published elsewhere, and confirmed that the article has been checked for plagiarism, misconduct, and fabrication before submission. The authors confirmed that no AI tools were used for writing and preparing the article. All authors accept full responsibility for the originality of the manuscript before submission and before publication.

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