Expression of high productivity in Ayrshire cows under breeding farm conditions in the Northern European region of Russia

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Abstract. This article presents a comparative analysis of dairy cow productivity on two Ayrshire cattle farms in the Republic of Karelia. The study covers a wide range of quantitative and qualitative milk production characteristics, including milk yield, fat and protein content, live weight, and milk biochemical parameters. It was found that, despite similar feeding and milking conditions, the farms had different milk yields and average milk fat content, as well as differences in protein content and total fat and protein yield. Factors influencing productivity were examined, including housing conditions, feeding technology, animal age, and lactation stage. Significant variability was found in key productivity indicators, particularly milk yield and milk fat and protein production. Cow age was shown to have a significant impact on most economically valuable indicators, with the greatest impact on live weight and milk yield. The chemical composition of milk was analyzed in detail. Significant differences in dry matter and fat content were noted between farms. Correlation analysis revealed typical relationships between key productivity indicators. Particular attention was paid to the assessment of heritable traits. Heritability coefficients (h^2) were calculated for various milk components. It was found that the heritability of dry matter, milk fat, and protein varies across farms. The influence of sire genealogical groups on offspring productivity was studied. The obtained results confirm the importance of an integrated approach to dairy herd productivity management, considering both genetic and environmental factors. The results of the study can be used to optimize selection and breeding efforts, improve animal management and feeding practices, and predict changes in the productive qualities of cows depending on age and lactation stage.

1 Introduction

In the Republic of Karelia, located in the northern European part of Russia, the main dairy breed is the Ayrshire. Over the past decades, targeted breeding efforts by a group of researchers and agricultural specialists have resulted in the creation of the "Karelian" type of Ayrshire. It is characterized by high milk yield combined with a balanced composition of

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milk components and is well adapted to industrial technologies in northern climatic conditions. The Karelian-type Ayrshire breed is raised on two breeding farms located in close proximity to each other. Breeding young stock is sold both within the republic and abroad, to other regions of the country. Both farms produce high-quality milk. However, under similar production conditions and similar genetic background of the herds, some paratypic and genetic factors may influence milk productivity and milk composition. Determining the influence of these various factors can lead to increased milk production and improved nutritional value.

The aim of our study was to compare milk production level, milk composition, and the factors influencing them at these two farms.

2 Materials and methods

The research was conducted at the “Ilyinskoye” and “Megrega” farms (Republic of Karelia), which are breeding farms for the Karelian Ayrshire cattle. Cows are housed uniformly, in loose housing, and without access to pasture. Milking is performed in a DeLaval milking parlor. With feed consumption amounting of 8.4–8.8 thousand feed energy units per cow (88–92 thousand megajoules), the share of concentrated feed in the cows’ diet ranges from 50.7 to 58.2% of the total nutritional value.

Using livestock records, we analyzed the productivity data of 3,511 cows of various ages during the completed lactation. The following milk productivity indicators were studied: milk yield over 305 days of lactation (MY, kg), milk fat content (MF, %) and protein content (MP, %), and milk fat (MF, kg) and protein (MP, kg) production. The average live body weight (BW, kg) of the cows was also assessed.

A specialized laboratory analyzed the composition of individual milk samples using laser infrared spectrometry. The following parameters were determined: dry matter (DM, %), dry nonfat milk content (NDM, %), fat content (MF, %), protein content (MP, %), milk lactose (ML, %), milk urea (MU, mg%), and milk freezing point (°C). Daily milk yield (DMY, kg/day) was recorded.

Statistical data processing was performed using Excel software and the Statistica 10.0 statistical package. Mean values of the characteristics (X), standard errors of the means (m), and coefficients of variation (Cv) were calculated. A single-factor analysis was used to determine the magnitude of influence (η^2) of individual factors (farm, age, lactation stage, season, and origin) on cow productivity. Heritability coefficients (h^2) were calculated for milk yield and milk composition parameters. Rank correlation coefficients (r_s) were determined for the parameters, taking into account the cows' origin.

3 Results and Discussion

Cow productivity indicators on the two farms are presented in Table 1. It was found that milk yield on the “Megrega” farm was 512 kg higher than on another farm. In addition to milk quantity, milk quality indicators are important. These include fat and protein content and their production. This farm also demonstrated a 0.04% higher protein content and as well as higher fat and protein yields (14.7 kg and 19.2 kg, respectively, ($P \leq 0.001$). The cows in the herd are larger (average live weight is 23 kg higher). The farm lagged behind only in average milk fat content by 0.08%.

Studies of cattle productivity traits revealed typical variability in key indicators. In particular, milk yield, milk fat, and milk protein production showed significant variability, ranging from 15.5–20.9%, 16.4–19.8%, and 15.1–20.8%, respectively. This indicates a high degree of genetic and environmental variability affecting animal productivity. Milk fat and protein content also exhibit significant variability, ranging from 3.9–6.0% and 3.9–4.4%, respectively. These indicators reflect the genetic characteristics of the animals and their living conditions.

It was noted that at the "Megrega" farm, the variability of most parameters was slightly lower than at the other farm, with the exception of milk fat percentage (MF, %). This may be due to more effective breeding efforts aimed at improving the herd's genetic potential and optimizing animal welfare. Thus, the study results highlight the importance of breeding and environmental management for improving cattle productivity.

Table 1. Milk productivity and live body weight of cows in breeding farms.

Indicators	"Ilyinskoye"		"Megrega"	
	X±m	Cv, %	X±m	Cv, %
Number of cows	1655		1856	
Average age of cows, lactation	2.4		2.6	
MY, kg	7997±41	20.9	8509±31***	15.5
MF, %	4.09±0.004	3.9	4.01±0.01***	6.0
MF, kg	326.1±1.6	19.8	340.8±1.3***	16.4
MP, %	3.21±0.003	4.4	3.25±0.003***	3.4
MP, kg	257.0±1.3	20.8	276.2±1.3***	15.1
BW, kg	536±1	9.3	559±1***	8.9

Note: * P≤0.05, ** P≤0.01, *** P≤0.001

The average age of cows in the herds of these enterprises is 2.4–2.6 lactations. These are relatively low values. However, in the structure of "Ilyinsky" herd, cows in their first lactation accounted for 32.8%, while those in their third or older lactation accounted for 37.5%. In the "Megrega" herd, the figures were 23.0% and 44.5%, respectively. The higher number of mature cows may have contributed to the increase in average milk yield at this enterprise. However, it was found that milk yield per cow here was consistently higher by 518–572 kg, and variability was lower than at the first farm, both in the first and subsequent lactations.

Milk yields of first-calf heifers at "Ilyinskoye" (7,149 kg) were lower than at "Megrega" (7,653 kg), but by the second and third lactations they increase at a similar rate (1,107-1,353 kg). After the third lactation, a decline in productivity is observed – more significant at "Ilyinskoye" (248 kg, P ≤ 0.001) than at Megrega (-49 kg). The fat content of first-calf heifers' milk is 0.14% higher at "Ilyinskoye" (4.11%), but by the third calving it decreases to 4.06%. At "Megrega" the opposite trend is observed – an increase in fat content in milk to 4.09%. As a result, by the fifth lactation, the indicators converge (4.05% and 4.04%). The protein content was initially lower in "Ilyinsky" (3.22%) and remained so in the second lactation, while in "Megrega" it increased to 3.27%, after which it gradually decreased, remaining fairly stable.

The influence of farm factors and cow age on milk yield and composition was assessed. The degree of their influence on productivity indicators was calculated (Table 2).

The greatest impact of farm management was found on cow live weight (6.43%) and milk yield over 305 days of lactation (5.83%), with a weak impact on milk protein content (2.52%) and fat content (0.65%). This impact was highly significant (P≤0.001), but the low values are likely due to similar climatic, technological, and other conditions.

The influence of individual factors on the concentration of milk components in young cows varied. Specifically, the influence of farm management on dry matter (DM) and milk fat (MF, %) content was 4.10% and 7.54%, respectively. Meanwhile, the influence of farm management on milk protein (MP, %) and urea concentration was very weak – only 0.34% and 0.57%, respectively.

Housing and feeding conditions also influence the concentration of milk components. Seasonal changes usually have a significant impact on milk production, primarily due to changes in feeding rations, daylength, and environmental heat stress. Under year-round uniform housing and feeding conditions on these farms, season affected only the concentration of individual milk components. The most significant seasonal influences were on urea content (9.72%) and freezing point (7.01%). Seasonality had a lesser effect on milk fat content (2.84%), dry matter content (2.71%), and, accordingly, on solids-nonfat content (2.32%), lactose content (2.10%), and protein (1.14%). Season had the weakest effect on daily milk yield (0.72%).

Lactation stage is one of the most significant factors influencing the concentration of milk components. In particular, lactation stage had the greatest impact on milk protein (MP) and milk lactose (ML), accounting for 33.63% and 16.80%, respectively. Lactation stage had a lesser effect on fat content and urea concentration – 4.98% and 5.42%, respectively. All results are highly significant (P≤0.001). This is consistent with the findings [1] regarding the influence of lactation stage on milk yield and composition.

These studies demonstrate that different factors affect the concentration of milk components to varying degrees in young cows. In particular, farm management, housing and feeding conditions, and the stage of lactation are important factors that must be considered when analysing milk composition [2,3].

Cow age had a greater impact on economically useful traits during 305 days of lactation, but the trends were similar. Age had the greatest impact on live body weight (20.67%), milk yield (16.32%), and milk fat and protein production (17.94% and 14.26%), while it had a weaker impact on protein and fat content (0.99% and 0.56%).

Table 2. The influence (η^2) of various factors on milk productivity, live body weight and milk composition.

Indicators	Factors	
	farm	age in lactations
MY, kg	0.0583***	0.1632***
MF, %	0.0065***	0.0056***
MF, kg	0.0480***	0.1794***
MP, %	0.0252***	0.0099***
MP, kg	0.0426***	0.1426***
BW, кг	0.0643***	0.2067***
Milk yield and component composition of milk in 3052 individual samples:		
Daily milk yield, kg	0.0008**	0.0665***
Dry matter (DM), %	0.0338***	0.0221***
including in DM: fat, %	0.0468***	0.0014*
nonfat dry milk content (NDM), %	0.0025***	0.0629***
in NDM: protein, %	0.0034***	0.0093***
milk lactose, %	0.0005*	0.0998***
milk urea, mg%	0.0057***	0.0114***
Freezing temperature, °C	0.0083***	0.0132***

* P≤0.05, ** P≤0.01, *** P≤0.001

Analysis of the chemical composition of milk showed that cow age has a greater impact on lactose content (9.98%), daily milk yield (6.65%), and nonfat dry milk content (6.29%), with this factor having a stronger influence than farming conditions. Parameters such as dry matter (2.21%) and fat (0.14%, $P \leq 0.05$) content in milk are less dependent on age and are more dependent on farming factors. Lactose and urea (1.14%) content in milk, as well as the freezing point of milk (1.32%), are more dependent on animal age than on farming conditions.

According to other authors, age affects milk quality [1], with the most significant impact on mass fraction of protein in % and protein yield in kg – 1.4% and 1.3%, respectively [4]. In our study, the effect of cow age on protein production was significantly higher.

The nutritional value of milk is determined by a complex of nutrients. The dry matter content, which includes all the constituent components of milk, is of great importance. The levels of NDM, MF %, MP %, and ML largely determine the organoleptic, energy, and technological properties of milk. When comparing the composition of cows' milk based on individual samples during the first lactation, significant differences were found only in dry matter and fat content (Table 3). The milk fat content at the "Ilyinskoye" farm (4.08%) exceeded the fat content at the "Megrega" farm (3.78%) by 0.3% ($P \leq 0.001$). Furthermore, the dry matter content at this farm was also significantly higher by 0.28%.

In the studied herds, the average urea content in the milk of first-calf heifers was 29.4 mg% and 28.4 mg% ($P \leq 0.001$). The urea content in milk is an indicator of protein metabolism in the body of dairy cows. It can be used to indirectly assess the balance of feeding rations. The physiological norm is considered to be the concentration of urea in milk of 15–30 mg% [5,6]. With a milk yield of 8000 kg or more per lactation, the milk should contain no more than 20 mg% urea. Thus, the average MU value approaches the upper limit of the norm in both enterprises. We assume that this is a general trend for high-yielding cows in industrial milk production conditions and is associated with a high level of concentrated feed in the diet. Some researchers have noted an increase in the proportion of concentrates in large high-yielding herds with industrial production technology [7].

The freezing point value is 0.001°C lower in "Ilyinskoye" (-0.485°C) than in "Megrega" (-0.484°C, $P \leq 0.05$). Freezing point is a stable characteristic of milk, remaining virtually unchanged even when fat or protein content fluctuates, and helps determine its naturalness and quality. The temperature at which milk freezes depends on the content of soluble components, such as lactose and salts, and is independent of the fat content or density of the product. In the Russian Federation, the freezing point of milk sold to processing plants must not exceed minus 0.505°C. In our study, natural milk exhibited a relatively higher freezing point with low variability in individual samples. The secretion of milk with this physical characteristic is likely explained by metabolic changes in cows fed a high-concentrate diet.

Differences in other parameters, such as daily milk yield, protein and lactose content, and dry nonfat matter, were statistically insignificant between farms.

Table 3. Composition of cows' milk in the first lactation.

Indicators	"Ilyinskoye"		"Megrega"	
	X±m	Cv, %	X±m	Cv, %
Number of samples	1304		1754	
DY, kg/day	25.9±0.2	23.0	26.0±0.1	22.3
DM, %	12.64±0.02***	5.5	12.36±0.02	5.4
in DM: fat, %	4.08±0.02***	13.6	3.78±0.01	13.8
NDM, %	8.66±0.01	4.1	8.67±0.01	4.1
in NDM: protein, %	3.28±0.01	8.4	3.26±0.01	7.7
milk lactose, %	4.82±0.01	4.0	4.83±0.004	3.9
milk urea, mg%	29.4±0.1***	16.2	28.4±0.2	21.5
Freezing temperature, °C	-0.485± 0.0003*	2.2	-0.484 ± 0.0003	2.2

Correlation coefficients (r) were determined to assess the relationship between productivity indicators. They had typical values. Thus, the correlation between milk yield and DM, NDM, MF, and MP was negative and ranged from -0.19 to -0.53 depending on the farm and the age of the cows. The correlation of DY with ML is +0.22 – +0.54, with MU +0.15 – +0.21 (all results are highly reliable, $P \leq 0.001$). Changes in correlation coefficients with age have also been noted in other studies [8].

An analysis of the heritability of dairy productivity parameters in cows was conducted. The study included data from individual milk samples of 580 daughters of 16 bulls in "Ilyinskoye" and 814 daughters of 15 bulls in "Megrega". Differences in heritability (h^2) of individual milk components were identifieded and compared between two farms (Table 4). Thus, in "Ilyinskoye", the heritability of DM, MF, MP was 0.208, 0.251 and 0.098, respectively ($P \leq 0.001$). In "Megrega", the heritability of these parameters was significantly lower - 0.036, 0.058, 0.027, respectively ($P \leq 0.001$). The exception is urea concentration, for which heritability was higher than in the 1st fam (0.202 versus 0.109), and the genotype of bulls has the greatest influence on the freezing point of milk of first-calf cows (0.392 versus 0.265, $P \leq 0.001$).

Table 4. Heritability (h^2) of productivity indicators and chemical composition of cows' milk (according to data from the first lactation) in different farms.

Indicators	Farm	
	"Ilyinskoye"	"Megrega"
Number of bulls	16	15
Number of cows	580	814
Number of samples	1276	1718
DY, kg/day	0.145***	0.059***
DM, %	0.208***	0.036***
in DM: fat, %	0.251***	0.058***
NDM, %	0.125***	0.126***
in NDM: protein, %	0.098***	0.027***
milk lactose, %	0.137***	0.101***
milk urea, mg%	0.109***	0.202***
Freezing temperature, °C	0.265***	0.392***

The effectiveness of breeding for individual productivity traits is largely determined by their heritability. Moreover, according to the literature, the heritability coefficient (h^2) can have different values. For example, for milk yield, it is 0.291–0.406 [7, 9]. For milk composition, heritability can vary for DM, NDM, milk fat, and protein in the ranges of 0.41–0.59, 0.17–0.68, 0.24–0.49, and 0.19–0.53, respectively [10, 11]. In some studies, the heritability of most productivity parameters is higher in the first lactation compared to the second and subsequent lactations [11]. In our study, a decrease in the heritability coefficient in the third lactation compared to younger cows was noted for the percentage of fat to 0.041–0.080 and milk lactose to 0.101–0.035. The heritability of MP (%) increased slightly, depending on which farm the assessment was conducted on (h^2 up to 0.132–0.069).

The herd's genealogical structure is represented by Ayrshire bulls from nine lines. These are genetic group B (R. Urho Errant line 13093B), group C (Dick 768C, Frasse NRF 1606C, Sniperum 63640C, O. R. Lichting 120135C, S.B. Commander 174233C), and group D (Juttero Romeo 15710D). One of the farms also breeds animals of the King Errant 12656B line, while another breeds Toosilan Brahma 11489C.

At the "Ilyinskoye" farm, the highest milk yield among first-calf heifers was demonstrated by animals of the 120135C line. At "Megrega", the highest average daily milk yield in the first lactation was recorded by cows of the 11489C line. Second place in milk production at both farms was taken by the daughters of six different bulls belonging to the 768C line. In terms of dry matter (DM) and fat content (FM), the daughters of three bulls of the 15710D line led (ranged from 12.60% to 12.84% and from 4.16% to 4.25%, respectively, depending on the farm). The highest mass fraction of protein (MP, %) was observed in cows of lines 13093B and 174233C in “Ilyinskoye” (3.33%), as well as lines 15710D and 1606C in “Megrega” (3.32–3.30%).

Based on a combination of indicators, lines 13093B and 174233C performed best at the first farm, while line 768C performed worst. At the second farm, on the contrary, first-calf heifers from line 768C performed best, while line 174233C performed worst.

The strength of influence (η^2) of the lines in “Ilyinskoye” is high for milk yield, fat and protein percentage: 10.5%, 9.4%, 3.2% (Table 5). This is probably due to the fact that these are the parameters by which the breeding value of animals is primarily assessed and selection work is carried out. In “Megrega”, the influence of the lines on milk yield, fat and protein content is significantly lower (3.7%, 4.2%, 1.0%). This, in our opinion, indicates the genetic balance of the herd. It is worth noting the high (η^2) value for urea concentration (12.6%), which is likely due to genetic factors, including metabolic factors. The influence of line membership on the freezing point of milk is highly significant and ranges from 4.9–12.9% ($P \leq 0.001$). These differences may be due to the individual characteristics of bulls in the analyzed lines.

According to other authors [12], one of the main factors determining the percentage of protein and its total yield in cows is the influence of the sire, accounting for 7.9% and 19.6%, respectively.

Table 5. The influence (**η^2**) of bull line on the chemical composition of cow's milk (based on the first lactation) in different farms.

Indicators	Farm	
	“Ilyinskoye”	“Megrega”
Number of lines	8	8
Number of samples	1304	1748
DY, kg/day	0.105***	0.037**
DM, %	0.104***	0.016*
in DM: fat, %	0.094***	0.042***
NDM, %	0.055***	0.066***
in NDM: protein, %	0.032**	0.010
milk lactose, %	0.038**	0.062***
milk urea, mg%	0.020*	0.126***
Freezing temperature, °C	0.049**	0.129***

The evaluation of breeding performance in animals during their first lactation is crucial in breeding. Maintaining productivity with age is equally important. The performance of the most common lines varied across farms. Line 15710D demonstrated the highest performance across herds for a range of productivity indicators. Lines 13090B, 768C, and 174233C demonstrated inconsistent breeding performance depending on the farm and the age of the cows. It was established that line 15710D (3rd place), which performed relatively well in both herds during the first lactation, maintained its high rank in the third lactation (1st–3rd place). Line 13093B was the best line in the first lactation in one herd (“Ilyinsky”) and one of the worst in the second. In the third lactation, its results were the worst on both farms. Rank correlation coefficients (r_s) were calculated for the productivity indicators of cows from different lines in the first and third lactations. A high value (r_s=+0.688, $P \leq 0.05$) was obtained only for milk fat at “Megrega”. This confirms the complexity of breeding work in high-producing herds and the need for an individual approach to selecting pairs when planning matings.

The largest number of cows with a milk yield of at least 10 thousand kg of milk were obtained from mothers with the same high milk yield. Thus, in the 2nd lactation, 14.7% of cows in this group were identified, which is significantly higher compared to those obtained from mothers with a milk yield of 7.0–7.9 thousand kg (5.6%, $P \leq 0.05$). According to the results of the 3rd lactation, the number of highly productive daughters in the group of 10 thousand kg or more was higher than in groups with mothers' milk yield of less than 9.0 thousand kg of milk (27.9% versus 6.6–11.8%, P≤0.001).

4 Conclusion

The selection of cows based on their own productivity and selection of bulls to enhance the herd's genetic potential are important components of breeding. The research shows that cow productivity varies between the two farms, even when the same management methods are used for animals of the same breed under identical climatic conditions. The herds differ in milk yield and milk composition, trait variability, and genetic structure. This largely determines the different results obtained when analyzing the influence of various factors and stimulates a highly creative approach to breeding planning.

References

1. S.Washaya, T. Cheruwa, Int. J. Dairy Technol, **78 (3)**: e70050 (2025) doi:10.1111/1471-0307.70050
2. C. Öztürk, Kafkasya Journal of Health Sciences, **2(1)**, 21–27 (2025) doi:10.5281/zenodo.15700957
3. B.H. Schwendel, T.J.Wester, P.C. Morel, M.H. Tavendale, C. Deadman, N.M. Shadbolt, D.E. Otter, J. Dairy Sci. **98(2)**, 721-46 (2015) doi: 10.3168/jds.2014-8389.
4. A. P. Palii, T.L. Osipenko, P.S. Syromiatnikov, Y.A. Boyko, V.V. Nechyporenko, I.V. Levchenko, V.I. Ostapenko, M.F. Prykhodko, O.V. Korzh, V.V. Popsuy, A.P. Paliy, Ukrainian Journal of Ecology **11(1)**, 25-31 (2021) doi:10.15421/2020_304
5. J. W. Spek, J. Dijkstra, G. Van Duinkerken, A. Bannink, J. Agri. Sci. **151**, 407-423 (2013) doi: 10.3168/jds.2012-6265
6. A. S. Shamshidin, Y. Batyrgaliyev, D. Aitmukhanbetov, A. Seitmuratov, J. Anim. Sci. **98 (4)**, 343 (2020) doi: 10.1093/jas/skaa278.608
7. D. Qin, R.Gao, D. Ji, Front. Anim. Sci. **6**:1653052. (2025) doi: 10.3389/fanim.2025.1653052
8. O.V. Gorelik, P.S. Galushina, I.V. Knysh, E. Y. Bobkova, I.A. Grigoryants, IOP Conf. Ser.: Earth Environ. Sci. AGRITECH-IV, **677** (2021) doi: 10.1088/1755-1315/677/3/032013
9. H.Schneider, J. Heise, J. Tetens, G. Thaller, R. Wellmann, J.Bennewitz, J. Anim. Breed. Genet. **140**, 390–399 (2023) doi:10.1111/jbg.12765
10. Fikadu Wodajo Tirfie, Anim. Vet. Sci. **11(3)**, 64-70 (2023) doi: 10.11648/j.avs.20231103.12
11. S. Pangmao, P.C. Thomson, M.S. Khatkar, Anim Biosci. **35(10)**, 1499-1511 (2022) doi: 10.5713/ab.21.0559
12. A.P. Palii, T.L. Osipenko, V.A. Chigiryov, I.Y. Gurko, R.V. Petrov, A.V. Berezovsky, O.A. Khitska, S.V. Furman, D.V. Lisohurska, O.V. Lisohurska, Ukrainian Journal of Ecology, **11(3)**, 353-359 (2021) doi : 10.15421/2021_183