Scientific Papers. Series D. Animal Science. Vol. LXVIII, No. 2, 2025
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

PARTIAL RESULTS REGARDING THE ESTIMATION OF THE GENETIC DETERMINISM OF THE ROMANIAN SPOTTED SIMMENTAL CATTLE FOR PRODUCTION CHARACTERS

Andreea-Raluca MOCLEAȘĂ, Horia GROSU

University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: andreea.mocleasa@icloud.com

Abstract

This study investigates milk production traits in dairy cattle from Harghita County, emphasizing heritability and correlations among milk yield, fat content, and protein content. A dataset of 2,823 cows, including detailed pedigree, production records, and environmental factors, was analyzed to estimate genetic and phenotypic variability. Heritability values for milk yield (0.1), fat yield (0.09), and protein yield (0.102) reveal limited genetic influence, indicating that genetic progress will be gradual, requiring multiple generations for substantial improvement. Strong phenotypic and genotypic correlations between milk yield and its compositional traits were observed, supporting simultaneous trait enhancement through targeted breeding. Environmental correlations were relatively low, underscoring that genetic factors predominantly govern these traits, with minimal shared influence from environmental conditions. This study concludes that integrating selective breeding with superior management practices offers the best strategy for optimizing milk production. The findings align with previous research, reinforcing the importance of genetic selection as a long-term solution for sustainable productivity and enhanced quality in dairy farming systems. These insights contribute to designing effective breeding programs for improving milk yield, fat content, and protein yield in dairy cattle.

***Key words**: genetic correlations, heritability, milk production, phenotypic variability, selective breeding.*

INTRODUCTION

Milk production is one of the cornerstones of modern agriculture, playing a vital role in global food security and the rural economy. Milk and dairy products provide essential nutrients - high-quality proteins, fats, vitamins, and minerals - indispensable for a balanced and healthy diet. At the same time, the livestock and dairy sectors sustain millions of households worldwide, serving as a primary source of income for small and medium-sized farms (FAO, 2023).

As global demand for dairy products continues to grow, driven by population expansion, urbanization, and changing dietary habits, improving the efficiency and sustainability of milk production has become a priority. According to the Food and Agriculture Organization of the United Nations (FAO, 2023), a significant portion of recent research in animal science focuses on identifying methods to maximize productivity without compromising animal welfare or environmental balance.

The performance of dairy cows is influenced by multiple interrelated factors, including genetics, nutrition, environmental conditions, farm management, and animal health (Cosima, 2023; Defta et al., 2023). Among these, genetics plays a central role, as it determines an animal's productive potential. The selection of superior individuals represents the foundation of modern breeding programs (Grosu et al., 2019). However, the full expression of genetic potential is strongly affected by environmental and management conditions - factors such as feed quality, climate, housing, and health status (Schneider & Van Vleck, 1986; Dragotoiu et al., 2015).

A key concept in animal breeding is heritability, which quantifies the proportion of the total variation in a trait that is attributable to genetic differences among individuals. Heritability estimates allow researchers and breeders to predict the efficiency of selection and the expected rate of genetic progress in a population. Reported heritability values for milk yield typically range between 0.2 and 0.4, while those for fat and protein content are often higher, between 0.5 and 0.7, depending on breed and environmental conditions (Nistor et al., 2008; Schneider & Van Vleck, 1986; Soufleri et al., 2019).

In Romania, several studies have examined these parameters. For instance, Nistor et al. (2008) reported heritability estimates of 0.31 for milk yield, 0.68 for milk fat, and 0.73 for protein content in the Romanian Black Spotted breed, confirming the strong genetic basis of milk composition. Other studies carried out in Romanian regions such as Moldova and Transylvania have found similar moderate-to-high heritability estimates for these traits (Roșca et al., 2018; Schneider & Van Vleck, 1986).

Datasets used for such analyses typically include detailed animal information - registration numbers, farm origin, date of birth, annual yield, milk composition, and pedigree data. In addition, environmental and management-related variables such as herd size, feeding system, lactation number, calving interval, season of calving, and housing conditions are often incorporated to account for non-genetic sources of variation (Schneider & Van Vleck, 1986; Roșca et al., 2018). Comprehensive and accurate data collection is essential, as missing or inconsistent pedigree information can bias heritability estimates and reduce the reliability of breeding value predictions.

The application of statistical and mixed-model methodologies**,** particularly the *animal model*, allows researchers to separate genetic effects from environmental influences and to estimate parameters such as additive genetic variance, heritability, and repeatability with high precision. Modern genetic evaluations increasingly rely on Best Linear Unbiased Prediction (BLUP) and Restricted Maximum Likelihood (REML) methods to analyze large and complex datasets (FAO, 2023; Soufleri et al., 2019). These methods make it possible to estimate individual breeding values and predict genetic trends across generations.

Furthermore, with the advancement of molecular technologies, genomic information has become an integral component of contemporary dairy cattle breeding programs. The integration of genomic data - such as single nucleotide polymorphism (SNP) markers - with traditional pedigree-based models improves the accuracy of heritability estimation and breeding value prediction, particularly in young animals that lack phenotypic records (Meuwissen et al., 2020; Powell & Norman, 2006). Such combined approaches, known as *genomic selection*, enable faster genetic progress and more efficient identification of superior sires and dams, contributing to the long-term sustainability and productivity of the dairy sector.

In this context, the present study aims to contribute to the optimization of milk production by analyzing detailed production data from cattle raised in Harghita County, Romania. Specifically, it focuses on evaluating variability in milk, fat, and protein production, and on estimating the heritability of these key traits. The findings are expected to provide valuable insights for improving genetic selection, enhancing farm management efficiency, and supporting the development of sustainable dairy practices adapted to the specific conditions of the Harghita region.

MATERIALS AND METHODS

To investigate the variability and heritability of milk production and its associated traits, data were collected from dairy farms in Harghita County, belonging to the Romanian Spotted Simmental cattle breed. The dataset comprises detailed records of 2,823 cows, providing comprehensive information necessary for a robust statistical analysis. Each record includes essential identifiers and production metrics:

- Animal registration number: a unique identifier for each cow;
- Farm of origin: the location where each cow is raised and managed;
- Date of birth: used to calculate age-related effects on production;
- Date of calving: important for determining lactation periods and production cycles;
- Milk production (kg)**:** the total annual yield of milk per cow.
- Fat production (kg): the total annual yield of milk fat.
- Protein production (kg): the total annual yield of milk protein.
- Pedigree information: including details about each animal's sire (father) such as matriculation certificate number and date of birth.

Descriptive Analysis

A descriptive analysis was conducted to evaluate the central tendency and dispersion of milk, fat, and protein production. Key statistics such as mean, variance, standard deviation, and coefficients of variation were calculated. This step provides an initial understanding of production variability and highlights the range and distribution of each trait.

Calculation of Variances and Covariances

Variance and covariance analyses were performed using standard statistical formulas to quantify variability and relationships among milk, fat, and protein production. Variance measures the degree of variation within each trait, while covariance assesses the extent to which two traits vary together.

Heritability Estimation

Heritability (h^2) was estimated for milk quantity, fat quantity, and protein quantity. The ratio of genetic variance to total phenotypic variance was computed to determine the proportion of trait variation due to genetic differences. Heritability values provide insight into the potential for genetic improvement through selective breeding.

Phenotypic, Genotypic, and Environmental Correlations

Correlations between traits were analyzed at the phenotypic, genotypic, and environmental levels. Phenotypic correlation reflects observable relationships between traits, genotypic correlation indicates genetic associations, and environmental correlation captures shared environmental influences.

The statistical analyses were performed using specialized software tools designed for genetic and phenotypic data analysis, ensuring precise and reliable results (REML Method). By integrating these comprehensive methodologies, this study aims to deliver valuable findings that enhance understanding and guide future improvements in dairy production.

RESULTS AND DISCUSSIONS

Results of population phenotypic characterization

A sample of 2823 cows was analyzed for this study and the following average character performances were observed - 4496.63 kg milk with an error of 27.74, 176.53 kg fat with an error of 1.07, 145.94 kg protein with an error of 0.88. For the error of each analyzed character we can see a relatively small estimate, this suggests that the population mean is estimated with a relatively high precision (Table 1).

Table 1. Results of population phenotypic characterization

Trait kg	N	$\bar{X} \pm s_{\bar{x}}$	S	CV%	L_{min} /L_{max}
Milk quantity	2823	4496.63± 27.74	1.473,95	32.78	763/10.584
Fat quantity	2823	176.53 ± 1.07	56.89	32.26	23/424.5
Protein quantity	2823	145.94 ± 0.88	46.64	31.96	19/351.01

The average values of the analyzed characters, in terms of milk quantity, fat quantity and protein quantity, have as deviation values of 1473.95 for milk, 56.89 for fat and 46.64 for protein.

For the amount of fat and the amount of protein a coefficient of variability of 32% is observed, one unit lower than the coefficient of variability for the amount of milk which is 33%, the range of the coefficient of variability indicating similar and moderate variability for all characters taken into account.

Following the analysis of the minimum and maximum limits, the following results were obtained:

For milk production, the minimum limit value is 763 kg and the maximum limit value is 10,584 kg. The range of variability obtained between these two values is 9,821 kg.

For the amount of fat, the value of the minimum limit is 23 kg, and the value of the maximum limit is 42.456 kg, with a range of variability of 42.433 kg.

For the amount of protein, the value of the minimum limit is 19 kg, and the value of the maximum limit is 351.01 kg, with a range of variability of 332.01 kg.

Variance component analysis results

Following the analysis of the phenotypic variance, values of 2,172,522 kg were obtained for the amount of milk, indicating significant diversity in the amounts of milk produced by cows, while values of 2,175.56 kg were obtained for the amount of protein. A smaller variance than that of milk yield suggests that protein production is more uniform between cows (Table 2).

Table 2. Variance component analysis results

Trait	$\sigma^2_{P_i}$	$\sigma^2_{G_i}$	σ^2_{Ri}
Milk quantity	2,172,522	213,475.68	1,959,045.92
Fat quantity	3,235.95	315.58	2,920.36
Protein quantity	2,175.56	222.84	1,952.71

For the amount of fat, values of 3,235.95 kg were estimated. This indicates significant differences in the amount of fat produced by the animals studied.

For the genotypic variance analysis, values of 213,475.68 kg were observed for milk production indicating a high genetic variance. For the amount of protein, values of 222.84 kg were obtained, and for the amount of fat, values of 315.58 kg, these being significant results that suggest that genetic selection can be used to increase the fat and protein content of milk, important aspect for certain dairy products such as butter and cheese.

Regarding the environmental variance analysis, values of 1,959,045.92 kg were obtained for milk production, the high value indicating that environmental factors play a significant role in influencing the amount of milk produced by cows. For the amount of protein, values of 1,952.71 kg were estimated, a much lower value compared to the environmental variant for the amount of milk. Compared to the environmental variance for protein amount, the environmental variance for fat is a slightly higher 2,920.36 kg, indicating a slightly greater influence of environmental factors on fat production.

Heritability

The heritability value for milk quantity was found to be 0.1, signifying that only 10% of the variation in milk production among the cows studied can be attributed to genetic differences (Table 3).

Table 3. Heritability value for milk quantity

Trait	$h^2 \pm S_{h^2}$
Milk quantity	0.1± 0.024
Fat quantity	0.09 ± 0.024
Protein quantity	0.102 ± 0.024

This low heritability suggests that genetic progress in improving milk yield through selective breeding will be slow and require many generations to produce noticeable results. Since the majority of the variation in milk production is driven by non-genetic factors, improvements in management practices, environmental conditions, and feeding strategies are important for optimizing milk yield in the short term. Nonetheless, the cumulative effect of genetic selection over time can lead to substantial gains, especially when using advanced breeding techniques that incorporate genomic information. Higher values of heritabiliries were found by different authors: 0.37-0.41 (Pelmuș et al., 2021), 0.35 (Trivunović et al., 2011), 0.22 (Panić & Vidović, 2006), and 0.21 (Amariții, 2024).

For protein quantity, the heritability value of 0.102 indicates that 10.2% of the variability in protein yield is due to genetic factors, while the remaining 89.8% is influenced by external conditions, including environmental factors, feed composition, health management, and overall herd management practices. Although genetic influence is modest, it provides a pathway for incremental improvement through breeding programs that target higher protein content. Given the importance of protein in determining the nutritional quality and processing efficiency of dairy products like cheese, enhancing this trait remains a priority. Combining selective breeding with optimized feeding strategies can maximize protein yield within the constraints of genetic potential.

The heritability for fat quantity, at 0.09, means that approximately 9.8% of the variation in fat content among cows is genetically determined. Similar to protein, fat production is significantly affected by management, dietary adjustments, and environmental influences, which account for 90.2% of the observed variation. Since fat content plays a key role in determining the richness and market value of dairy products such as butter and cream, strategies to improve fat yield involve both genetic and management components. Low heritability indicates that genetic improvements alone will be slow, but combined with precision nutrition and health interventions, production efficiency and profitability can still be enhanced.

Overall, these heritability estimates highlight the complex interplay between genetics and environment in dairy production. While genetic selection remains a vital tool for long-term improvements, focusing on environmental optimizations, such as superior nutrition, herd health, and comfort, is essential for maximizing the productivity and economic value of dairy herds in the immediate term. By leveraging both genetic and management strategies, farmers can achieve a balanced and sustainable approach to milk, protein, and fat production.

Phenotypic, genotypic and environmental covariances

The covariance of 80,359.41 kg² between milk and fat production indicates a positive relationship between these two variables in the study population (Table 4).

Table 4. Results obtained for the phenotypic, genotypic and environmental covariances

Pair of traits	$\sigma_{P_{ij}}$	$\sigma_{G_{ij}}$	σ_{Rij}
Milk quantity x Protein quantity	61,430.28	2,500	58,930.28
Milk quantity x Fat quantity	80,359.41	2,500	77,859.41
Protein quantity x Fat quantity	2,876.89	250	2,626.89

The covariance of 61,430.28 kg² for milk production and protein amount, positive and quite high, suggests that there is a positive relationship between milk production and protein production. In general, as milk production increases, protein production also tends to increase, and vice versa.

A study by Xiang et al. (2020) reported similar phenotypic covariance values for milk and protein, indicating a significant positive relationship between these two traits. Phenotypic covariance values vary by population and environmental conditions, but general trends are consistent with the results presented.

The values obtained for the pairs of characters regarding the phenotypic variant are similar for the amount of milk x the amount of protein 0.965 and the amount of milk x the amount of fat 0.969 indicating a very close relationship between the amount of milk and the amount of fat, but also between the amount of milk x the amount of protein (Table 5).

Table 5. Phenotypic, genotypic and environmental correlations

Pair of traits	$r_{P_{ij}} \pm S_{r_P}$	$r_{G_{ij}} \pm S_{r_G}$	$r_{R_{ij}}$
Milk quantity x Protein quantity	0.965±0.026	0.983± 0.050	0.1054
Milk quantity x Fat quantity	0.969 ± 0.142	0.985 ± 0.098	0.1053
Protein quantity x Fat quantity	0.946 ± 0.186	0.993 ± 0.065	0.0922

The values obtained for the environmental correlation for the pairs of characters are relatively low, indicating a low relationship that affects the amount of milk and the amount of fat. This suggests that environmental factors influencing milk production do not have a very strong effect on fat production.

In a study published by Pantelić et al. (2012), phenotypic and genetic correlations between milk yield and protein were reported to be high, with genetic correlations between 0.80 and 0.92, and phenotypic correlations between 0.86 and 0.94, which is consistent with the calculated values (rG = 0.9838 for milk and protein and rP = 0.9654).

A study by Pelmuș et al. (2021) reported heritability values of 0.37-0.41 for milk yield and 0.11-0.23 for fat yield. These heritability estimates are not directly comparable to the genetic correlation value of 0.969, as heritability measures the proportion of phenotypic variation attributable to genetic factors, whereas genetic correlation indicates the strength of the genetic relationship between two traits. Nevertheless, the findings are consistent in demonstrating a strong genetic linkage between milk yield and fat yield, supporting their simultaneous improvement through selective breeding.

Studies on environmental correlations are less common, but the results presented suggest a low environmental correlation between milk and fat (0.1053). This is consistent with the literature indicating that environmental factors have less impact on the relationship between milk yield and fat compared to genetic influences.

CONCLUSIONS

The presented results align closely with existing literature, reinforcing the findings of significant phenotypic and genetic correlations between milk quantity and protein quantity, as well as between milk and fat. These strong correlations suggest that increases in milk production are often accompanied by proportional increases in protein and fat content, indicating that these traits are genetically linked. This genetic relationship provides an opportunity for breeders to simultaneously improve multiple production traits through targeted selection strategies.

Phenotypic correlations observed in this study reflect observable relationships influenced by both genetic and environmental factors.

However, the genotypic correlations, which are derived solely from genetic variation, highlight the potential for long-term improvements in dairy productivity through selective breeding. High genotypic correlations confirm that shared genetic factors govern the production of milk, fat, and protein, making it feasible to enhance these traits collectively in future breeding programs.

Conversely, the environmental correlations, which measure the extent to which external factors affect trait relationships, were found to be relatively low. This suggests that environmental conditions have a minimal impact on the interplay between milk yield and its compositional elements. The limited influence of environmental factors indicates that consistent improvements in milk production traits are more likely to be driven by genetic advancements rather than changes in management practices alone. These findings are consistent with studies showing that while environmental improvements can optimize milk yield, the underlying genetic potential sets the ceiling for production efficiency and quality.

In summary, the data support the conclusion that genetic selection remains a powerful tool for enhancing dairy production, with phenotypic and genetic correlations providing a reliable basis for multi-trait selection. The low environmental correlations emphasize the importance of breeding strategies focused on genetic merit rather than relying solely on environmental modifications to achieve sustainable productivity gains.

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