ASSESSMENT OF PERFORMANCE VARIABILITY AND BASIC COMPONENTS OF MILK FROM POLISH HOLSTEIN-FRIESIAN COWS

Ewa Salamończyk#, Piotr Guliński

Siedlce University of Natural Sciences and Humanities, Faculty of Agrobioengineering and Animal Husbandry, Institute of Animal Science and Fisheries, Prusa 14, 08-110 Siedlce, Poland
#e-mail: ewa.salamonczyk@uph.edu.pl

Abstract

The aim of the study was to evaluate the performance diversity and the level of basic components in milk obtained from Polish Holstein-Friesian cows and to identify the main sources of this variability. The research covered 4822 data points related to the daily milk yield of Polish Holstein-Friesian cows. The assessment of the influence of various factors on the variability of milk components was conducted in designated production groups, successive lactation periods, age groups of animals, groups of cows with appropriate levels of urea and protein in milk (UP), as well as groups of animals whose milk was characterized by a specific fat-to-protein ratio (FPR) and somatic cell count (SCC) per 1 ml. The study demonstrated that significant differentiation in performance and milk components occurred in the actual cow population. The coefficients of variation characterizing them were as follows: 20% for milk yield, 13% for fat content, 5% for protein content, 13% for lactose content, 39% for dry matter content, 37% for urea level, and 223% for somatic cell count. The main sources of variability in milk components were production level, cow health status, and the level of energy and protein balance in feed rations. In the subset population selected specifically for the study, which included only healthy cows receiving fully balanced feed rations, a significant reduction in the variability of the evaluated traits was demonstrated. The coefficient of variation (CV) for the content of fat, protein, lactose, and dry matter in individual production groups were 7%, 3%, 3%, and 4%, respectively. The study showed that fully healthy Polish Holstein-Friesian cows fed optimally produce milk with a similar chemical composition regardless of their production level.

Keywords: dairy cows, Polish Holstein-Friesian breed, milk yield variability, milk composition variability

Introduction

Since the technological capabilities of assessing the composition of cow's milk have been established, it is known that milk composition is not constant. The variability in milk composition, described in scientific studies and reflected in official animal performance data, poses significant challenges in the rational evaluation of milk yield in cows. A proper assessment of data regarding diverse milk performance should be considered as a fundamental element in efforts aimed at further improving milk quality. This assessment is particularly crucial for optimizing the selection indexes applied in breeding programs. It also enables a comprehensive evaluation of the nutritional value and technological suitability of milk.

Modification of the chemical composition of cow's milk is the result of various factors that consistently differentiate the levels of its individual components at the production level. These factors include the season of the year (Jenness, 1988; Summer et al., 2007), cow's age (Guliński et al., 2003; Brzozowski and Zdziarski, 2006; Milogo et al., 2008; Tsioulpas et al., 2007), lactation stage (Borkowska and Januś, 2001; Milogo et al., 2008; Varga and Ishler, 2007), condition during milk production (Rodenburg, 1992; Guliński, 2006), diseases (mainly metabolic and udder-related) (Kitchen, 1981; Bruckmaier et al., 2004; Rajčevič et al., 2003), and feeding technologies (Fox and McSweeney, 1998; Bogucki, 2006). Changes in milk composition result from genetic assumptions of animals (their genotypes), which play a fundamental role in the hormonal regulation of milk component synthesis (Gaunt, 1980; Barłowska et al., 2006; Król et al., 2011), as well as the level of nutrient components provided in feed rations, which determine the level and quality of available nutrients for animals (Jamroz and Potkański, 2001; Bogucki, 2006). The processes of lactose, protein, and fat synthesis and secretion are independent but regulated by the availability of nutrients and the hormonal control of their utilization (Osorio et al., 2016).

In the study by Forsbäck et al. (2010) concerning changes in the level of milk performance traits in cows during successive days of lactation, the smallest variability in milk traits was observed for lactose (0.9%), while the greatest variability was found in fat level (7.7%). The changes in the evaluated traits, such as daily protein yield, and the concentration of casein and protein, ranged from 1.4% to 1.8% across successive days of lactation. The changes in daily milk yield and somatic cell count (SCC) between consecutive days of lactation were determined to be 7.9% and 2.0%, respectively. According to Guliński et al. (2018), the variability in the content of major milk components in a population of cows kept under the conditions of southern Podlasie, as measured by the coefficient of variation, was as follows: 48.6% for urea, 5.3% for lactose, 13.8% for protein, and 19.5% for fat.

According to Elgersma et al. (2018), the variability in daily milk yield in dairy cows is heritable and genetically associated with cow longevity and common diseases in dairy herds, such as mastitis and ketosis. Therefore, milk yield variability can be utilized as an indicator of resilience in dairy cattle breeding. The authors suggest that diseased cows typically have lower milk yield, which is also characterized by increased variability. The strongest genetic correlations (0.3-0.5) were found between milk yield variance and indicators of udder health, ketosis, and cow longevity. Based on these findings, the authors hypothesized that cows with genetically low milk yield variability exhibit lower susceptibility to udder inflammation and ketosis and demonstrate higher longevity compared to their peers with average milk yield variability. Therefore, the authors considered milk production variability as a promising trait for enhancing the resilience of cows in terms of improving their resistance to commonly occurring diseases and prolonging their productive lifespan in dairy herds (Elgersma et al., 2018).

The aim of the study was to assess the variability in milk yield and the level of basic milk components obtained from Polish Holstein-Friesian cows and identify the fundamental sources of this variability.

Materials and methods

The study included 4822 data points regarding the daily milk yield of Polish Holstein-Friesian (PHF) cows. These animals were kept in 10 dairy herds located in the Mazowieckie and Podlaskie voivodeships between 2019 and 2021.
A range of performance and milk quality traits were examined. These included:

- Actual daily milk yield (kg): The measured amount of milk produced per day in kilograms.
- Fat-corrected milk yield (FCM) (kg): Milk yield adjusted for fat content.
- Energy-corrected milk yield (ECM) (kg): Milk yield adjusted for both fat and protein content.
- Percentage of fat, protein, lactose, dry matter: The proportion of these components in milk.
- Urea level (mg/1 l.): The concentration of urea in milk.
- Somatic cell count (SCC) (thousands/1 ml): The number of somatic cells in milk per milliliter.

These traits were examined to assess the performance and quality of milk in the cows under study.

The individual daily milk yield of cows was adjusted to milk with: 4% fat content (FCM) using the formula 4% FCM = 0.4 × milk yield (kg) + 15 × fat yield (kg) (Gains, 1928), and milk with 4% fat and 3.5% protein content (ECM) using the formula ECM = (milk yield × (0.383 × % protein + 0.242 × % protein + 0.7832) / 3.1138) (Østergaard et al., 2003). Since the actual somatic cell count (SCC) does not follow a normal distribution, it was transformed to the natural logarithm (LNSCC) based on its actual count.

The influence of various factors on the variation of milk component levels was assessed within designated production groups, consecutive lactation periods, age groups of animals, groups of cows with specific levels of urea and protein in milk (UP), as well as groups of animals characterized by specific fat-to-protein ratio (FPR) and somatic cell count (SCC) per 1 ml of milk. Three levels of daily milk yield were distinguished (<20, 20-30, and >30 kg), along with four lactation periods covering consecutive months of lactation: 1-3, 4-6, 7-10, and 11-18; and four age groups of cows including animals that completed I, II, II-IV, and V-XI lactation, respectively. To assess the impact of dietary balance on the variation of milk performance traits, the evaluated cow population was divided into nine groups (UP) based on the level of urea content (mg/1) and protein concentration (%), as follows: I - <150 and <3.2; II - <150 and >3.6; III - >250 and <3.2; IV - >250 and >3.6; V - 150-250 and 3.2-3.6; VI - <150 and 3.2-3.6; VII - >250 and 3.2-3.6; VIII - 150-250 and <3.2; IX - 150-250 and >3.6. Furthermore, based on the fat-to-protein ratio in milk (FPR), the analyzed cow population was classified into three groups (<1.2, 1.2-1.6, >1.6). Regarding somatic cell count (SCC), the animals were grouped as follows: milk containing <200, 200-400, and >400 thousand cells per 1 ml of milk. Detailed data on the number of animals within each group are presented in Table 1.

The variation of the analyzed milk traits was determined using standard deviations from the mean, coefficients of variation, and percentage differences between the trait values and their population means. The variation in milk yield and its components was assessed using analysis of variance. A linear model was applied, taking into account the effects of production level, lactation period, cow age, groups of cows with specific levels of urea and protein in milk (UP), fat-to-protein ratio (FPR) groups, and somatic cell count (SCC) groups. The results were subjected to statistical analysis using the least squares method in a multifactorial analysis of variance. The significance of differences between means was assessed using Duncan's test at a significance level of $P \leq 0.01$. The calculations were performed using the GLM and FREQ procedures in the SAS statistical package (SAS Institute, 2008).

Results

Table 1 presents the results concerning the values of the analyzed performance and milk composition traits in the analyzed population. The mean actual daily milk yield during the full lactation period was 22.1 kg, and the percentage content of fat, protein, lactose, and dry matter were 4.33, 3.44, 4.74, and 13.12, respectively. The average urea level in 1 liter of milk and somatic cell count (SCC) in 1 ml of milk were 200 mg and 470,000, respectively. The results presented in Table 1 confirm the well-known and extensively described large variability in milk performance traits. In the case of the analyzed population in this study, this result was the effect of the interaction of several significant environmental factors, as specified in the methodology. For each milk performance and composition trait, evaluated within each factor, such as production level, lactation period, age group of animals, group with a specific urea and protein level in milk, and groups with defined FPR and SCC values, a high degree of variability was observed. The conducted analysis of variance confirmed the significance of these differences at P≤0.01. The discussed results confirm the crucial importance of the production level of cows in shaping the milk performance and composition. An increase in the production level resulted in negative changes in the levels of basic chemical components of milk. Milk from cows characterized by the highest production level (>30 kg), compared to the group of cows with the lowest performance level (<20 kg), contained less fat, protein, lactose, and solids by 0.89%, 0.45%, 0.1%, and 1.0%, respectively. Milk from cows in the highest production group, compared to milk from cows with the lowest performance, had more than 40 mg of urea and exhibited higher cytological quality, indicated by a lower somatic cell count per ml (reduced by 82 thousand).

Therefore, it is appropriate to accept the hypothesis that the production level is also the main cause of differentiation in milk performance characteristics for the two consecutive factors, namely lactation period and cow age. The results obtained in this part of the study should be considered typical and characteristic for the dairy cattle population. They confirm the existing knowledge regarding the importance of lactation period and cow age in differentiating milk yield in cows.

Of particular interest are the data illustrating the variation in milk performance between groups of animals fed with diets of varying levels of energy-protein balance. Feeding diets with an excess of energy (3.6%) (UP group - II, IV, and IX) resulted in a decrease in milk yield and an increase in fat and protein content. On the other hand, milk from animals fed diets with an excess of protein (>250 mg) (UP group - III, IV, and VII) was characterized by a very high level of urea in the milk. The results presented in this part of Table 1 indicate a highly statistically significant effect of the group of cows whose milk contained a specific level of urea and protein on the evaluation of milk performance traits. In light of these results, the level of energy and protein balance in the diet can be considered one of the fundamental sources of variation in dairy cow performance characteristics.

The significant differences in fat and protein content for milk characterized by different FPR ratios are considered evident. The differences in the percentage of fat and protein content between cows suspected of acidosis and ketosis, as presented in Table 1, should be evaluated as typical. They amounted to +1.62% and -0.37%, respectively.

When discussing the impact of the mammary gland's health status on the milk production traits, it is important to emphasize that it mainly affected milk yield and lactose content. Animals with the lowest SCC (<200,000 cells/ml) compared to their counterparts with the highest SCC (>400,000 cells/ml) exhibited higher daily milk yield (+1.8 kg), and the lactose content in the milk of these cows was higher by +0.19%.

The main objective of the study was to assess the variability of milk production traits in a selected population of Polish Holstein-Friesian cows. Table 2 and 3 present the magnitude of selected measures of statistical dispersion for the analyzed milk production traits. By applying the classical criterion of division, the coefficients of variation (CV) presented in Table 2 can be classified into three groups. The first group comprises traits with low variability, with CV values below 25%. In this study, the traits with the lowest variability belonged to the following: fat content (20%), protein content (13%), lactose content (5%), and dry matter content (13%).

The second group includes traits with average variability, such as daily milk yield: actual (39%), FCM (fat-corrected milk) (36%), ECM (energy-corrected milk) (35%), and urea concentration (37%). Among the evaluated population, the trait exhibiting a very strong variability was the somatic cell count (SCC) in 1 ml of milk. The average CV for this trait in the entire population was 223%.

Table 3 presents the variability of the discussed milk production traits expressed as percentage differences between the actual level of the trait and its mean value in the entire population. The data provided in Table 3 confirm the high variability of the traits within individual sources of variation. The obtained indicators demonstrate that the following groups of cows exhibited the highest percentage values compared to the population mean: for actual milk yield (producing >30 kg); fat content (FPR>1.6); protein content (Group II of UP); dry matter content (Group II and IV of UP); urea concentration (Group III, IV, and VIII of UP). For the classified subclasses, the percentage differences in the size of the traits were as follows: +66%, +28%, +17%, 8% and 8%, 50%, and 50% and 48%.

In order to identify the main cause of the described high variability in the performance and composition traits of PHF cows' milk, Tables 4 and 5 present the results of variation in performance and milk composition traits within selected subpopulations. In Table 4, the subpopulation was limited to fully healthy animals, i.e., those with somatic cell counts below 200,000 per ml and a fat-to-protein ratio ranging from 1.2 to 1.6. The conducted selection excluded the influence of basic metabolic disorders such as acidosis or ketosis. In Table 5, the subpopulation was further narrowed down to Group V UP, indicating that the dietary doses used for the nutrition of this group of cows were fully balanced in terms of energy and protein. The data presented in Tables 4 and 5 indicate a significant reduction in the variability of traits within these selected subpopulations. The CV (coefficient of variation) values for the fundamental milk components, such as fat, protein, lactose, and dry matter, in different production groups ranged from 3% to 7%. Furthermore, it was demonstrated that the impact of production level on the variability of basic milk components in this subpopulation was not statistically significant. The results presented in this part of the study provide the basis for stating that in the examined population of PHF cattle, the main sources of variability in milk production traits were the level of energy-protein balance in the dietary doses and the health status of the animals. This also gives rise to the hypothesis that fully healthy PHF cows fed a balanced diet produce milk with a very similar chemical composition, regardless of their production level.

Table 1. The impact of studied factors on the formation of milk production traits in cows

Factors	Number of observations /n/	Daily milk yield			Milk quality traits						
		Real /kg/	FCM /kg/	ECM /kg/	Fat /%/	Protein /%/	Lactose /%/	Dry matter /%/	Urea /mg/1/	LNSCC	SCC /thous./1ml/
		$\bar{x}$±SD									
Production level, kg											
<20	2092	14,6^{C}±3,4	15,9^{C}±3,8	16,1^{C}±3,8	4,66^{A}±0,84	3,64^{A}±0,47	4,69^{C}±0,25	13,48^{A}±2,23	186^{C}±73	5,33^{A}±1,2	505±1146
20-30	1950	24,2^{B}±2,9	24,9^{B}±3,9	24,8^{B}±3,7	4,19^{B}±0,77	3,32^{B}±0,39	4,77^{B}±0,22	12,99^{B}±1,11	204^{B}±70	5,15^{B}±1,2	450±1010
>30	780	36,6^{A}±5,5	35,2^{A}±6,1	35,2^{A}±5,7	3,77^{C}±0,78	3,19^{C}±0,33	4,79^{A}±0,22	12,48^{C}±0,95	226^{A}±72	5,02^{C}±1,3	423±840
Lactation period, months											
1-3	1343	27,5^{A}±8,5	27,4^{A}±8,2	27,0^{A}±8,1	4,11^{C}±0,85	3,11^{D}±0,34	4,80^{A}±0,23	12,56^{D}±1,82	198^{B}±76	4,89^{D}±1,3	414±1005
4-6	1347	22,9^{B}±7,6	23,1^{B}±7,1	23,1^{B}±7,1	4,13^{C}±0,74	3,33^{C}±0,32	4,76^{B}±0,22	13,40^{B}±1,56	209^{A}±73	5,20^{C}±1,2	473±978
7-9	1214	19,0^{C}±7,1	20,1^{C}±6,9	20,2^{C}±6,9	4,48±0,81^{B}	3,61^{B}±0,39	4,71^{C}±0,25	12,83^{C}±1,67	200^{B}±71	5,35^{B}±1,2	487±1095
10-18	918	17,1^{D}±7,1	18,6^{D}±7,0	19,0^{D}±7,1	4,72^{A}±0,93	3,85^{A}±0,45	4,68^{D}±0,22	13,98^{A}±1,28	191^{C}±69	5,49^{A}±1,1	522±1136
Age of cows, completed lactation											
I	1649	20,9^{D}±7,6	21,4^{D}±7,1	21,5^{D}±7,1	4,31^{B}±0,82	3,41^{C}±0,45	4,85^{A}±0,20	13,06^{B}±2,00	204^{A}±75	4,87^{D}±1,2	328±851
II	1292	21,6^{C}±8,8	22,5^{C}±8,2	22,5^{C}±8,1	4,43^{A}±0,87	3,52^{A}±0,47	4,73^{B}±0,22	13,26^{A}±1,78	196^{B}±76	5,11^{C}±1,2	403±878
III-IV	1433	22,9^{B}±8,6	23,5^{B}±8,2	23,5^{B}±8,0	4,31^{B}±0,91	3,43^{B}±0,46	4,68^{C}±0,24	13,15^{AB}±1,21	198^{B}±70	5,49^{B}±1,3	603±1270
V-XI	448	24,8^{A}±10,1	25,2^{A}±9,6	25,1^{A}±9,4	4,19^{C}±0,78	3,35^{D}±0,42	4,63^{D}±0,26	12,79^{C}±1,57	206^{A}±68	5,84^{A}±1,2	756±1242
Group of cows with appropriate levels of urea and protein in milk (UP)											
I	444	23,1^{D}±6,5	22,8^{E}±6,7	22,2^{D}±6,4	3,92^{e}±0,75	2,95^{E}±0,18	4,77^{B}±0,25	12,16^{D}±1,96	110^{C}±28	4,97^{D}±1,3	414±1036
II	443	14,9^{I}±5,8	17,1^{I}±6,3	17,5^{F}±6,4	5,03^{A}±0,85	4,01^{A}±0,33	4,65^{E}±0,26	14,14^{A}±2,17	112^{C}±23	5,58^{A}±1,2	604±1157
III	416	27,6^{A}±8,7	26,6^{A}±8,1	26,2^{A}±7,8	3,82^{F}±0,79	2,98^{E}±0,16	4,80^{A}±0,22	12,36^{C}±0,89	300^{A}±42	4,82±1,3	333±706
IV	357	19,2^{F}±7,6	21,3^{F}±8,2	21,9^{D}±8,4	4,82^{B}±0,78	3,97^{B}±0,32	4,70^{CD}±0,21	14,13^{A}±1,32	300^{A}±43	5,39^{B}±1,1	488±1084
V	796	22,9^{D}±7,9	23,4^{D}±7,6	23,5^{C}±7,6	4,21^{D}±0,69	3,40^{D}±0,11	4,76^{B}±0,22	12,98^{B}±1,41	201^{B}±27	5,22^{C}±1,2	475±1045
VI	390	20,1^{E}±6,8	20,7^{G}±6,6	20,8^{E}±6,6	4,30^{C}±0,73	3,39^{D}±0,10	4,72^{C}±0,26	12,94^{B}±1,84	112^{C}±23	5,21^{C}±1,3	489±1072
VII	388	24,8^{C}±8,9	25,1^{C}±8,5	25,2^{B}±8,5	4,16^{D}±0,75	3,41^{D}±0,10	4,78^{AB}±0,21	13,09^{B}±0,79	296^{A}±38	5,04^{D}±1,2	403±1071
VIII	804	26,7^{B}±8,6	26,1^{B}±8,1	25,5^{B}±7,8	3,89^{E}±0,69	2,98^{E}±0,17	4,81^{A}±0,22	12,29^{D}±1,36	198^{B}±28	5,01^{D}±1,3	405±836
IX	787	17,8^{G}±6,7	19,9^{H}±7,2	20,4^{E}±7,3	4,87^{B}±0,78	3,94^{C}±0,29	4,69^{D}±0,23	14,10^{A}±1,51	200^{B}±27	5,53^{A}±1,1	573±1261
Fat-to-protein ratio (FPR)											
<1,2	1915	23,9^{A}±9,3	22,5^{B}±8,1	22,9^{B}±8,2	3,71^{C}±0,62	3,47^{A}±0,43	4,73^{AB}±0,24	12,54^{C}±1,52	208^{A}±72	5,29^{A}±1,3	513±1045
1,2-1,6	2619	20,7^{C}±7,7	22,3^{B}±7,6	22,2^{C}±7,5	4,65^{B}±0,67	3,45^{A}±0,47	4,75^{A}±0,22	13,43^{B}±1,75	196^{B}±73	5,17^{B}±1,2	467±1024
>1,6	288	22,6^{B}±8,1	27,5^{A}±9,8	26,2^{A}±9,2	5,53^{A}±0,95	3,12^{B}±0,43	4,72^{B}±0,28	14,06^{A}±1,17	192^{C}±79	5,05^{C}±1,3	438±1244
Somatic cell count, thousand/1 ml.											
<200	2682	22,7^{A}±8,6	23,2^{A}±8,0	23,2^{A}±7,9	4,27^{C}±0,84	3,37^{C}±0,42	4,81^{A}±0,20	13,02^{B}±1,79	205^{A}±75	4,32^{C}±0,6	91±51
200-400	988	21,4^{B}±8,1	22,1^{B}±7,7	22,2^{B}±7,5	4,44^{A}±0,87	3,53^{A}±0,47	4,72^{B}±0,21	13,29^{A}±1,74	194^{B}±72	5,62^{B}±0,2	281±55
>400	1152	20,9^{C}±8,7	21,9^{B}±8,4	22,0^{B}±8,2	4,36^{B}±0,91	3,51^{B}±0,51	4,62^{C}±0,63	13,19^{A}±1,41	194^{B}±68	6,93^{A}±0,8	1512±1772
Total / average	4822	22,1±8,6	22,7±8,1	22,7±7,9	4,33±0,86	3,44±0,46	4,74±0,24	13,12±1,76	200±73	5,21±1,3	470±1047

Means within columns for factors labeled with different letters differ significantly at P≤0.01

Table 2. Coefficients of variation for milk yield traits (V%) analyzed in the study, with consideration of determined factors

Factors	Daily milk yield			Milk quality traits						
	Real /kg/	FCM /kg/	ECM /kg/	Fat /%/	Protein /%/	Lactose /%/	Dry matter /%/	Urea mg/1/	LNS CC	SCC /thous. /1ml
	CV (%)									
Production level, kg										
<20	23	24	24	18	13	5	16	39	23	1146
20-30	12	16	15	18	12	5	8	34	23	1010
>30	15	17	16	21	10	5	8	32	26	840
Lactation period, months										
1-3	31	30	30	21	11	5	14	38	27	1005
4-6	33	31	31	18	10	5	12	35	23	978
7-9	37	34	34	18	11	5	13	36	22	1095
10-18	42	38	37	20	12	5	10	36	20	1136
Age of cows, completed lactation										
I	36	33	33	19	13	4	15	37	25	259
II	41	36	36	20	13	5	13	39	23	218
III-IV	38	35	34	21	13	5	9	35	24	211
V-XI	41	38	37	19	13	6	12	33	21	164
Group of cows with appropriate levels of urea and protein in milk (UP)										
I	28	29	29	19	6	5	16	25	26	250
II	39	37	37	21	8	6	15	21	22	192
III	32	30	30	21	5	5	7	14	27	212
IV	40	38	38	16	8	4	9	14	20	222
V	34	32	32	16	3	5	11	13	23	220
VI	34	32	32	17	3	6	14	21	25	219
VII	36	34	34	18	3	4	6	13	24	266
VIII	32	31	31	18	6	5	11	14	26	206
IX	38	36	36	16	7	5	11	14	20	220
Fat-to-protein ratio (FPR)										
<1,2	39	36	36	17	12	5	12	35	25	204
1,2-1,6	37	34	34	14	14	5	13	37	23	219
>1,6	36	36	35	17	14	6	8	41	26	284
Somatic cell count, thousand/1 ml										
<200	38	34	34	20	12	4	14	37	14	56
200-400	38	35	34	20	13	4	13	37	4	20
>400	42	38	37	21	15	14	11	35	12	117
Average	39	36	35	20	13	5	13	37	25	223

Table 3. Percentage differences in milk yield and selected milk composition traits, taking into account the tested factors (trait level expressed as a percentage relative to the mean value in the population)

Factors	Daily milk yield			Milk quality traits						
	Real /kg/	FCM /kg/	ECM /kg/	Fat /%/	Protein /%/	Lactose /%/	Dry matter /%/	Urea /mg/1/	LNS CC	SCC thous/ 1 ml
Production level, kg										
<20	-34	-30	-29	8	6	<-0,1	3	-7	2	35
20-30	10	10	9	-3	-3	<0,1	-1	2	-1	-20
>30	66	55	55	-13	-7	<0,1	-5	13	-4	-47
Lactation period, months										
1-3	24	21	19	-5	-10	<0,1	-4	-1	-6	-56
4-6	4	2	2	-5	-3	<0,1	2	5	0	3
7-9	-14	-11	-11	3	5	<-0,1	-2	0	3	17
10-18	-23	-18	-16	9	12	<-0,1	-4	-5	5	52
Age of cows, completed lactation										
I	-5	-6	-5	0	-1	<0,1	0	2	-7	-142
II	-2	-1	-1	2	2	<-0,1	1	-2	-2	-67
III-IV	4	4	4	0	0	<-0,1	0	-1	5	133
V-XI	12	11	11	-3	-3	<-0,1	-3	3	12	286
Group of cows with appropriate levels of urea and protein in milk (UP)										
I	5	0	-2	-9	-14	<0,1	-7	-45	-5	-56
II	-33	-25	-23	-7	17	<-0,1	8	-44	7	134
III	25	17	15	-12	-13	<0,1	-6	50	-7	-137
IV	-13	-6	-4	11	15	<-0,1	8	50	3	18
V	4	3	4	-3	-1	<0,1	-1	1	0	5
VI	-9	-9	-8	-1	-1	<-0,1	-1	-44	0	19
VII	12	11	11	-4	-1	<0,1	0	48	-3	-67
VIII	21	15	12	-10	-13	<0,1	-6	-1	-4	-65
IX	-19	-12	-10	12	15	<-0,1	7	0	6	103
Fat-to-protein ratio (FPR)										
<1,2	8	-1	1	-14	1	<-0,1	-4	4	2	43
1,2-1,6	-6	-2	-2	7	0	<0,1	2	-2	-1	-3
>1,6	2	21	15	28	-9	<-0,1	7	-4	-3	-32
Somatic cel count, thousand/ 1ml										
<200	3	2	2	-1	-2	<0,1	-1	3	-17	-379
200-400	-3	-3	-2	3	3	<-0,1	1	-3	8	-189
>400	-5	-4	-3	1	2	<-0,1	1	-3	33	1042

Table 4. The influence of production level and level of balanced feed rations on the development of milk yield traits in cows with a proper fat-to-protein ratio in milk (FPR=1.2-1.6) and optimal somatic cell count (<200 thousand/1 ml)

Factors	Number of observations /n/	Daily milk yield			Milk quality traits						
		Real /kg/	FCM /kg/	ECM /kg/	Fat /%/	Protein /%/	Lactose /%/	Dry matter /%/	Urea /mg/1/	LNSCC	SCC thous/ 1ml
		$\bar{x}$±SD									
Production level, kg											
<20	705	15,0^{C}±3,0	16,8^{C}±3,3	16,7^{C}±3,3	4,83^{A}±0,62	3,57^{A}±0,43	4,81^{B}±0,18	13,53^{A}±0,43	190^{C}±73	4,42^{A}±0,68	98±50
20-30	603	23,8^{B}±2,7	25,3^{B}±3,2	24,9^{B}±3,2	4,42^{B}±0,55	3,27^{B}±0,38	4,84^{A}±0,19	13,20^{B}±1,15	204^{B}±73	4,27^{B}±0,70	88±51
>30	184	36,3^{A}±5,3	37,1^{A}±5,8	36,4^{A}±5,8	4,14^{C}±0,48	3,11^{C}±0,30	4,83^{AB}±0,17	12,76^{C}±0,78	222^{A}±68	4,12^{C}±0,84	82±51
Group of cows with appropriate levels of urea and protein in milk (UP)											
I	145	22,6^{C}±6,3	22,7^{CD}±6,2	22,1^{D}±6,1	4,06^{D}±0,36	2,96^{D}±0,18	4,85^{A}±0,20	12,28^{C}±2,13	109^{C}±27	4,18^{D}±0,72	82±49
II	119	15,5^{I}±4,8	18,5^{H}±5,4	18,8^{F}±5,5	5,33^{A}±0,61	3,96^{A}±0,32	4,77^{B}±0,17	14,16^{A}±2,92	115^{C}±20	4,49^{AB}±0,66	106±51
III	139	22,6^{A}±8,7	26,6^{A}±8,4	25,9^{A}±8,3	4,02^{D}±0,37	2,98^{D}±0,16	4,84^{A}±0,18	12,64^{C}±0,74	304^{A}±48	4,15^{D}±0,75	80±51
IV	95	18,4^{G}±7,7	21,5^{EF}±8,6	21,8^{D}±8,8	5,18^{B}±0,53	3,93^{AB}±0,28	4,76^{B}±0,18	14,53^{A}±0,81	302^{A}±45	4,55^{A}±0,53	106±47
V	242	20,4^{E}±6,9	22,2^{DE}±7,2	22,0^{D}±7,1	4,61^{C}±0,35	3,40^{C}±0,10	4,84^{A}±0,16	13,37^{B}±1,55	200^{B}±27	4,36^{BC}±0,62	93±49
VI	131	19,2^{F}±5,6	21,1^{FG}±6,2	20,9^{E}±6,1	4,66^{C}±0,37	3,40^{C}±0,10	4,81^{AB}±0,16	13,27^{B}±2,1	113^{C}±25	4,21^{CD}±0,64	87±49
VII	105	21,5^{D}±7,7	23,4^{C}±8,1	23,3^{C}±8,0	4,61^{C}±0,37	3,42^{C}±0,10	4,86^{A}±0,17	13,57^{B}±0,42	297^{A}±40	4,21^{CD}±0,66	81±45
VIII	298	25,3^{B}±7,8	25,6^{B}±7,7	24,9^{B}±7,5	4,08^{D}±0,34	2,98^{D}±0,16	4,86^{A}±0,20	12,40^{C}±1,7	198^{B}±28	4,15^{D}±0,80	82±52
IX	218	17,3^{H}±5,5	20,4^{G}±6,7	20,7^{E}±6,7	5,20^{B}±0,46	3,92^{B}±0,26	4,77^{B}±0,17	14,46^{A}±1,5	200^{B}±26	4,59^{A}±0,53	113±50
Total/Average	1492	21,2±7,7	22,7±7,6	22,5±7,7	4,58±0,63	3,39±0,43	4,82±0,18	13,31±1,89	199±73	4,32±0,70	92±51

Means within columns for factors labeled with different letters differ significantly at P≤0.01

Table 5. Level of milk yield traits in cows with a proper fat-to-protein ratio in milk (FPR=1.2-1.6), optimal somatic cell count (<200 thousand/1 ml), and fed fully balanced feed rations within each production group

Factors	Number of observations /n/	Daily milk yield			Milk quality traits						
		Real /kg/	FCM /kg/	ECM /kg/	Fat /%/	Protein /%/	Lactose /%/	Dry matter /%/	Urea /mg/1/	LNSCC	SCC thous./1 ml
		$\bar{x}$ ±SD V%									
Production level, kg											
<20	135	15,5^{C}±2,5 16	17,2^{C}±2,9 16	17,1^{C}±2,9 16	4,70^{A}±0,35 7	3,42^{A}±0,11 3	4,83^{A}±0,17 3	13,32^{A}±0,59 4	198^{A}±27 13	4,41^{B}±0,58 13	96±47 48
20-30	83	23,8^{B}±2,7 11	25,7^{B}±2,7 10	25,6^{B}±2,7 10	4,52^{B}±0,35 8	3,39^{A}±0,10 3	4,86^{A}±0,16 3	13,45^{A}±0,39 3	200^{A}±28 14	4,34^{B}±0,63 14	92±50 54
>30	24	35,5^{A}±4,7 13	37,7^{A}±4,7 12	37,5^{A}±4,6 12	4,43^{B}±0,31 7	3,37^{A}±0,09 2	4,84^{A}±0,12 2	13,30^{A}±0,49 3	209^{A}±27 13	4,11^{A}±0,76 18	79±53 67
Total/Average	242	20,4±6,9 33	22,2±7,2 32	22,0±7,1 32	4,61±0,35 7	3,40±0,10 3	4,84±0,16 3	13,37±0,55 4	200±27 13	4,36±0,62 14	93±49 52

Means within columns with different letters differ significantly at $P \leq 0.01$

Discussion

In light of existing knowledge and the results obtained in this study, the variability in milk production and composition should be considered a typical phenomenon observed in dairy cattle populations. A precise answer to the question of how high phenotypic variability arises in animals with the same genotypes is one of the key issues in modern dairy breeding. Pigliucci et al. (2006) defined this variability as phenotypic plasticity, which they described as the "ability of individual genotypes to produce different phenotypes under different environmental conditions." According to Lee et al. (2022), phenotypic plasticity describes the phenomenon by which genetically identical units within a population can differ from each other through epigenetic means. In the context of rapidly changing conditions, organisms with variable phenotypes within genetically similar populations provide the opportunity for individuals to randomly adapt to uncertain conditions. Vogt (2015) states that phenotypic variability in populations results from genetic variability as well as two non-genetic sources of variability, namely environmentally induced variability and stochastic developmental variability. The author explains that stochastic developmental variability is triggered in the environment by stochastic (random) cellular events and nonlinear mechanisms during patterning and morphogenesis.

According to Pèlabon et al. (2020), a meaningful comparison of variability in a quantitative trait requires controlling both the dimension of the variable entity and the dimension of the factor generating variability. Although the coefficient of variation (CV) is often used to measure and compare variability in quantitative traits, it only takes into account the dimension of the traits themselves, and its use for comparing variability can sometimes be inappropriate. These authors emphasize the need to be aware of the dimensions of traits and the relationship between the mean and standard deviation when comparing CVs, even if the scales on which the traits are expressed allow for reliable CV calculations.

In their research conducted on Holstein-Friesian cows in the Czech Republic, Kejdova Rysova et al. (2023) demonstrated significant variability in the coefficients of variation for the assessed milk components. For cows in the early lactation period, the coefficients of variation for the percentage content of fat, protein, lactose, and dry matter were reported as follows: 60.29%, 8.80%, 8.01%, and 13.30%, respectively. Similar magnitudes of coefficients of variation for milk components, obtained from 159,360 data points concerning Holstein-Friesian cows in Italy, were described by Stocco et al. (2023), consistent with the findings of the present study. In this study, the coefficients of variation for fat, protein, and lactose content were reported as 19%, 11%, and 4%, respectively. Lu et al. (2021) provided the coefficients of variation for primary milk components in 1,800 first-parity Holstein-Friesian cows in the Netherlands. The coefficients of variation for fat, protein, and lactose content were reported as 15%, 9%, and 3%, respectively.

In light of available data, fat is the milk component with the highest variability. Significant variations in fat concentration are observed within dairy cattle breeds (Maurice-Van Eijndhoven et al., 2013; Litwińczuk et al., 2012). Feeding technologies are the most important pathway leading to changes in milk fat content. They can result in alterations in fermentation patterns or the absorption of fat from the digestive tract. Genetic selection influences milk fat content, but it also has an impact on other components due to the high correlation among individual milk components (Miglior et al., 2005; Bovenhuis et al., 2013). In the United States, Jersey cows (5.5%) and Guernsey cows (5.0%) are known for having the highest fat content, while Holstein cows produce milk with the lowest fat content (3.5%) (Jenness, 1988). The influence of breed on milk composition is supported by the findings of Litwińczuk et al. (2012). The composition of cow's milk changes over subsequent completed lactations (Fox and McSweeney, 1998; Millogo et al., 2008; Tsioulpas et al., 2007). Cows reach their peak milk production during the period of full somatic maturity, typically between the third and fifth lactation, after which their milk yield gradually declines (Litwińczuk and Szulc, 2005). The fat content in milk is negatively correlated with the age of cows. Rogers and Stewart (1982) reported a decrease of 0.2% in milk fat content over five lactations. In the evaluated Holstein cattle population in the USA, milk protein content decreased by 0.1-0.5% over the first five lactations, and by 0.02-0.05% within a single lactation (Rook and Thomas, 1980). Conducting similar analyses in Poland, Stenzel et al. (2003) demonstrated a clear decrease in the percentage of fat content with increasing number of lactations (from 4.25% in the first lactation to 4.17% in the fifth lactation).

Several authors highlight the lactation period as an important source of variability in milk fat content in cows (Borkowska and Januś, 2001; Millogo et al., 2008; Summer et al., 2007; Varga and Ishler, 2007). The highest level of fat is observed in colostrum. During the first two months of lactation, there is typically a decrease in its concentration, followed by a systematic increase in milk fat concentration from the third month until the end of lactation.
Based on a series of research findings, the production season is considered a significant factor that differentiates the level of milk fat content. According to Jenness (1985), seasonal variations in the percentage of milk fat can reach up to +0.45% in favor of milk produced during winter months. According to Litwińczuk and Szulc (2005), feed supply and quality are associated with the time of year, resulting in cows producing the most milk during spring and early summer. However, higher milk component content, as observed by Barłowska et al. (2005), was obtained during the winter feeding period for both Simmental and Holstein-Friesian cows. During this time, the milk contained 0.59% (Black-White cattle) and 0.12% (Simmental) more dry matter compared to milk obtained during the summer feeding period. These cited results are consistent with the findings of experiments conducted by other authors (Borkowska and Polski, 2004; Gardzina-Mytar et al., 2008; Górska and Mróz, 2004; Litwińczuk et al., 2001; Summer et al., 2007; Varga and Ishler, 2007), where higher levels of individual milk components were generally observed during the autumn-winter months, while the lowest levels were found during the spring-summer period.

The percentage of protein in milk and its composition can be mainly modified through genetic selection (Bovenhuis et al., 2013). The heritability of protein content in milk is high and ranges from 0.3 to 0.7. The proportion of specific proteins in milk can be slightly modified by feeding practices. The overall percentage of protein in milk can be reduced by incorporating fats into the diet or increasing the fat content of milk through the provision of high-fiber feed (Magan et al., 2021).

Lactose is one of the most stable components in cow's milk. This stability is due to the tight relationship between lactose synthesis and the amount of water taken into the milk (Allesio et al., 2021). Lactose is easily metabolized by microorganisms, making milk an easily fermentable substance. Therefore, the reduction in lactose levels in milk primarily occurs as a result of decreased hygienic quality of milk and increased somatic cell counts (Costa et al., 2019a; Alessio et al., 2021). Additionally, the age of cows is a significant factor in differentiating lactose levels in milk. According to Haile-Mariam and Pryce (2017) and Costa et al. (2019b), the lactose concentration in milk was higher in primiparous cows compared to multiparous cows. These authors demonstrated a decrease in lactose levels with the age of cows in dairy cattle populations in Australia and Italy, respectively.

According to Guliński and Kłopotowska (2019), the primary factor influencing the variability of milk components is the level of animal productivity. These authors observed that an increase in the daily yield of PHF cows by 1 kg was associated with a decrease in the percentage of fat, protein, and dry matter by approximately -0.03%, -0.03%, and -0.05%, respectively. At the same time, there was a slight increase in lactose concentration by 0.004%.

Inflammation of the udder and the associated somatic cell count in milk are considered one of the primary factors differentiating the chemical composition of cow's milk. An increase in somatic cell count in milk is accompanied by significant changes in its chemical composition and a decrease in yield. These changes drastically reduce its technological suitability. The consequences of udder inflammation, also known as mastitis, include a decrease in milk's dry matter content by 1-3%, a decrease in fat content by 0.5-1.5%, and a decrease in the proportion of casein from 77% to 68%. *Mastitis* typically leads to a significant reduction in fat content and changes in milk fat composition (Kitchen, 1981; Needs and Anderson, 1984; Schultz, 1977). It is worth noting that udder inflammation is associated with an approximately 10% decrease in fat content. For lactose and casein, the decrease is even higher, reaching around 15-18% (Harmon, 1994).

Ketosis is the most common metabolic disorder occurring in high-yielding dairy cows during the first 6-8 weeks of lactation (Brunner et al., 2019; Buttchereit et al., 2012; Guliński, 2019; Fiorentin et al., 2018; Januś and Borkowska, 2013). Its main cause is a low level of structural carbohydrates in the blood, resulting from a negative energy balance during this phase of lactation. Imbalance in the energy intake leads to the release of large amounts of fatty acids derived from subcutaneous fat reserves, which affects the reduction in dry matter intake by the animals. The main symptoms of ketosis include the presence of excessive amounts of ketone bodies (β-hydroxybutyric acid, acetoacetic acid, and acetone) in body fluids (blood, milk, and urine), which result from the incomplete breakdown of fatty acids in the liver. Among the primary indicators of ketosis are an increase in milk fat content (above 5%) accompanied by a decrease in protein content (below 2.9%). The fat-to-protein ratio is elevated to a level above 1:1.4 (Guliński, 2021).

In conclusion, it should be stated that there is significant variation in milk yield and composition in the actual population of cows. The coefficients of variation for milk yield, fat content, protein content, lactose content, dry matter content, urea level, and somatic cell count were 20%, 13%, 5%, 13%, 39%, 37%, and 223%, respectively. The study demonstrated that the main sources of variation in milk composition were production level, cow health, and the balance of energy and protein in the feed ration. In a selected subpopulation included in the study, consisting only of healthy cows receiving fully balanced feed rations, a significant reduction in the variation of evaluated traits was observed. The coefficients of variation for fat content, protein content, lactose content, and dry matter content in different production groups were 7%, 3%, 3%, and 4%, respectively. Particularly noteworthy are the results of the analysis of variance conducted within this subpopulation, which did not confirm the significant impact of production level on milk composition. The obtained results confirm that Polish Holstein-Friesian cows, when healthy and fed a balanced diet, produce milk with a very similar chemical composition regardless of their production level.

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