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ANALYSIS OF PRODUCTION PROGRESS IN SELECTED DAIRY HERDS IN TERMS OF ASSESSMENT OF UTILITY VALUE. PART 1. ANALYSIS OF THE PROGRESS OF PRODUCTION IN MILK YIELD, INCLUDING MILK YIELD, PROTEIN PERCENTAGE AND FAT PERCENTAGE AND THEIR MUTUAL RELATIONSHIP

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Abstract. The purpose of the study was to analyze the production progress in selected dairy cattle herds included in the performance evaluation. The study analyzed production traits such as milk yield, percentage fat, percentage protein, somatic cell count, urea content in milk and the following sources of variation: year of study, month of year and herd, in addition, the fat-protein ratio and energy corrected milk (ECM) and fat corrected milk (FCM) indices were calculated over 21 years in the herds included in the analysis. In addition, the study took into account the most important aspects of dairy farming and breeding, which can include: behavior, nutrition, welfare, milking systems, and the functional types of cattle and the breeds belonging to them.Analysis of variance for production traits showed that all sources of variation (year of study, month of year, herd) had a statistically high effect on the traits evaluated (milk yield, percent fat, percent protein, somatic cell count, urea content fat-protein ratio, and FCM and ECM indices). An analysis of variance was also conducted for interactions: month × herd, year × month and year × herd.Least-squares means and standard deviation were calculated for the analyzed traits in successive study years and months of the year by herd. Detailed results of the analyzed traits by study year and herd and month and herd are presented in line graphs. Summarizing the results of the analyses, it can be said that all the analyzed herds showed significant production progress in basic traits such as milk yield, fat and protein percentages. It should be noted that the number of somatic cells was characterized by significant fluctuations, which may indicate a significant influence of the environment on this parameter. However, it should be emphasized that during most of the study period, the number of somatic cells was definitely within the specified norms.Improvement of milk yield in herds was achieved as a result of changes in cow breeding technology. The introduction of a change in the herds' feeding system from traditional to total mixed ration (TMR) feeding resulted in an improvement in both milk yield and milk quality composition. The production results obtained in these herds are of great application importance. Therefore, it is recommended to implement modern technological systems in the form of the TMR feeding system in dairy cattle herds.Dairy performance in the selected cow herds has increased over the analyzed period of 21 years. This testifies to properly conducted breeding work, thanks to which there was an increase in production in these herds.

Key words: milk production, farm, cattle, phenotypic progression.

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INTRODUCTION

Dairy cattle farming in Poland is a very important branch of the economy. It is a source of livelihood for numerous farms and their support structures. Milk obtained from cows allows for the production of many dairy products that are highly valuable in the human diet. From milk, the human body acquires a range of micro and macro elements necessary for its proper functioning. Milk is also used in the cosmetic and pharmaceutical industries (Barłowska et al. 2011).

Over the past 20 years, the milk yield of cattle has significantly increased. The intensification of cattle farming has led to a decrease in the number of cattle while simultaneously increasing milk production. This growth is associated with greater knowledge among breeders, leading to better feed selection and the appropriate choice of sires to improve the genetic traits of cows. In free-stall barns, farmers strive to create the best possible living conditions for the cattle, which also contributes to increased productivity. Additionally, the awareness among cattle breeders regarding cow health and preventive health measures is rising.

In 2022, Poland had the third largest population of dairy cows in the European Union, amounting to 2.1 million head. Only Germany, with 3.8 million head, and France, with 3.2 million head, had larger populations. The total population of dairy cows in the EU in 2022 was estimated at 20.1 million head. In the European Union, the total production of raw milk in 2022 was 160 million tons. The average lactation yield per cow in 2022 was 7,653 kg (EUROSTAT 2022).

In Poland, the milk yield per lactation from an assessed cow was 8,857 kg in 2021. This yield increased by 3,440 kg from 2000 to 2021, which means an average annual increase in milk yield of 163 kg (PFHBiPM). The milk yield of dairy cows in the USA has steadily increased since the 1950s, growing at an average rate of 1.4% per year from 1980 to 2017, while the annual milk yield per cow grew linearly, with an average regression rate of 141 kg per year (Capper and Cady 2019). In France, the milk yield per assessed cow in 2021 was 8,887 kg, an increase of 180 kg compared to 2020. In Germany, from 2000 to 2022, the milk yield per cow increased from 6,208 kg to 8,504 kg, which is an increase of 2,296 kg (SRD 2024).

The objective of the study was to analyze the production progress related to the amount of milk in selected herds. The following characteristics were analyzed: amount of milk produced, percentage of fat and protein content, protein-energy ratio, as well as FCM and ECM indices. The research was conducted in five dairy cattle herds under the performance monitoring program managed by the Polish Federation of Cattle Breeders and Dairy Farmers (PFHBiPM).

The study period covered 21 years of evaluation conducted from 2000 to 2020.

Literature review: Dairy cattle belong to the order Artiodactyla and the family Bovidae. The wild ancestor of the domesticated form of cattle was the aurochs, *Bos primigenius Bojanus*. It inhabited all of Europe, Asia, and the northern part of Africa. The presence of the aurochs is confirmed by numerous fossil remains found in these areas. According to preserved woodcuts and chronicles, the aurochs resembled large primitive breeds of cattle, such as the Piedmontese cattle or the Hungarian Grey steppe cattle (Vuure 2005; Guliński and Salamończyk 2016).

The domestication of cattle began about 10,000 years ago. Breeds, however, started to differentiate in the second half of the 18th century when the Industrial Revolution in Europe created the need for more efficient milk and meat production (according to Moczarski et al. from 1927, cited in: Sasimowski 1976).

The demand for milk and meat continues to increase. Although cattle were domesticated 10,000 years ago, traditional methods of cattle farming, which involved grazing animals on pastures, were used until the mid-20th century (Socha and Kołodziejczyk 2021).

In 2012, based on data from the Commission on Genetic Resources for Food and Agriculture, 1,210 cattle breeds were registered worldwide, including 107 international, 1,004 local, and 99 regional breeds. Local and regional breeds are mostly dual-purpose, for both milk and meat production, whereas international breeds are generally specialized for either milk or meat production (Czerniawska-Piątkowska et al. 2020).

The most widespread dairy cattle breed is the Holstein-Friesian, developed in the USA, and found in 128 countries. In Poland, 90% of the cattle population is made up of the Holstein-Friesian breed (Guliński 2017).

The Polish Holstein-Friesian cattle breed currently accounts for over 90% of the dairy cattle maintained in Poland (Guliński et al. 2005). Cows produce an average of 6,000 to 8,000 kg of milk per lactation, with a fat content of 4.2% and a protein content of 3.3%. Currently, the Polish Holstein-Friesian cattle constitute 95% of the cattle population in Poland (Juszczak 2001).

Dairy cattle are kept for milk production. Milk is a fundamental human food product in its pure form as well as when processed into cheese, yogurt, buttermilk, and similar products. Milk provides humans with many nutrients essential for health and well-being. Here are some of the nutrients present in cow's milk: protein, calcium, vitamin D, B vitamins, and fats (Staszak 2010; Jeżewska 2018). Protein in cow's milk is one of the most important nutrients in the human diet. Cow's milk is a source of many vitamins, including vitamin A, D, E, K, B1, B2, B3, B5, B6, and B12 (Kuczyńska et al. 2013). Cow's milk is one of the most important sources of fats in the human diet. The chemical composition of fats in cow's milk is quite complex and depends on various factors such as the cow breed, age, diet, and lactation stage (Kowalski 2004).

Genetic and environmental factors influence production progress. When breeding animals, improving their genetic potential by introducing animals with outstanding breeding values into herds from selected breeds with low productivity also requires improving environmental conditions for the animals. Among the basic environmental conditions, feeding animals is crucial, mainly ensuring that cattle receive essential nutrients to enhance their productivity. Based on information from the Polish Federation of Cattle Breeders and Dairy Farmers (PFHBiPM), the productivity of dairy cows in our country has significantly increased. Traditional feeding methods relying mainly on roughage such as grass and silage have been replaced with modern feeding systems like total mixed ration (TMR) and partial mixed ration (PMR). Another significant factor contributing to the increased productivity of dairy cattle is ensuring proper animal welfare, which involves changing the housing system for the animals in barns. To improve the efficiency of dairy cattle breeding and management, it is crucial to significantly increase the number of dairy herds under performance testing. It should be emphasized that the participation of breeders themselves who are involved in cattle rearing and breeding is indispensable in all these efforts.

The issues of breeding and production progress have been analyzed by many authors specializing in cattle breeding and management (Szulc et al. 2016; Guliński 2017), as well as by numerous other international authors.

MATERIAL AND METHODS

The research material came from 5 farms located in the Podlaskie Voivodeship, which are under the milk production control conducted by the Polish Federation of Cattle Breeders and Dairy Farmers (PFHBiPM). Due to personal data protection (GDPR), only farm (herd) numbers were used for identification in the study. The following traits were examined:

- actual milk production,
- percentage of fat content in milk,
- percentage of protein content in milk,
- fat-to-protein ratio,
- milk yield converted to energy corrected milk (ECM) index,
- milk yield converted to fat corrected milk (FCM) index.

The analysis covered five herds of Polish Holstein-Friesian cattle over a period of 21 years from 2000 to 2020.

Farm 1 (herd 1) is located in the Klukowo municipality, Wysokie Mazowieckie county. In the year 2000, the farm maintained 60 cattle in a loose housing system. By 2020, the farm maintained 65 dairy cows. The breeding work of the farm owner, which involved systematically inseminating cows with purebred Holstein-Friesian bulls and replacing animals with purebred Holstein-Friesian cows, resulted in all dairy cows on the farm being of the Polish Holstein-Friesian breed by 2020. From the beginning, the cattle on this farm were fed a feed mix prepared according to the TMR system.

Farm 2 (herd 2) included in the study is located in the Szepietowo municipality, Wysokie Mazowieckie county. In 2000, the herd on the farm consisted of 52 cows, and over the analyzed years, this number gradually increased to 71. Initially, the cattle were kept in a tied housing system and fed traditionally. However, in 2010, with the increase in the herd size, the barn was modernized to a loose housing system, and the feeding method was changed to the TMR system. The cattle kept on the farm were of the Polish Holstein-Friesian breed.

Farm 3 (herd 3) included in the study is located in the Poświętne municipality, Białystok county. In 2000, the farm maintained 19 dairy cattle. However, to increase milk production, the farmer improved the breeding value of the animals by inseminating cows with semen from purebred Holstein-Friesian bulls and expanding the herd with Holstein-Friesian heifers. By 2020, the herd had grown to 85 dairy cows. In 2007, the farmer built a loose housing barn and relocated the herd there. In December 2020, an automated milking system (AMS) was introduced in the barn. In the old-style barn, traditional feeding was practiced until 2007, after which the TMR feeding system was introduced in the new loose housing barn.

Farm 4 (herd 4) included in the study is located in the Korycin municipality, Sokółka county. In 2020, the farm maintained 83 Polish Holstein-Friesian dairy cows. In 2000, the herd consisted of 77 cows, and the number of cows in the herd showed only slight fluctuations over the observed years. From the beginning of the milk production analysis, the cattle were kept in a loose housing barn. Milking took place in a milking parlor. The cattle were fed using the TMR system, and periodically the PMR system.

Farm 5 (herd 5) is located in the Sokoły municipality, Wysokie Mazowieckie county. Over the analyzed years, the farm maintained an average of about 80 dairy cows in two tied housing barns. Until 2008, the cattle were fed traditionally, and then using the TMR system. Milking was carried out using a cordless milking machine. From the beginning, the farm maintained Polish Holstein-Friesian cows.

The collected data on cow productivity over 21 years in the 5 herds included in the study were used to evaluate the analyzed production indicators after changes in the breeding technology were introduced in the respective farms (this particularly applies to herds 2 and 5).

In the analyzed farms, the actual milk yield was converted to ECM content according to the formula (Miciński 2006):

$$ECM (kg) = milk \times [(0,383 \times fat \% + 0, 242 \times protein \% + 0,7832)/3,140)];$$

Milk yield corrected for 4% fat content was calculated as FCM according to the formula (Januś and Borkowska 2006):

$$FCM = 0,4 \times milk\ yield + 15 \times fat\ yield\ (kg).$$

The fat-to-protein ratio was calculated.

The obtained research results were subjected to statistical analysis. Arithmetic means and standard deviations were calculated, taking into account the influences of the year of study, calendar month within the year, and herd (farm). Correlations were also estimated between sources of variability and the analyzed traits, as well as among the analyzed traits. Regression indices were calculated depending on the year of study and month for the traits under investigation.

For each trait, multifactorial analyses of variance with interaction were conducted, taking into account the influences of the year of study, calendar month, and herd (farm). Specialized statistical software SAS was used for the calculations (SAS Institute 2000).

RESULTS

In 5 dairy farming operations undergoing milk production evaluation, a study on production progress was conducted. The research spanned 21 years from 2000 to 2020. The traits analyzed included:

– actual milk yield,
– percentage of fat content,
– percentage of protein content,
– fat-to-protein ratio,
– milk yield converted to FCM and ECM indicators.

Table 1 presents the results of the analysis of variance for the analyzed milk production traits of cows. The data in this table indicate that all factors examined in the study, namely year of study, month, and herd, exerted a significant and highly statistically significant influence on the variability of the evaluated milk production traits in cows. The F-test values for the year of study regarding milk yield, percentage of fat and protein content, fat-to-protein ratio, as well as FCM and ECM were respectively: 89.21**; 7.28**; 15.82**; 2.40**; 107.21** and 98.71**.

Table 2 presents detailed results regarding changes in evaluated indicators over the 21-year period of the study. The data in this table indicate that in the analyzed population of cows, from 2000 to 2021, there was an increase in actual daily milk yield, as well as FCM and ECM milk by 8.4 kg, 9.6 kg, and 9.6 kg respectively. Thus, the annual production progress in daily actual milk yield, FCM milk, and ECM milk was 0.4 kg, 0.46 kg, and 0.46 kg respectively.

The fat content remained fairly stable throughout the entire research period, although there was an upward trend, starting at 4.25% at the beginning of the study period and ending at 4.47% in the last year of the study. Despite varying levels of fat content, all herds in the analyzed farms showed a similar increase in fat content in milk of approximately 0.2%. The protein content showed minor changes, starting at 3.12% in the initial study period and reaching 3.37% by the end of 2020.

The fat-to-protein ratio did not significantly differ between years and ranged from 1.33 to 1.38. Animals on the farms maintained a fairly stable ratio throughout the entire study period, with values consistently between 1.25 and 1.35.

Table 1. Results of the analysis of variance for milk yield, percentage of fat content, percentage of protein content, fat-to-protein ratio, ECM, and FCM indicators (F-test values) for the variability factors determined in the study methodology

Source of variability	Milk yield	Percentage of fat content	Percentage of protein content	STB	ECM	FCM
Year of study	89.21**	7.28**	15.82**	2.40**	107.21**	98.71**
Month of the year	2.21*	4.55**	3.81**	3.04**	2.27*	2.61*
Herd	2629.14**	233.98**	120.40**	179.74**	2069.98**	1985.19**
Interaction month × herd	2.51**	1.83**	1.63**	1.88**	1.82**	1.84*
Interaction year × month	1.08	1.43**	1.20*	1.20*	1.14	1.17
Interaction year × herd	10.65**	3.02**	3.46**	3.88**	10.22**	9.67**

Table 2. Means and standard deviations for daily milk yield, percentage of fat and protein content, as well as FCM and ECM milk yield depending on the year of study

Year	Daily milk yield [kg]		Fat [%]		Protein [%]		ECM [kg]		FCM [kg]		STB	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
2000	20.5	4.4	4.25	0.25	3.13	0.16	20.8	4.1	21.2	4.1	1.35	0.07
2001	21.2	4.6	4.28	0.20	3.12	0.12	21.6	4.4	22.1	4.5	1.37	0.09
2002	22.1	4.2	4.25	0.14	3.14	0.10	22.5	4.1	22.9	4.2	1.35	0.07
2003	22.9	4.4	4.28	0.13	3.15	0.11	23.4	4.3	23.8	4.3	1.36	0.09
2004	23.8	4.6	4.30	0.33	3.22	0.17	24.4	4.4	24.8	4.5	1.38	0.10
2005	23.4	4.6	4.33	0.19	3.24	0.11	24.2	4.4	24.5	4.5	1.38	0.06
2006	23.5	4.9	4.32	0.20	3.22	0.17	24.2	4.7	24.6	4.8	1.34	0.06
2007	23.6	4.8	4.30	0.19	3.25	0.14	24.3	4.6	24.6	4.7	1.32	0.06
2008	23.4	5.1	4.34	0.33	3.25	0.12	24.2	4.8	24.4	4.9	1.33	0.10
2009	24.1	5.4	4.39	0.33	3.21	0.18	25.1	5.1	25.4	5.1	1.37	0.14
2010	24.5	5.1	4.33	0.23	3.20	0.12	25.2	4.9	25.6	5.1	1.35	0.07
2011	25.2	4.8	4.35	0.19	3.19	0.14	26.1	4.6	26.5	4.8	1.36	0.05
2012	25.2	4.9	4.33	0.27	3.24	0.11	26.1	4.8	26.4	4.8	1.34	0.10
2013	24.4	6.4	4.38	0.23	3.27	0.12	25.4	6.1	25.7	6.2	1.34	0.06
2014	25.2	5.4	4.37	0.28	3.25	0.16	26.2	5.2	26.5	5.2	1.35	0.12
2015	25.8	5.5	4.41	0.23	3.29	0.15	27.1	5.2	27.3	5.3	1.34	0.06
2016	25.9	5.8	4.36	0.40	3.28	0.11	26.9	5.5	27.2	5.6	1.33	0.14
2017	26.7	5.9	4.49	0.38	3.29	0.15	28.2	5.6	28.5	5.4	1.37	0.17
2018	26.6	7.1	4.22	0.28	3.32	0.15	27.8	6.9	28.1	7.1	1.33	0.10
2019	27.6	5.9	4.42	0.23	3.30	0.11	29.1	5.8	29.3	5.8	1.34	0.07
2020	28.9	6.7	4.47	0.31	3.28	0.15	30.4	6.4	30.8	6.5	1.36	0.13

$\bar{x}$ – arithmetic mean; SD – standard deviation.

The average milk yield over the span of 21 years of research increased by an average of 8.4 kg per day, starting from 20 kg in 2000 and reaching 29 kg in 2020. This is a significant production improvement of over 30%. Along with the increase in milk yield, the value of the standard deviation increased from 4.26 in 2002 to 7.13 in 2018. The fat content was quite stable throughout the entire research period, although the trend was upward, starting at 4.25% at the beginning of the research period and ending at 4.47% in the last year of the study. The standard deviation of this trait was significant, ranging from 0.13 to 0.40. The protein content underwent slight changes, starting at 3.12% in the initial research period and reaching 3.37% by the end. The value of the standard deviation also showed minor fluctuations, ranging from 0.1 to 0.18. The fat-to-protein ratio did not differ significantly between years, ranging from 1.33 to 1.38, while the standard deviation ranged from 0.058 to 0.175. The FCM performance indicator over the span of 21 years of research increased by 9 kg per day, starting at 21 kg in the year 2000 and reaching 30 kg in 2020. This represents a significant production progress of almost 45%. Along with the increase in milk yield, the differences in the value of the standard deviation also increased, from 4.2 in the year 2000 to 7.0 in 2018. The ECM performance indicator consistently increased over the entire research period, from 21 kg in the year 2000 to 30 kg in 2020. The standard deviation of this trait ranged from 4.07 to approximately 7 units.

Table 3 presents the correlations and significance levels regarding the traits (milk yield, fat percentage, protein percentage, fat-protein ratio, FCM indicator, and ECM indicator) as well as sources of variability (year of study, month of the year, herd). The highest correlation value can be observed between the FCM and ECM indicators, which is 0.9984, and between milk yield and the FCM and ECM indicators, which are 0.9884 and 0.9899, respectively. The lowest correlation value is between protein percentage and fat-protein ratio, which is −0.5318, and between milk yield and fat percentage, which is −0.3848. The herd had a statistically highly significant impact on all analyzed traits.

Table 3. The correlation coefficient between the traits (milk yield, fat percentage, protein percentage, fat-protein ratio, FCM indicator, ECM indicator) as well as sources of variability (year, month, herd)

	Milk yield [kg]	Fat percentage	Protein percentage	Fat-protein ratio [%]	FCM indicator [kg]	ECM indicator [kg]
Year	0.3373 <0.0001	0.2124 <0.0001	0.3218 <0.0001	−0.0226 0.4220	0.3907 <0.0001	0.3995 <0.0001
Month	−0.0128 0.6492	−0.0325 0.2496	0.0746 0.0081	−0.0709 0.0118	−0.0192 0.4962	−0.0148 0.5990
Herd	0.5828 <0.0001	−0.3290 <0.0001	−0.2516 <0.0001	−0.1266 <0.0001	0.5555 <0.0001	0.5465 <0.0001
Milk yield [kg]	1.0000	−0.3849 <0.0001	−0.0364 0.1970	−0.3013 <0.0001	0.9884 <0.0001	0.9899 <0.0001
Fat percentage	–	1.0000	0.1357 <0.0001	0.7609 <0.0001	−0.2433 <0.0001	−0.2626 <0.0001
Protein percentage	–	–	1.0000	−0.5318 <0.0001	−0.0158 0.5759	0.0321 0.2548
Fat-protein ratio [%]	–	–	–	1.0000	−0.1939 <0.0001	−0.2411 <0.0001
FCM indicator [kg]	–	–	–	–	1.0000	0.9984 <0.0001

Table 4 presents the regression coefficients between the traits (milk yield, fat percentage, protein percentage, fat-protein ratio, FCM indicator, and ECM indicator) and sources of variability (year, month). The lowest coefficient was between the month and the FCM indicator (−0.0314).

Table 4. The regression coefficients between the traits (milk yield, fat percentage, protein percentage, fat-protein ratio, FCM indicator, ECM indicator) and sources of variability (year, month)

	Year	Month
Millk yield [kg]	0.3172	−0.0212
Fat percentage	0.0096	−0.0026
Protein percentage	0.0081	0.0033
Fat-protein ratio [%]	−0.0004	−0.0021
FCM indicator [kg]	0.3643	−0.0314
ECM indicator [kg]	0.3699	−0.0241

DISCUSSION

Dairy cattle farming in Poland constitutes a very important economic and food sector. Dairy cattle in Poland are continuously selected and bred in a way that maximizes milk production while maintaining high milk quality (Guliński and Salamończyk 2007). Milk production is crucial for many farms where milk is the main or even the only source of income. This branch of agricultural production is also closely linked to dairy processing, primarily with dairies. Piątkowski et al. (2010) demonstrated that the animal production system is a compromise between elements of ecology, economy, and ethology. The intensification of milk production allows for a reduction in the cattle population while simultaneously increasing overall milk production. In the year 2000, 3.097 million dairy cows were maintained with a milk production of 11,543 million liters.

The milk yield of cattle is measured by the amount of milk one animal produces in a year. The average milk yield of a cow in 2020 in the Podlaskie Voivodeship was 8,697 kg of milk per year (PFHBiPM 2021). The lowest milk yield recorded in 2020 among the studied farms was 7,300 kg per lactation per year in farm number 1. The highest results were noted in farm number 5, where the average annual milk yield was 12,800 kg of milk. Over the years of conducting our own research, milk yield has increased in all farms. Over the years, all the studied farms have made noticeable progress in terms of milk yield. High milk yield in cattle has a positive impact on the dairy economy because the animals produce more milk, which increases profits for farmers and milk producers. One of the factors that affects the milk yield of cattle is the animals' diet. It is important for the diet to be balanced and to provide all the necessary nutrients, such as proteins, carbohydrates, fats, vitamins, and minerals. Grela et al. (2022) also confirms the significant impact of proper nutrition on the level of milk yield. The milk yield of cattle also depends on genetic factors. Breeders strive to select animals with the best milk-producing traits and breed them to produce offspring with high milk yield.

According to Kuczyńska (2014), the goal of breeders should be to have a cow that is healthy and long-lived, yet also productive. Such an animal should produce high-quality milk, which is also useful in cheesemaking. Variables such as these influenced milk yield in the studies:

1. Month: There are statistically significant differences between months in the amount of milk produced. The average amount of milk produced varies depending on the month, and this difference was statistically significant.
2. Herd: There are statistically significant differences between herds in the amount of milk produced. The average amount of milk produced varies depending on the herd, and this difference was statistically significant.
3. Study year: There are statistically significant differences between the study year and the amount of milk produced. The average amount of milk produced varies depending on the study year, and this difference was statistically significant.

Month × Herd Interaction: There are statistically significant interactions between month and herd in the amount of milk produced. Differences in milk production were statistically significant depending on the month and herd. Year × Month Interaction: There are no statistically significant interactions between the study year and month in the amount of milk produced. Year × Herd Interaction: There are statistically significant interactions between the study year and herd in the amount of milk produced.

Differences in the amount of milk produced are statistically significant depending on the study year and herd. In summary, the results of the analysis of variance indicate statistically significant differences between variables in milk production, highlighting the need for further research to identify factors influencing these differences and to improve the efficiency of dairy cattle farming.

Various factors influence milk production. For instance, Sablik et al. (2003, 2014) analyzed the impact of lactation stage on milk yield and milk quality in Polish Holstein-Friesian cows. The study aimed to determine whether specific lactation stages affect the variability of milk yield and milk quality. The research results indicated that the lactation stage significantly affects milk yield and milk quality. The authors concluded that lactation stage is an important factor influencing milk yield and milk quality in Polish Holstein-Friesian cows.

In the traditional approach to measuring milk yield in cows, it is evaluated solely based on the quantity of milk produced. However, the quantity of milk produced does not necessarily reflect its nutritional value and quality, as milk with different chemical compositions can have varying energy values. Measuring milk yield using ECM is beneficial for breeders and milk producers because it allows for a more accurate determination of milk yield values. This enables better planning of nutrition and management of cow herds. The ECM method is used in many countries around the world. To calculate ECM values, a mathematical formula is applied that takes into account the fat, protein, and lactose content in milk, as well as its energy value. The energy value is determined based on a standard milk energy equivalent of 3.4 Mcal/kg. ECM is particularly useful for high-yielding dairy cow breeding because it allows for a more accurate assessment of milk yield.

Dairy cows require carefully balanced nutrition that meets their needs, veterinary care, and proper handling. Farmers must monitor the health of their cattle and their nutrition to provide them with the appropriate nutrients (Sakowski and Suchocki 2013, 2019). For this purpose, various feeding methods are commonly used, such as TMR, in which different feed ingredients such as hay, silage, grains, proteins, fats, and vitamins are combined into a single proportionate mixture. This method allows for precise adjustment of the diet to meet the nutritional needs of animals at various stages of development. It should be noted that there has been an improvement in milk yield in the studied herds, particularly in herds 2 and 5, due to a change in cattle farming technology. These herds transitioned from a traditional feeding system to a TMR system. This resulted in an improvement in both milk yield, increasing from an average of 31.4 kg to 41.2 kg – a rise of approximately 30% (herd 5), and the percentage of protein in milk, increasing from 3.27% to 3.52% – a rise of 0.25% (herd 2).

The issue of changes in milk yield and their impact on its quality after implementing modern technologies using TMR has been highlighted by Fiedorowicz (1998 and 2006). Studies following the adoption of new cattle management technologies showed significant improvements in milk yield and quality. The improvement of milk yield and quality was also analyzed in works by Guliński (2017) and Guliński et al. (2002). The issue of milk quantity and quality and the impact of environmental factors, primarily diverse feeding systems, has been analyzed in studies – including original papers and monographs – by Litwińczuk (2000), Litwińczuk et al. (2018), and Litwińczuk and Szulc (2005). Additionally, Schroeder et al. (2003) investigated the impact of particle size of forage on the use of TMR components by dairy cows. The authors conducted research on a group of dairy cows and compared the results based on the particle size of forage feed. The conclusions from the study indicate a significant impact of feed particle size on digestion and nutrient utilization by dairy cows, which is highly important for the efficiency of TMR (Total Mixed Ration) feeding.

The reality is that intensive production requires a significant improvement in cattle rearing conditions, particularly in terms of nutrition. This affects both the quantity of the final production and the chemical composition of the milk. This issue was highlighted by Reklewski (2008).

The composition of cow's milk can slightly vary depending on the nutrition, health status of the animal, lactation stage, age of the cow, and the breed of the animal (Sakowski and Suchocki 2019). Cow's milk is composed of 87% water, with various proteins (such as casein, albumin, and globulin) making up 3.2 to 3.5% of the milk mass, fat from 3.4 to 4%, and carbohydrates from 4.6 to 5%, with lactose being the main carbohydrate. Additionally, milk contains B-group vitamins as well as vitamins A, D, E, K, and pantothenic acid. Additionally, milk contains minerals such as calcium, potassium, phosphorus, sodium, magnesium, and chlorine. Hanuš et al. (2010) and Januś et al. (2019) demonstrated a connection between the health condition of the animal and the composition and quality of the milk. In their research, they also noticed differences in the composition of milk depending on the farm studied. The fat content in milk depends on many factors, including the breed and diet of the animals from which the milk comes, the season, and the stage of lactation. The average fat content in cow's milk is about 3.7%, but it can range from 2% to 5.5%. In our own studies, the fat content ranged from 4.1% to 4.7%. On average, all farms recorded an increase in milk fat content of about 0.2% over time. Papademas et al. (2019) discuss the factors influencing the fat content in cow's milk. The article presents a review of the scientific literature on the impact of various factors on this content, including genetics, age and stage of lactation, nutrition, seasonality, diseases, and stress.

The protein content in cow's milk is an important factor affecting the quality of milk and dairy products such as cheese and yogurt. Many factors can influence the protein content in milk, including genetics, age, diet, and the lactation level of the cow. Studies have shown that different breeds of cows vary in their milk protein content, with beef breeds tending to produce milk with higher protein content than dairy breeds. Changes in protein content can also be observed with the cow's age, as younger cows produce milk with higher protein content compared to older cows. The cow's diet should be properly balanced to ensure an adequate amount of protein and other nutrients. Feeding cattle high-protein feed can increase the protein content in milk, but it can also lead to higher nitrogen content in the milk, which is unfavorable for the dairy industry. The average protein content in milk from the farms I studied ranged from 3.51% to 3.16% in 2020, whereas in 2000, the average protein content in milk was lower, ranging between 2.97% and 3.28%. All farms, except for farm number 3, recorded an increase in milk quality of about 0.2% protein. Sablik et al. (2003) reported similar results for protein content in milk with a properly balanced feed ration.

The milk productivity of cattle in our country has been the subject of research by many distinguished scholars. Their studies are compiled both in original publications and in monographs and textbooks. It is essential to mention at least some of the authors who have presented the full range of issues related to cattle productivity, namely Litwińczuk (2000), Litwińczuk and Szulc (2005), Reklewski (2005, 2008), Szulc et al. (2013, 2016), Guliński (2017), and Szarek (2010), among many others. These works contain detailed analyses of factors related to cattle breeding and productivity. All these authors highlight the complexity of issues related to cattle rearing and breeding.

To summarize the results obtained in this study, it can be stated that they confirm the well-known and widely described increase in milk productivity of cows in the country over the past 20 years. They reflect the immense dedication of breeders – herd owners – to the overall issues related to improving both environmental factors and the genetic enhancement of cattle herds in terms of milk productivity. However, it should be acknowledged that production progress would not have been possible without improving the breeding value of the animals. High breeding value of the animals requires a significant improvement in environmental conditions, including nutrition, as well as improvements in the animal management system.

CONCLUSIONS

The study evaluated the production progress of selected milk productivity traits of Polish Holstein-Friesian cows over the last 21 consecutive calendar years. The analysis of variance showed that all sources of variability (i.e., year of study, month of the year, herd) and the interaction of year × herd had a statistically significant impact on the evaluated traits (i.e., milk yield, fat percentage, protein percentage, fat-to-protein ratio, and FCM and ECM indices).

The study demonstrated that the daily milk yield over the span of 21 years of research increased by an average of 8.4 kg (30%). The increase in milk yield was confirmed by the evaluated standardizing indices for milk production in terms of ECM (kg) and FCM (kg). These indices increased by an average of 9.6 kg per day over the 21 years of research.

The fat content was consistent throughout the entire research period, although there was a slight upward trend, starting at 4.25% at the beginning of the period and ending at 4.47% in the final year of the study. Despite varying fat levels, all herds in the analyzed farms experienced a similar increase in milk fat content of approximately 0.2%. The protein content underwent minor changes, starting at 3.12% in the initial period of the study and reaching 3.37% by the end in 2020. During the evaluated period, all farms recorded an increase in milk protein content of approximately 0.2% (with the exception of herd 3).

The fat-to-protein ratio did not differ significantly between the years, ranging from 1.33 to 1.38. The animals in the farms maintained a fairly stable ratio throughout the entire research period, with values ranging from 1.25 to 1.35.

The achieved production progress in terms of milk quantity and quality was due to both the improvement of the animals' breeding value and the enhancement of environmental factors, mainly nutrition. In these herds, the feeding system was changed from traditional to the TMR (Total Mixed Ration) feeding system.

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ANALIZA POSTĘPU PRODUKCYJNEGO W WYBRANYCH STADACH BYDŁA MLECZNEGO OBJĘTYCH OCENĄ WARTOŚCI UŻYTKOWEJ. CZĘŚĆ 1. ANALIZA POSTĘPU PRODUKCYJNEGO W ZAKRESIE WYDAJNOŚCI MLECZNEJ, W TYM WYDAJNOŚCI MLEKA, PROCENTU BIAŁKA I PROCENTU TŁUSZCZU ORAZ ICH WZAJEMNEJ RELACJI

Streszczenie. Celem pracy była analiza postępu produkcyjnego w wybranych stadach bydła mlecznego objętych oceną wartości użytkowej. Przeprowadzono analizę cech produkcyjnych takich jak: wydajność mleczna, procentowa zawartość tłuszczu, procentowa zawartość białka oraz następujących źródeł zmienności: rok badań, miesiąc w roku oraz stado. Ponadto obliczono stosunek tłuszczowo-białkowy (STB) oraz wskaźniki mleka przeliczone na zawartość energii (ECM) i zestandaryzowane na 4% zawartość tłuszczu (FCM) w okresie 21 lat. Wyniki analizy wariancji dla cech produkcyjnych wykazały, że wszystkie źródła zmienności (rok badań, miesiąc w roku, stado) miały statystycznie wysoki wpływ na oceniane cechy (wydajność mleczną, procentową zawartość tłuszczu i białka, STB oraz wskaźniki FCM i ECM). Przeprowadzono również analizę wariancji dla interakcji: miesiąc × stado, rok × miesiąc oraz rok × stado.We wszystkich analizowanych stadach odnotowano znaczący postęp produkcyjny w zakresie ocenianych cech użytkowości mlecznej. Stwierdzono, że w analizowanym okresie 21 lat wzrosła użytkowość mleczna w wybranych stadach krów. Za podstawę sukcesu produkcyjnego uznano zmianę technologii chowu krów. Zmiana tradycyjnego systemu na system TMR (ang. *total mixed ration* – całkowicie wymieszana dawka) przyczyniła się do poprawy zarówno wydajności mlecznej, jak i składu jakościowego. Uzyskane wyniki mają bardzo duże znaczenie aplikacyjne, wskazujące, że w stadach bydła mlecznego korzystanie z nowoczesnych systemów technologicznych w postaci systemu żywienia TMR skutkuje znaczącym wzrostem użytkowości mlecznej krów.

Słowa kluczowe: produkcja mleka, gospodarstwo rolne, bydło, postęp fenotypowy.