

A comparison between Polish Holstein-Friesian and F₁ hybrid Polish Holstein Friesian × Swedish Red cows in terms of milk yield traits

DOI: 10.15567/mljekarstvo.2021.0207

*Paweł Solarczyk, Jan Ślósarz, Marcin Gołębiewski, Kamila Puppel**

Warsaw University of Life Sciences, Institute of Animal Sciences, Department of Animal Breeding, Ciszewskiego 8, 02-786 Warsaw, Poland

Received: 15.07.2020. / Accepted: 16.02.2021.

*Corresponding author: kamila_puppel@sggw.edu.pl

Abstract

The intensive breeding work of Holstein-Friesian cattle has led to the decrease in the diversity within the population and to inbreeding depression, which may impair its functional traits. In addition, as shown by the research, production traits are negatively correlated with functional traits such as reproduction, health, and longevity, which have a very strong impact on the profit of dairy farms. The aim of this study was to compare milk yield traits of hybrids obtained by crossbreeding of Polish Holstein Friesian (PHF) cows and Swedish Red (SRB) bulls with values obtained for pure PHF cows. For the study, 100 primiparous cows were selected and divided into two groups. The experimental group consisted of 50 crossbreds (PHF×SRB), while the control group consisted of 50 purebred PHF cows. The study showed a higher content of milk components (fat by 11.78 %, protein by 9.06 %, dry matter by 5.75 %) in PHF×SRB, as compared to PHF. A lower level of SCC (by 38.94 %) has also been shown in hybrids, which indicates their higher resistance to udder diseases. The experiment demonstrated a highly significant impact of heterosis on performance parameters and technological quality of milk in F₁ generation obtained as a result of crossbreeding between PHF cows and SRB bulls.

Key words: inbreeding; inbreeding depression; crossbreeding; heterosis; milk

Introduction

According to the commonly accepted definition, heterosis is a phenomenon consisting in increasing the phenotypic value of quantitative traits of the first generation of hybrids with respect to homozygous parents. The effects of heterosis are opposite to the effects of inbreeding depression, if the breeds are properly selected for breeding. Therefore, any crossbreeding program should start from an appropriate selection of breeds, which should be complementary.

Dairy farming around the world is based on the most efficient Holstein Friesian (HF) breed of two color varieties: black and white (HO), and red and white (RW). In Poland, the local variety is Polish Holstein Friesian (PHF) breed, which was created as a result of crossing the Polish Black - White and Polish Red - White cows with HF bulls (Nowicki, 2011). According to the data of the Polish Federation of Cattle Breeders and Dairy Farmers (PFCBDF), in 2019 the PHF breed accounted for almost 88.61 % of the active population (HO - 84.87 %, RW - 3.81 %). In 2018, the average life expectancy of the PHF breed of the HO variety was 5.41 years, whereas of the RW was 5.37 years, which indicates that cows have been in use for almost 3 years (HO - 2.93 years, RW - 2.79 years) (PFHBiPM, 2020), but the length of use has been shortened in relation to the results obtained in 2016 (Adamczyk et al., 2017). The earlier deficiency is associated with cow's health problems (82.84 %) (Adamczyk et al., 2017), which very often starts with high nutritional requirements, especially with regard to energy demands in the early stages of lactation, leading to problems with metabolic disorders (Puppel and Kuczyńska, 2016; Puppel et al., 2017; Puppel et al., 2019). According to Adamczyk et al., (2017), they are the direct cause of about 8 % of deficiencies in the PHF breed, which was also observed by Ghaderi-Zefrehei et al. (2017). Among metabolic diseases, ketosis is the most important and common disease affecting dairy herds (van der Drift et al., 2012). Metabolic diseases are usually only the starting point of growing expenses related to veterinary care, because very often they are accompanied by problems with udder inflammation and reproduction (Adamczyk et al., 2017; Clasen et al., 2017). However, these problems are related not only to the high energy demand and poorly balanced feed (Schaeffer et al., 2011; Puppel et al., 2018). The selection of only the best bulls in terms of production traits caused a deterioration in the results of functional traits such as health, fertility, and longevity (Smith et al., 1998; Thompson et al., 2000; Adamec et al., 2006; Bjelland et al., 2013; Pryce et al., 2014; Doekes et al., 2019; Hofmannová et al., 2019). Such a breeding model reduced the diversity of the population, leading to inbreeding depression, which reduces the level of productivity (Schaeffer et al., 2011; Smith et al., 1998; Thompson et al., 2000; Adamec et al., 2006; Bjelland et al., 2013; Pryce et al., 2014; Doekes et al., 2019; Hofmannová et al., 2019). According to Pryce et al. (2014), a 1 % increase in the inbreeding level was associated with a decrease in milk yield by 28 L/lactation in Holstein-Friesian cows, and by 12 L/lactation in

Jersey cows. Additionally, the increase in inbreeding level was correlated with a decrease in milk, fat, and protein yields. Also, Smith et al. (1998) and Doekes et al. (2019) showed that an increase in the inbreeding level by 1 % in HF resulted in productivity reduction by 36.3 kg and 27 kg/lactation, respectively. In addition to the problems associated with increased homozygosity, there may also appear problems with an increased incidence of rare lethal or harmful recessive disorders, such as bovine leukocyte adhesion deficiency - BLAD (Kehrl et al., 1990) or uridine monophosphate synthase deficiency - DUMPS (Shanks et al., 1984).

The increasing level of inbreeding does not allow taking full advantage of the effect of the breeding progress. Therefore, crossing procedures become an excellent alternative because these extend the length of animal use, improve reproduction parameters, and reduce metabolic disorders (PFHBiPM, 2017; PFHBiPM, 2018; PFHBiPM, 2019; PFHBiPM, 2020; Sørensen et al., 2008). In addition, a steady increase in the inbreeding of the Holstein-Friesian population (around +0.2 % per year) indicates that crossings will be necessary for most milk producers in the future. Modern breeding should be focused on product quality as well as animal health and welfare, because they guarantee the profitability of production. The main goal of crossbreeding Holstein-Friesian cows with bulls of other dairy breeds is to improve performance traits. Thus, the aim of this study was to compare Polish Holstein-Friesian and F1 hybrid Polish Holstein Friesian × Swedish Red cows in terms of milk yield traits.

Material and methods

The experiment was carried out in an experimental dairy farm of the Warsaw University of Life Sciences (WULS, Warsaw, Poland), where about 350 cows were kept in a free stall housing system with an average yield exceeding 10,000 kg of milk in lactation. For the study, 100 primiparous cows were selected and divided into two groups. The experimental group consisted of 50 crossbreeds (Polish Holstein Friesian × Swedish Red; PHF×SRB), while the control group consisted of 50 purebred PHF cows. Data from milk performance evaluation were the basis for obtaining information on milk performance (milk production in individual lactation months, fat, protein, dry matter content, somatic cell count and milk performance in the whole lactation). Samples of milk were collected from the cows for laboratory analyses at monthly intervals, at ten time points. FTIR was used to analyze the composition of the milk. The cows' feeding regime was based on the total mixed ration (TMR) diet (*ad libitum*) (Table 1).

The data obtained were analysed statistically using IBM SPSS 6.0 package. The distribution of the milk chemical composition was checked by the Shapiro-Wilk test. The ANOVA analysis was performed to establish influence of the genotype on milk chemical composition and somatic cell count (SCC). The changes in concentration of basic

Table 1. Ingredient and chemical composition of the TMR

TMR diet	
Ingredient [kg/dDM]	
Maize silage	9.23
Alfalfa silage	3.70
Corn silage	2.42
Soybean meal	2.32
Pasture ground chalk	0.20
VIT-RA BML- vitamin mix	0.20
Salt	0.05
Rapeseed meal	2.17
Magnesium oxide	0.07
Chemical composition [g/kgDM]	
Ash	5.25
Crude protein	16.05
Fat	4.94
Starch	291.11
Sugar	76.95
Acid detergent fiber	30.19
Neutral detergent fiber	41.33
Ca	0.93
P	0.63
NEL (Mcal/kg)	1.64
Total, kg of DM (offered)	21.13
Daily intake (kg)	19.22
Average milk production (kg)	33.21
UFL (unit of milk production) balance (%)	3.19
PDIN (protein digested in the small intestine when rumen-fermentable nitrogen is limiting)	2.31
PDIE (protein digested in the small intestine when rumen-fermentable energy is limiting)	-2.81

TMR - total mixed ration

chemical components in regard of genotype and lactation stage were established by the multi-variance analysis.

The following statistical model was applied:

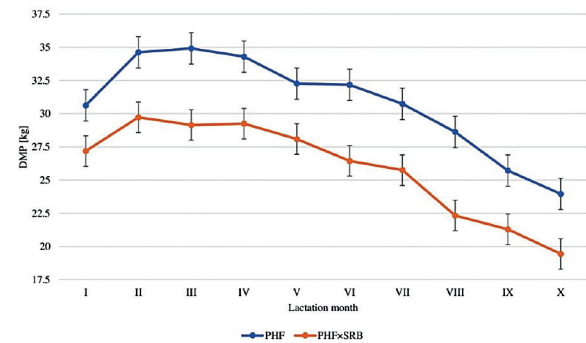
$$Y = \mu + A_i + B_j + (A \times B)_{ij} + e_{ijk}$$

where, μ - mean, A_i - day in lactation, B_j - genotype (PHF, PHF×SRB), $A \times B$ - interaction between day in lactation and genotype, e_{ij} - random error. Only the interactions between factors whose influence was statistically significant ($P \leq 0.01$ or $P \leq 0.05$) were considered. The Pearson's correlation was used to quantify the degree of a linear relationship between two variables (x and y).

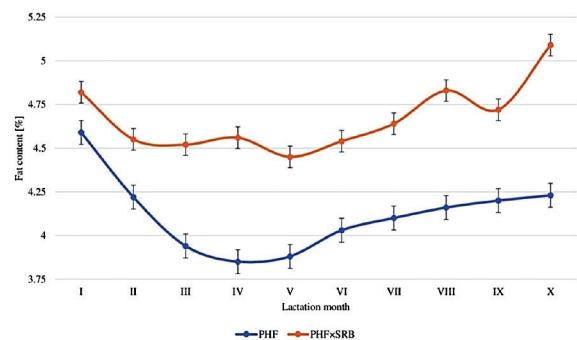
Results and discussion

Figure 1 shows the lactation curves of PHF and PHF×SRB cows. The lactation curve is a reflection of the daily production of milk, which is a resultant of both genetic and environmental factors. The shape of both curves is similar, which may indicate that neither purebred cows or hybrids had feeding problems. Heins et al. (2006) also showed a similar trend. According to Lopez et al. (2015), the peak lactation in HF cows is between weeks 4 and 8

of lactation. However, as shown by results obtained, the peak lactation in cows from the PHF group fell on the 3rd month after calving, i.e. about the 9th week of lactation. PHF×SRB crossbreds reached their lactation peak earlier, which decreased in the second month of lactation, i.e. about 5 weeks after calving. Similar tendencies were observed by Słószar et al. (2016).

**Figure 1.** Lactation curve

PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red; DMP: daily milk production
Samples of milk were collected from the cows for laboratory analyses at monthly intervals, at ten time points

**Figure 2.** Changes in the content of fat depending on genotype

PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red
Samples of milk were collected from the cows for laboratory analyses at monthly intervals, at ten time points

Figure 2 shows changes in fat content of milk from PHF group cows and from PHF×SRB group cows. Fat content depends on many factors including health status, food intake, performance, and physiological status. The obtained results showed significant differences in the level of this component during the lactation period. The first month of lactation was characterized by a high concentration of fat, after which it decreased to the metabolic state, and by changes in both the amount of milk produced and dietary dose. This dependence was confirmed by Heins et al. (2008) and Kuczyńska et al. (2011). The dilution effect was observed in the present study after the 1st till the 5th month of lactation, both in the purebred cows and the hybrids. However, the reduction in fat content was more tangible

in the purebred cows (-0.74 %) than in the hybrids (-0.37 %). The obtained trends confirm those reported earlier by Ślósarz et al. (2016). After the 5th month of lactation, the fat content increased, due to the changing physiological and metabolic state of cows, as well as to decreasing productivity, which is confirmed in Figure 1. Changes in fat content in relation to milk production were confirmed by a negative correlation of -0.245 (Table 2).

Table 2. Pearson correlations between individual milk components

Variable	DMY	Fat	Protein	Dry matter	SCC
DMY	1	-0.245**	-0.583**	-0.375**	-0.049
Fat	-0.245**	1	0.397**	0.945**	0.000
Protein	-0.583**	0.397**	1	0.647**	0.860
Dry matter	-0.375**	0.945**	0.647**	1	0.110
SCC	-0.049	0.000	0.860	0.110	1

**Correlation significant at a 0.01 level (two-sided). DMY - daily milk yield; SCC - somatic cell count

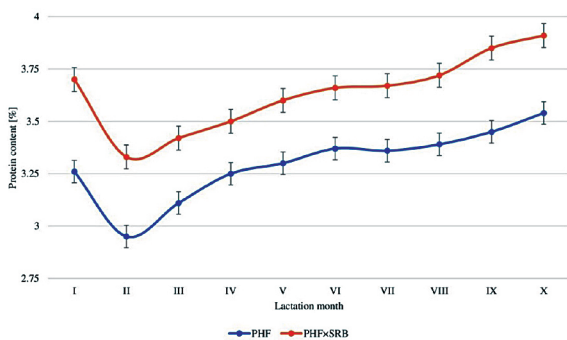


Figure 3. Changes in the content of protein depending on genotype

PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red
 Samples of milk were collected from the cows for laboratory analyses at monthly intervals, at ten time points

Figure 3 shows changes in the protein content of milk. The high technological quality of milk is associated to the concentration of total proteins; in particular to the casein content, which is responsible for both, the rate of formation of the curd and its compactness, making it one of the most important components of the raw material. This ingredient is of a great interest not only to dairies, but also to farmers, who perceive it as a factor affecting the higher price of raw material (Król et al., 2011). Protein is one of the milk constituents that is difficult to modify, since its content can mainly be obtained by working in this direction selection of genetics. This component is a highly inherited trait ($h^2 = 0.3-0.5$) (Toghiani, 2012; Hofmannová et al., 2019), hence the measures undertaken to increase its content in milk are not difficult to control, as in the case of low-hereditary traits. The obtained results show that the protein content was similar in the whole lactation period

in both the purebred and crossbred cows, which indicates, first of all, consistent breeding work of the whole dairy herd in which the experiment was conducted. The difference visible from the very beginning is related to the higher content of this component in hybrids, which is connected with the use of SRB breed, which according to PFCBDF data is characterized by a significantly higher average protein content in comparison with PHF cows (SRB 3.55 %, PHF HO 3.34 %, respectively) (PFHBiPM, 2020). However, Ezra et al. (2016) did not show any significant differences in protein content between HF and HF×NRF. In the present study, at the beginning of lactation, the protein content was at the highest level, which was associated to the physiology and colostrum secretion, i.e. colostrum is rich in immunoglobulins and whey proteins. The concentration of this component then decreased to the lowest level in the second month of lactation, which was probably associated with a high energy demand (Figure 3). Additionally, studies have shown that the protein content of milk is negatively correlated with milk production, which is confirmed by result -0.583 (Table 2). Moreover, Heins et al. (2006) confirmed a higher protein content in the milk of the crossbreds, while Hazel et al. (2017) demonstrated higher fat and dry matter contents and higher milk yields.

Changes in the dry matter content during lactation in purebreds and hybrids are presented in Figure 4. Dry matter is a very important parameter from the technological point of view, it is a resultant of components such as: protein, fat, lactose and other components defined as ash (Jaworski and Kuncewicz, 2007). Our research showed differences in the dry matter content, which may be indicative of a higher technological usefulness of hybrid milk. Studies have shown that the appearance of the curve is similar to that obtained in Figures 2 and 3, confirming the dilution effect, and a significant correlation between fat (0.945), protein (0.647), and dry matter (Table 2). A similar relationship was established by Jaworski and Kuncewicz (2007). The obtained results demonstrate a significantly higher content of particular milk components (fat by 11.78 %, protein by 9.06 %, dry matter by 5.75 %) in PHF×SRB in comparison to the milk of PHF cows. Similar trend was observed by Swalve (2007), Malchiodi et al. (2011), and Malchiodi et al. (2014).

Figure 5 shows changes in the cytological quality (SCC) during lactation. The number of somatic cells in milk is an indicator of udder health and technological quality of milk. According to Malinowski (2001), environmental factors such as cow's age, lactation phase, and calving period have a small influence on the somatic cell count in milk. Piepers et al. (2009) and De Vlieghe et al. (2012) have shown the udder inflammation in heifers to be a common problem affecting milk production during the first lactation. Archer et al. (2013a, 2013b, 2014c) demonstrated that a higher content of somatic cells between the 5th and 30th day after calving reduced milk production not only during the first lactation, but also affected the possibility of udder inflammation in later lactations, life expectancy of cows, and length of their use. According to Juozaitiene and Juozaitis (2005), the SCC up to 100,000/mL in milk

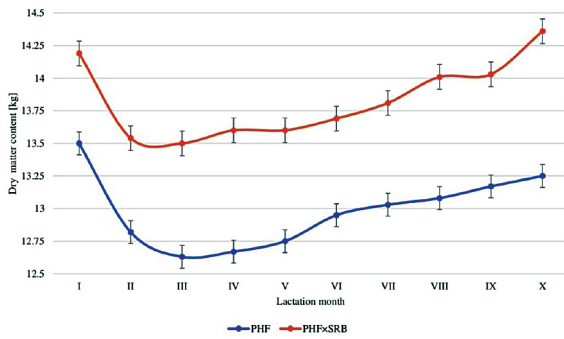


Figure 4. Changes in the content of dry matter depending on genotype

PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red
 Samples of milk were collected from the cows for laboratory analyses at monthly intervals, at ten time points

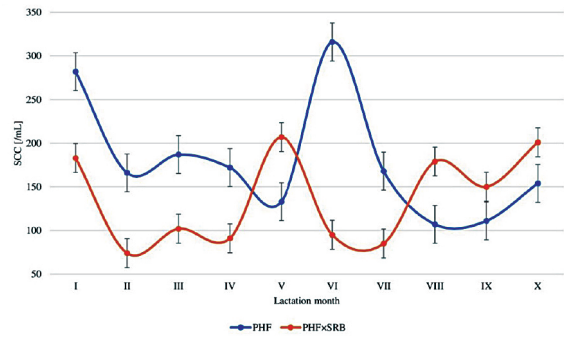


Figure 5. Changes in the content of SCC depending on genotype

PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red; SCC: somatic cell count
 Samples of milk were collected from the cows for laboratory analyses at monthly intervals, at ten time points

indicates healthy udder, while that above 200,000 /mL in milk indicates the occurrence of subclinical mastitis. In the present study, in the first month of lactation of purebred cows and hybrids we found a higher number of somatic cells in milk than in the following months, which is due to the beginning of lactation and changes related to the production and secretion of milk with lower efficiency. It is worth noting that the content of somatic cells in the purebred cows exceeded 200,000 /mL, which according to Juozaitiene and Juozaitis (2005) proves the occurrence of subclinical mastitis. In hybrids, however, the content of somatic cells did not exceed this value, which may indicate their higher resistance to mastitis. In the final stage of lactation, the number of somatic cells increased in both analysed groups, which was caused by the lower milk production and ongoing lactation. A similar trend, in which at the beginning and in the end of lactation the content of somatic cells in milk is higher, and at the peak of lactation a lower number of somatic cells is maintained, was shown by Jakiel et al. (2011). In our study, crossbreds were characterized by a lower level of somatic cells (38.94 %) in comparison to PHF, which indicates their greater resistance to udder disease, which was also confirmed by Heins and Hansen (2012a, 2012b). In the studies by Swalve (2007), Malchiodi et al. (2011), and Hazel et al. (2017), the crosses of HF×SRB and HF×SR were characterized by a higher SCC than the purebred HF.

Table 3 presents the average production values for purebred PHF and crossbreds. Daily milk production in the first lactation was significantly higher by 14.61 % in the purebreds than in the crossbreds. A similar relationship was found in the studies by Heins et al. (2006), Malchiodi et al. (2011), Malchiodi et al. (2014), Piccardi et al. (2014), and Saha et al. (2017). However, Puppel et al. (2018) demonstrated that PHF×MO cows were characterized by the highest milk yield, reaching 27.97 kg, while the lowest daily performance has been demonstrated for PHF×NO cows -18.93 kg. These results do not confirm the reports of other authors (Neja et al., 2010; Brodziak et al., 2012; Litwińczuk et al., 2014) concerning the daily milk producti-

on in PHF breed, which according to these researchers is higher in comparison with cows of other breeds.

On the basis of the results obtained for the fat-to-protein ratio (FPR), it can be concluded that the feeding dose for both groups of animals was composed correctly and the animals did not show any metabolic disorders; due to the average value of this parameter (1.26 for PHF and 1.29 for PHF×SRB). According to Haas and Hofirek (2004), the appropriate FPR in milk should be from 1.2 to 1.4. A ratio below 1.1 indicates the occurrence of a metabolic disorder such as acidosis. However, the ratio above 1.5 may indicates the occurrence of ketosis (Riehardt, 2004; Puppel and Kuczyńska, 2016), which was also confirmed by Ranaraja et al. (2018).

Table 3. Daily milk production [kg] and chemical composition of milk [%]

Variable	Breeds		P-value
	PHF	PHF×SR	
DMY [kg]	LSM	30.36	0.000
	SEM	7.221	
Fat [%]	LSM	4.16	0.000
	SEM	0.763	
Protein [%]	LSM	3.31	0.000
	SEM	0.311	
Dry matter [%]	LSM	13.04	0.000
	SEM	0.917	
SCC [10 ³ /mL]	LSM	181.47	0.064
	SEM	322.678	
Fat/Protein	LSM	1.26	0.489
	SEM	0.226	

LSM - Least square of mean; SEM - Standard error of LSM.
 PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red; DMY: daily milk yield; SCC: somatic cell count

Table 4. Milk performance of Polish Holstein Friesian × Swedish Red and pure Polish Holstein Friesian cows

Milk performance		Breeds		P-value		
		PHF	PHF×SRB			
Days in Milk	LSM	297.71	273.50	0.001		
	SEM	17.738	42.100			
Milk [kg]	LSM	9038.48	7245.02	0.000		
	SEM	674.169	1389.856			
Fat	[%]	LSM	4.13	4.65	0.000	
		SEM	0.472	0.607		
	[kg]	LSM	376	336.89		0.069
		SEM	41.854	76.728		
Protein	[%]	LSM	3.31	3.61	0.000	
		SEM	0.177	0.223		
	[kg]	LSM	299.17	261.55		0.001
		SEM	17.938	42.126		
Dry matter	[%]	LSM	13.04	13.79	0.000	
		SEM	0.568	0.752		
	[kg]	LSM	1178.62	999.09		0.000
		SEM	74.787	186.546		

LSM - Least square of mean; SEM - Standard error of LSM.
PHF: Polish Holstein Friesian; PHF×SRB: Polish Holstein Friesian x Swedish Red.

Table 4 presents the results concerning milk performance results for full lactation of purebred PHF and PHF×SRB cows. The longer lactation (by 63.47 days) was shown in the PHF cows in comparison to the crossbreds; which may indicate problems with reproduction of the purebred cows. During the prolonged lactation, milk production by purebred cows is significantly higher (by 2919.4 kg), and the milk is characterised by lower contents of individual components (fat -0.50 %, protein -0.28 %, dry matter -0.74 %) that determine its technological quality, in comparison to milk from the hybrids. However, the amount of raw material obtained, despite the lower concentration of the above mentioned components, results in a higher milk yield from the PHF cows (fat +76.11 kg, protein +73.7 kg, dry weight +313.97 kg). Heins et al. (2006) reported a lower milk yield by hybrids with Scandinavian Red breeds (SR) during lactation, but the difference was not as big as in the present research. Whereas Petraškiene et al. (2011) and Petraškiene et al. (2013) stated that the milk yield of HF×SRB hybrids was similar to that of the HF cows. Slósarz et al. (2016) also achieved similar results.

Conclusion

Crossbreeding between the PHF and SRB breeds has a positive effect on the content of fat, protein and dry matter in milk, as well as on udder health. Additionally, the crossbreds were characterized by shorter lactation than the purebred PHF, which may be indicative of their smaller reproductive problems. However, more study is needed on the effects of crossing between breeds on dairy cattle.

Acknowledgements:

The paper is a part of the PhD thesis of MSc Paweł Solarczyk

Usporedba proizvodnih osobina poljskih holstein-friesian krava s F¹ križankama poljskog holstein-friesian × švedskog crvenog goveda

Sažetak

Intenzivan uzgojno-selekcijski rad u holstein-friesian populaciji doveo je do smanjenja genetske raznolikosti unutar populacije i povećanja razine uzgoja u srodstvu, što može oslabiti proizvodne karakteristike. Uz to, dosadašnja istraživanja upućuju na to da su proizvodne karakteristike u negativnoj korelaciji s funkcionalnim karakteristikama, kao što su reprodukcija, zdravlje i duljina života, što ima vrlo visok utjecaj na profit mliječnih farmi. Cilj ovog istraživanja je usporediti proizvodne osobine križanki poljskog holstein-friesian (PHF) × švedskog crvenog goveda (SRB), s proizvodnim osobinama jedinki čistokrvnog poljskog holstein-friesian goveda. Istraživanje je provedeno na 100 prvotelki podijeljenih u dvije skupine, 50 križanki (PHF × SRB) i 50 čistokrvnih PHF prvotelki. Utvrđen je veći sadržaj komponenti mlijeka (mliječne masti za 11,78 %, mliječnih proteina za 9,06 %, suhe tvari za 5,75 %) kod križanki (PHF × SRB) u odnosu na čistokrvne PHF prvotelke. Niža razina SCC-a (za 38,94 %) utvrđena je kod križanki, što ukazuje na njihovu veću otpornost na oboljenja vimena. Istraživanje je ukazalo na značajan učinak heterozisa na sadržaj mliječne masti, mliječnog proteina i broja somatskih stanica u mlijeku.

Ključne riječi: holstein-friesian; heterozis; proizvodnja mlijeka, broj somatskih stanica

References

- Adamczyk, K., Makulska, J., Jagusiak, W., Węglarz, A. (2017): Associations between strain, herd size, age at first calving, culling reason and lifetime performance characteristics in Holstein-Friesian cows. *Animal* 11, 327-334. <https://doi.org/10.1017/S1751731116001348>.
- Adamec, V., Cassell, BG., Smith, EP., Pearson, RE. (2006): Effects of Inbreeding in the Dam on Dystocia and Stillbirths in US Holsteins. *Journal of Dairy Science* 89, 307-314. [https://doi.org/10.3168/jds.S0022-0302\(06\)72095-1](https://doi.org/10.3168/jds.S0022-0302(06)72095-1).
- Archer, SC., Mc Coy, F., Wapenaar, W., Green, MJ. (2013a): Association between somatic cell count early in the first lactation and the lifetime milk yield of cows in Irish dairy herds. *Journal of Dairy Science* 96, 2951-2959. <https://doi.org/10.3168/jds.2012-6294>.
- Archer, SC., Mc Coy, F., Wapenaar, W., Green, MJ. (2013b): Association between somatic cell count after first parturition and cumulative milk yield in dairy cows. *Veterinary Record*, 173. <https://doi.org/10.1136/vr.101558>.
- Archer, SC., Mc Coy, F., Wapenaar, W., Green, MJ. (2013c): Association between somatic cell count early in the first lactation and the longevity of Irish dairy cows. *Journal of Dairy Science* 96, 2939-2950. <https://doi.org/10.3168/jds.2012-6115>.
- Bjelland, DW., Weigel, KA., Vukasinovic, N., Nkrumah, JD. (2013): Evaluation of inbreeding depression in Holstein cattle using whole-genome SNP markers and alternative measures of genomic inbreeding. *Journal of Dairy Science* 96, 4697-4706. <https://doi.org/10.3168/jds.2012-6435>.
- Brodziak, A., Litwińczuk, A., Topyła, B., Wolanciuk, A. (2012): Wpływ interakcji sezonu produkcji z rasą i systemem żywienia krów na wydajność i właściwości fizykochemiczne mleka. *Roczniki Naukowe Polskiego Towarzystwa Zootechnicznego* 8, 19-27.
- Clasen, JB., Norberg, E., Madsen, P., Pedersen, J., Kargo, M. (2017): Estimation of genetic parameters and heterosis for longevity in crossbred Danish dairy cattle. *Journal of Dairy Science* 100, 6337-6342. <https://doi.org/10.3168/jds.2017-12627>.

9. De Vliegher, S., Fox, LK., Piepers, S., Mc Dougall, S., Brkema, HW. (2012): Invited review: Mastitis in dairy heifers: Nature of the disease, potential impact, prevention, and control. *Journal of Dairy Science* 95, 1025-1040.
[https://doi.org/ 10.3168/jds.2010-4074](https://doi.org/10.3168/jds.2010-4074).
10. Doekes, HP., Veerkamp, RF., Bijma, P., de Jong G., Hiemstra, S.J., Windig, J.J. (2019): Inbreeding depression due to recent and ancient inbreeding in Dutch Holstein-Friesian dairy cattle. *Genetics Selection Evolution*, 51.
[https://doi.org/ 10.1186/s12711-019-0497-z](https://doi.org/10.1186/s12711-019-0497-z).
11. Ezra, E., Van Straten, M., Weller, JI. (2016): Comparison of pure Holsteins to crossbred Holsteins with Norwegian Red cattle in first and second generations. *Animal* 10, 1254-1262.
[https://doi.org/ 10.1017/S1751731116000239](https://doi.org/10.1017/S1751731116000239).
12. Ghaderi-Zefrehei, M., RabbaniKhah, E., Baneh, H., Peters, SO., Imumorin, IG. (2017): Analysis of culling records and estimation of genetic parameters for longevity and some production traits in Holstein dairy cattle. *Journal of Applied Animal Research* 45, 524-528.
<https://doi.org/10.1080/09712119.2016.1219258>.
13. Haas, D., Hofirek, B. (2004): The diagnostic importance of milk components for a human and cow's health. *CUA Prague, Proceedings of contributions: Milk day*, 26-29.
14. Hazel, AR., Heins, BJ., Hansen, LB. (2017): Production and calving traits of Montbeliarde × Holstein and Viking Red × Holstein cows compared with pure Holstein cows during first lactation in 8 commercial dairy herds. *Journal of Dairy Science* 100, 4139-4149.
<https://doi.org/10.3168/jds.2016-11860>.
15. Heins, BJ., Hansen, LB. (2012a): Short communication: Fertility, somatic cell score, and production of Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbreds versus pure Holsteins during their first 5 lactations. *Journal of Dairy Science* 95, 918-924.
<https://doi.org/10.3168/jds.2011-4523>.
16. Heins, BJ., Hansen, LB., De Vries, A. (2012b): Survival, lifetime production, and profitability of Normande × Holstein, Montbeliarde × Holstein, and Scandinavian Red × Holstein crossbreds versus pure Holstein. *Journal of Dairy Science* 95, 1011-1021.
<https://doi.org/10.3168/jds.2011-4525>.
17. Heins, BJ., Hansen, LB., Seykora, AJ. (2006): Production of pure Holstein versus crossbreds of Holstein with Normande, Montbeliarde and Scandinavian Red. *Journal of Dairy Science* 89, 2799-2804.
[https://doi.org/10.3168/jds.S0022-0302\(06\)72356-6](https://doi.org/10.3168/jds.S0022-0302(06)72356-6).
18. Heins, BJ., Hansen, LB., Seykora, AJ., Johnson, DG., Linn, JG., Romano, JE., Hazel, AR. (2008): Crossbreds of Jersey × Holstein compared with pure Holsteins for production, fertility, and body and udder measurements during first lactation. *Journal of Dairy Science* 91, 1270-1278.
<https://doi.org/10.3168/jds.2007-0564>.
19. Hofmannová, M., Přebyl, J., Krupa, E., Pešek P. (2019): Estimation of inbreeding effect on conception in Czech Holstein. *Czech Journal of Animal Science* 64, 309-316.
<https://doi.org/10.17221/154/2018-CJAS>.
20. Jakiel, M., Jesiołkiewicz, E., Ptak, E. (2011): Zależność między zawartością komórek somatycznych a cechami wydajności mlecznej w mleku krów rasy PHF odmiany czarno-białej. *Roczniki Naukowe Polskiego Towarzystwa Zootechnicznego* 7, 9-17.
21. Jaworski, J., Kuncewicz, A. (2007): Właściwości fizykochemiczne mleka. Mleczarstwo. Ziarka, S. Wydawnictwo UWM. Olsztyn, Poland, 1, 53-99.
22. Juozaitiene, V., Juzaitis, A. (2005): The influence of somatic cell count in milk on reproductive traits and production of Black – and White cows. *Veterinarski Archiv* 75, 407-414.
23. Kehrl, M., Schmalstieg, FC., Anderson, DC., van der Maaten, MJ., Hughes, BJ., Ackermann, MR., Wilhelmsen, CL., Brown, GB., Stevens, MG., Whetstone, CA. (1990): Molecular definition of the bovine granulocytopeny syndrome: Identification of deficiency of the Mac-1 (CD11b/CD18) glycoprotein. *American Journal of Veterinary Research* 51, 1826-1836.

24. Król, J., Brodziak, A., Litwińczuk, A. (2011): Podstawowy skład chemiczny i zawartość wybranych białek serwatkowych w mleku krów różnych ras i w serwatce podpuszczkowej. *ŻYWNOSĆ. Nauka. Technologia. Jakość* 4, 74-83.
25. Kuczyńska, B., Nałęcz-Tarwacka, T., Puppel, K., Gołębiowski, M., Grodzki, H., Słószarz, J. (2011): Zawartość bioaktywnych składników mleka w zależności od modelu żywienia krów w certyfikowanych gospodarstwach ekologicznych. *Journal of Research and Applications in Agricultural Engineering* 56, 7-13.
26. Litwińczuk, Z., Kowal, M., Barłowska, J. (2014): Podstawowy skład chemiczny oraz udział kwasów tłuszczowych i zawartość cholesterolu w mleku krów czterech ras użytkowanych w intensywnych technologiach chowu. *ŻYWNOSĆ. Nauka. Technologia. Jakość* 4, 108-121.
27. Lopez, S., France, J., Odongo, E., Mc Bride, RA., Kebreab, E., Al Zahal, O., Mc Brode, BW., Dijkstra, J. (2015): On the analysis of Canadian Holstein dairy cow lactation curves using standard growth functions. *Journal of Dairy Science* 98, 2701-2712.
<https://doi.org/10.3168/jds.2014-8132>.
28. Malchiodi, F., Cecchinato, A., Pensa, M., Cipolat-Gotet, C., Bittane, G. (2014): Milk quality, coagulation properties, and curd firmness modeling of purebred Holsteins and first- and second-generation crossbred cows from Swedish Red, Montbéliarde, and Brown Swiss bulls. *Journal of Dairy Science* 97, 4530-4541.
<https://doi.org/10.3168/jds.2013-7868>.
29. Malchiodi, F., Penasa, M., Tiezzi, F., Bittante, G. Milk yield traits, somatic cell score, milking time and age at calving of pure Holstein versus crossbred cows. *Agricultural. Conspect. Scientific.* 76, 259-261.
30. Malinowski, E. (2001): Komórki somatyczne mleka. *Medycyna Weterynaryjna* 57, 13-17.
31. Neja, W., Bogucki, M., Krężel-Czopek, S., Kunert, S. (2010): Wpływ systemu utrzymania na użyteczność mleczną krów. *Roczniki Naukowe Polskiego Towarzystwa Zootechnicznego* 6, 59-64.
32. Nowicki, B. (2011): Bydło. Rasy zwierząt gospodarskich, Pawlina, E. Wydawnictwo Naukowe PWN, Warszawa, Poland, 1, 39-72.
33. Petraškienė, R., Pečiulaitienė, N., Jukna, V. (2011): Crossbreeding influence on age at first calving and first lactation productivity in Lithuania bred dairy cattle. *Cuban Journal of Agricultural Science* 45, 237-241.
34. Petraškienė, R., Pečiulaitienė, N., Jukna, V. (2014): Crossbreeding influence of dairy breeds cattle on average of lactation length and on average of productivity. *Veterinarinarija Ir Zootechnica.* 64 65-69.
35. PFHBiPM.(2017): Ocena i hodowla bydła mlecznego dane za rok 2016. PFHBiPM, Parzniew, Poland.
36. PFHBiPM, (2018): Ocena i hodowla bydła mlecznego dane za rok 2017. PFHBiPM, Parzniew, Poland.
37. PFHBiPM. (2019): Ocena i hodowla bydła mlecznego dane za rok 2018. PFHBiPM, Parzniew, Poland.
38. PFHBiPM. (2020): Ocena i hodowla bydła mlecznego dane za rok 2019. PFHBiPM, Parzniew, Poland.
39. Piccardi, M., Pipino, D., Bó, GA., Balzarini, M. (2014): Productive and reproductive performance of first lactation purebred Holstein versus Swedish red & white Holstein in central Argentina. *Livestock Science* 165, 37-41.
<https://doi.org/10.1016/j.livsci.2014.04.025>.
40. Piepers, S., De Vlieghe, S., De Kruijff, A., Opsomer, G., Barkema, HW. (2009): Impact of intramammary infections in dairy heifers on future udder health., milk production, and culling. *Veterinary Microbiology* 134, 113-120.
<https://doi.org/10.1016/j.vetmic.2008.09.017>.
41. Pryce, JE., Haile-Mariam, M., Goddard, ME., Hayes, BJ. (2014): Identification of genomic regions associated with inbreeding depression in Holstein and Jersey dairy cattle. *Genetics Selection Evolution*, 46.
<https://doi.org/10.1186/s12711-014-0071-7>.
42. Puppel, K., Bogusz, E., Gołębiowski, M., Nałęcz-Tarwacka, T., Kuczyńska, B., Słószarz, J., Budziński, A., Solarczyk, P., Kunowska-Słószarz, M., Przysucha, T. (2018): Effect of Dairy Cow Crossbreeding on Selected Performance Traits and Quality of Milk in First Generation Crossbreds. *Journal of Food Science* 83, 229-236.
<https://doi.org/10.1111/1750-3841.13988>.

43. Puppel, K., Gołębiewski, M., Solarczyk, P., Grodkowski, G., Slósarz, J., Kunowska-Slósarz, M., Balcerak, M., Przysucha, T., Kalińska, A., Kuczyńska, B. (2019): The relationship between plasma β -hydroxybutyric acid and conjugated linoleic acid in milk as a biomarker for early diagnosis of ketosis in postpartum Polish Holstein-Friesian cows. *BMC Veterinary Research* 15, 367.
<https://doi.org/10.1186/s12917-019-2131-2>.
44. Puppel, K., Kuczyńska, B. (2016): Metabolic profiles of cow's blood, a review. *Journal of the Science Food and Agriculture* 96, 4321-4328.
<https://doi.org/10.1002/jsfa.7779>.
45. Puppel, K., Solarczyk, P., Kuczyńska, B., Madras-Majewska, B. (2017) Oleic acid as a biomarker for early diagnosis of elevated blood levels of non-esterified fatty acids and β -hydroxybutyric acid in the early stages of lactation in high-yielding Polish Holstein cows. *Animal Science Paper and Reports* 35, 387-396.
46. Ranaraja, U., Cho, KH., Park, MN., Kim, SD., Lee, SH., Do, CH. (2018): Genetic parameter estimation for milk β -hydroxybutyrate and acetone in early lactation and its association with fat to protein ratio and energy balance in Korean Holstein cattle. *Asian-Australian Journal of Animal Science* 31, 798-803.
<https://doi.org/10.5713/ajas.17.0443>.
47. Riehardt, M. (2004): Milk composition as an indicator of nutrition and health. *The Breeding* 11, 26-27.
48. Saha, S., Malchiodi, F., Cipolat-Gotet, C., Bittante, G., Gallo, L. (2017): Effects of Crossbreeding of Holsteins Cows with Montbéliarde and Swedish Red in First and Second Generation on Cheese Yield Traits. *Agriculturae Conspectus Scientificus* 82, 241-244.
49. Schaeffer, LR., Burnside, EB., Glover, P., Fatehi, J. (2011): Crossbreeding results in Canadian dairy cattle for production, reproduction and conformation. *The Open Agriculture Journal* 5, 63-72.
<https://doi.org/10.2174/1874331501105010063>.
50. Shanks, RD., Dombrowski, DB., Harpestad, GW., Robinson, JL. (1984): Inheritance of UMP synthase in dairy cattle. *Journal of Heredity* 75, 337-340.
<https://doi.org/10.1093/oxfordjournals.jhered.a109951>.
51. Slósarz, J., Solarczyk, P., Kunowska-Slósarz, M., Natęcz-Tarwacka, T., Gołębiewski, M., Wójcik, A. (2016): Dairy cattle crossbreeding and milk production. *Annals of Warsaw University of Life Sciences - SGGW Animal Science* 55, 267-273.
<https://doi.org/>
52. Smith, LA., Cassell, BG., Pearson, RE. (1998): The Effects of Inbreeding on the Lifetime Performance of Dairy Cattle. *Journal of Dairy Science* 81, 2729-2737.
[https://doi.org/10.3168/jds.S0022-0302\(98\)75830-8](https://doi.org/10.3168/jds.S0022-0302(98)75830-8).
53. Sørensen, MK., Norberg, E., Pedersen, J., Christensen, LG. (2008): Invited review: Crossbreeding in dairy cattle: A Danish perspective. *Journal of Dairy Science* 91, 4116-4128.
<https://doi.org/10.3168/jds.2008-1273>.
54. Swalve, HH. (2007): Crossbreeding in dairy cattle: International trends and results from crossbreeding data in Germany. *Lohman Information* 42, 38-46.
55. Thompson, JR., Rverett, RW., Hammerschmidt, NL. (2000): Effects of Inbreeding on Production and Survival in Holsteins. *Journal of Dairy Science* 83, 1856-1864.
[https://doi.org/10.3168/jds.S0022-0302\(00\)75057-0](https://doi.org/10.3168/jds.S0022-0302(00)75057-0).
56. Toghiani, J. (2012): Genetic relationships between production traits and reproductive performance in Holstein dairy cows. *Archives Animal Breeding* 55, 458-468.
<https://doi.org/10.5194/aab-55-458-2012>
57. van der Drift, SGA., Houweling, M., Schonewille, JT., Tielens, AGM., Jorritsma, R. (2012): Protein and fat mobilization and associations with serum β -hydroxybutyrate concentrations in dairy cows. *Journal of Dairy Science* 95, 4911-4920.
<https://doi.org/10.3168/jds.2011-4771>.