Livestock Studies 61(1), 1-8
http://doi.org/10.46897/livestockstudies. 610101

RESEARCH PAPER

LIVESTOCK STUDIES

Comparison of Parameters of Automatic Milking in Selected Countries in European Union and United States

Dariusz PIWCZYŃSKI[1,*], Magdalena KOLENDA[1], Jan GONDEK[2], Beata SITKOWSKA[1]

[1]Department of Animal Biotechnology and Genetics, UTP University of Science and Technology; Mazowiecka 28, 85-164 Bydgoszcz, Poland.
[2]Lely East Sp. z o. o.; Pocztowa 2, 86-065, Łochowo, Poland.
*Corresponding author

Article History
Received: 20 November 2020
Accepted: 26 March 2021
First Online: 15 April 2021

Corresponding Author
E-mail: darekp@utp.edu.pl

Keywords
Automatic milking system
Milking parameters
Dairy cows

Abstract

The aim of this study was to compare selected parameters of automatic milking in various European Union countries and United States recorded between 2018 and 2020. Statistical analysis showed highly significant effect of country on all tested milking parameters. It was noted that i.e. the average number of cows per one robot, depending on country, ranged between 51.49 (the Netherlands) and 60.03 (Germany). Cows were milked on the average 2.50 (France) – 2.83 (Latvia) per day, with milking speed ranging from 2.30 kg/min (Lithuania) to 2.99 kg/min (US). Daily milk yield obtained from one cow ranged from 25.12 kg (Lithuania) to 34.11 kg (US), while milk efficiency from 1.44 (Lithuania) to 1.77 kg/min (US). Results also showed that the daily milk yield from one robot ranged from 1 351 kg (Latvia) to 1 930 kg (US). The statistical differences between the milking parameters in the compared countries may be the result of the diversified genetic potential of milked cows and the diversity of the feed base.

Introduction

Automatic milking system (AMS) that may be used to milk dairy cattle is in the use from the year 1992 – back then the first robot was launched by Lely in the Netherlands (Nixon *et al.,* 2009). Since then the interest in the automatic milking of cows is systematically growing. In 1998 an estimated number of farms with AMS worldwide was 250, in 2009 it was over 8 ths while in 2015 over 14 ths (de Koning & Van der Vorst, 2002; de Koning, 2010; Taing, 2016). Salfer *et al.* (2017) estimated that in 2017 over 35 ths AMS operated all over the world. Today, the number of only Lely robot milkers exceeds 30 ths worldwide (Lely International, 2019). The dynamics of the growing number of AMS installations, that may be observed nowadays, may result mainly from the deepening deficit of qualified employees, as well as the beneficial effect of robotization of milking on the level of milking parameters (Brzozowski *et al.*, 2018; Piwczyński *et al.*, 2020b; Sitkowska *et al.*, 2020). The results of numerous studies suggest that the increase in milk yield after the AMS installation, even up to 20%, is directly caused by the increased number of milkings performed by the cow during the day (Rotz *et al.*, 2003; Österman *et al.*, 2005). Czerniawska-Piątkowska *et al.*, (2012) noted the increase in the number of milkings from 2 to 4 times a day, which resulted in an increse of milk yiled in 305-day lactation by 1160 kg. In the previous research by the authors of this study, it was shown that cows in AMS barns in selected Eropean Union (EU) and United States (US) countries milk on average from 2.50 to 2.73 per day (Piwczyński *et al.*, 2020a). At the same time, in the latest research, conducted on a vast dataset, it was found that the change of the milking system from conventional to automatic resulted in an increase in the yield of cows in the first (+ 1 078 kg) and the second (+ 1 182 kg) standardised 305-day lactation (Piwczyński *et al.*, 2020b). The beneficial effect of changing the milking system was also demonstrated in terms of the registered fertility traits (Brzozowski *et al.*, 2018; Piwczyński *et al.*, 2020b). It should be emphasized, however, that not in all herds covered by the study the effect of changing the milking system in terms of functional and production features was beneficial for the breeder (Brzozowski *et al.,* 2018; Piwczyński *et al.*, 2020b). Sitkowska *et al.* (2015) reported that the increase in milk yield on farms equipped with AMS is possible, but it depends on a number of factors related to the milk production process. On the other hand, Bogucki *et al.* (2014) noted that the beneficial effect of robotization of milking increased with the passage of time from the moment of AMS installation.

According to Tse *et al.* (2017), the AMS installation brings several benefits to farmers, including: higher daily milking frequency and milk production; better health and improvement of the herd's fertility rates, the possibility of better management of the herd based on collected information, lower requirement for manpower and greater work flexibility; better quality of life for breeders. AMS may record over 100 milking parameters (Lely International, 2019). Wethal and Heringstad (2019), who performed the study on Norwegian Red cattle, stated that the new parameters recorded by AMS (such as box time, average flow rate etc.) and which cannot be easily recorded in the conventional milking system (CMS), could be included in breeding programs.

The aim of this study was to compare selected parameters of automatic milking (monthly reports) in various European Union countries and United States recorded between January 2018 and October 2020.

Materials and Methods

The present study included data recorded between 1st January 2018 and 31st October 2020 by data recording system by Lely. The following data was gathered: Average number of robots per herd (no.), Number of cows per robot (no.), Daily milk yield per robot (kg), Robot's free time (%/24h), Average days in milk (days), Daily milking frequency (no./cow), Daily number of refusals (no./cow), Daily number of failed milking (no./cow), Box time – time spent by a cow in the robot during one visit (s), Milking speed (kg/min), Daily milk yield per cow (kg), Fat content (%), Protein content (%), Rumination time (min./24h) and Consumption of concentrated fodder per 100 kg of milk (kg). The accumulated data were recorded in the Czech Republic (CZ), France (FR), Germany (DE), Italy (IT), Latvia (LV), Lithuania (LT), the Netherlands (NL), Poland (PL) and the United States (US). In total, the results recorded approximately by 9 400 robots, distributed in 7 000 herds and concerning the productivity of 520 000 cows were analysed. Data was analysed with the use of two-way analysis of variance with the following linear model: $y_{ijk} = \mu + c_i + r_j + (cr)_{ij} + e_{ijk}$, where: y_{ijk} – registered value of a variable, μ – group average, c_i – effect of ith country, r_j – effect of jth year of milking, $(cr)_{ij}$ – country × milking year interaction, e_{ijk} – random error.

The significance of differences between countries was determined using the Scheffé test. A statistical analysis of the collected numerical material was carried out using the SAS v. 9.4 software (SAS Institute Inc., 2014).

Results and Discussion

Results showed a highly significant impact of the origin country of milked cows on all parameters recorded by AMS (Table 1), which is in accordance with the results of previous study carried out by the same authors (Waśkowicz *et al.*, 2014; Piwczyński *et al.*, 2020a). While these studies concerned analogous

Table 1. F statistic and significance (marked by *) of the impact of main factors and interactions on milking parameters.

Trait	Country (C)	Year (Y)	C×Y
Average number of robots per herd (no.)	3 845.97**	21.80**	40.33**
Number of cows per robot (no.)	200.87**	7.70**	4.11**
Daily milk yield per robot (kg)	269.79**	22.84**	2.09**
Robot free time (%/24h)	61.35**	9.45**	1.69*
Average days in milk (days)	54.96**	1.92	4.22**
Daily milking frequency (no./cow)	204.03**	4.40*	3.52**
Daily number of refusals (no./cow)	706.13**	2.24	4.85**
Daily number of failures (no./cow)	247.80**	38.88**	4.40**
Box time (s)	73.13**	10.38**	1.78*
Milking speed (kg/min)	410.82**	40.11**	1.84*
Daily milk yield per cow (kg)	366.22**	42.62**	3.14**
Milk efficiency (kg/min)	384.00**	16.01**	1.77*
Fat content (%)	148.41**	3.51*	1.05
Protein content (%)	138.19**	3.14*	0.47
Rumination time (min/24h)	98.22**	1 044.00**	3.84**
Consumption of concentrated fodder per 100 kg of milk (kg)	1 767.17**	47.80**	5.55**

*P ≤ 0.05, **P ≤ 0.01

features and countries, they spanned the period of operation from 2012-2017.

In these studies, authors suggested that the differentiation of countries in terms of controlled milk yields, was a result of a different genetic potential of dairy cows. In the present study, as well as in the previous one (Piwczyński *et al.*, 2020a) the statistical influence of milking year and the country × milking year interaction on most of the analysed features was demonstrated, with the exception of milking year on average daily days in milk and the number of rejected milkings, as well as interaction of country × year on percentage of fat and protein.

It was found that in the studied countries one farm on the average was equipped with 1.50 (in FR) - 3.32 (US) robots, with the average number of cows per one robot being at the level of 51.49 (NL) - 60.03 (DE) (Table 2). To a large extent, the observed differences can be explained by the different averages of herd sizes in countries included in this study (Piwczyński *et al*., 2020a). The study showed significant, statistical differentiation of the compared countries in terms of milk yield per robot i.e. from 1 351 kg (LT) up to 1 930 kg (US). At the same time, in 2018-2020 a general upward trend was shown in the number of robots in the herd, the number of cows per milking robot and daily milk yield per robot. This trend is in accordance with the one observed in past studies (Waśkowicz *et al.*, 2014; Piwczyński *et al.*, 2020a). It should be emphasized that a greater control over the herd, in which AMS is installed, may contribute to an increase in the number of cows per one robot without detriment to their health or their efficiency (Castro *et al.*, 2012; Tse *et al.*, 2017). Deming *et al.* (2013) found that herd performance could be increased by reducing the number of cows per robot and increasing access to the feed table and increasing the amount of provided feed. Tse *et al.* (2017) emphasize that the introduction of AMS in Canada gave breeders the opportunity to increase the number of cows in the herd (the average number of cows per robot was at the level of 52). It is very important to establish the optimal number of cows per robot. Rodenburg (2017) note that the optimal number of cows in a barn equipped with AMS should be less than 250 animals. On the other hand, Grant and Albright (2001) optimized for an even smaller herd size of less than 100 cows. In their opinion, it is good if animals recognize each other, then they can use AMS without stress. Barman *et al.* (2017) emphasize that the presence of cows in an unknown group exposes their body to stress, which results in a decrease in milk yield and weight loss. Perhaps, it is not possible to provide a universal and optimal number of cows per robot, and this number is best adjusted individually to each herd.

The results of studies by Castro *et al.* (2012) proved that the optimal free time of a robot should be about 10% of the day. In our research, it ranged from 19.00% (US) to as much as 27.42% (CZ) (Table 2). This presents a potential possibility of a significant increase in the number of cows per one robot, and then the daily milk yield and improving the profitability of production on the farm. One of the herd indicators recorded by AMS is the average lactation day (Table 2). In the present studies, the highest value of this indicator was found in NL (207.7 days), followed by PL (198.8 days), which proves that in these countries' lactation lasted the longest. On the other hand, the shortest lactations were noted in LV (181.7 days) and LT (185.3 days). In the studied herds, cows milked on average 2.71 times a day, the least frequently in FR (2.50 milkings/day), and most often in LV (2.83 milkings/day) and NL (2.82 milkings/day) (Table 2). The obtained results were generally characterized by a growing tendency in the reporting years 2018-2020, exceeding the results presented in previous studies (Waśkowicz *et al.*, 2014; Piwczyński *et al.*, 2020a). In the study by Sitkowska *et al.* (2020), who investigated primiparas performance, the importance of the average milking frequency (especially in the initial phase of the first lactation) on milk yield in its further stages was demonstrated with levels above 3.50 milkings a day considered optimal. In turn, Castro *et al.* (2012) found the range between 2.40 and 2.60 a day to be the optimal value of milking frequency per day.

It was found that in the studied countries, the milking robot software limited the animal's ability to undergo milking (refuslas milkings) on average from 1.57 (US) to 3.57 no./day (LT) (Table 3). At the same time, it was observed that the number of failed milkings ranged from 3.84 (FR) to 6.58 no./day (LT). It should be emphasized that in 2018-2020 there was a favorable tendency to reduce failed milkings (from 5.13 no./day to 4.72 no./day). Also the fact that the results presented in the present study were more favorable than those reported previously (Waśkowicz *et al.*, 2014) should also be noted. The frequency of milkings and milking time are the most common indicators of cow's maturity for full production. Castro *et al.* (2012) found that varying number of cows per robot and the milk speed had the greatest effect on the daily milk yield in AMS. Salfer *et al.* (2017) emphasised that management system in AMS equipped barns should be properly parameterized in such a way that it makes sure that cows occupy robots at the right time. In AMS, the amount of milk obtained by the robot per day is of key importance in shaping the profitability of production, which is directly related to the amount of milk collected per minute of the time cow spends in the milking stall – milk efficiency (kg/min). This feature, in turn, is directly dependent on the duration of the cow's stay in the milking stall, milking speed and milk yield, as well as time that is spend on preparing the cow for milking (including robot attachment time). Cows in the barns covered by the study spent on the average 394 s (IT) to 416 s (US) in the milking box, gave between 25.17 (LT) and 34.14 kg of milk (US), with the speed that ranged between 2.30 kg/min (LT) and 2.99 kg/min (US) (Table 3). The milk efficiency index, calculated for the entire dataset on the basis of this information, equalled 1.59 kg/min, and ranged in different counties from 1.44 kg/min (LV) to 1.77 kg/min (US).

Table 2. Milking parameters according to country and milking year.

Year	Statistics	Country									Total
		CZ	DE	FR	IT	LT	LV	NL	PL	US	
Average number of robots per herd (no.)											
2018	$\bar{x}$	2.08	1.66	1.47	1.70	2.66	1.90	1.98	1.79	3.12	2.04
2019	$\bar{x}$	2.00	1.68	1.50	1.71	2.43	1.84	2.00	1.71	3.32	2.02
2020	$\bar{x}$	1.97	1.74	1.54	1.77	2.40	1.95	2.05	1.66	3.57	2.07
Total	$\bar{x}$	2.02	1.69	1.50	1.73	2.50	1.90	2.01	1.72	3.32	2.04
		A	AB	ABC	ACD	ABCDE	ABCD EF	BCDE FG	ACEF GH	ABCD EFGH	
	CV	2.69	2.08	1.92	2.66	6.29	4.46	1.52	3.74	5.78	26.21
Number of cows per robot (no.)											
2018	$\bar{x}$	53.96	60.48	55.29	56.97	53.59	53.21	51.13	58.24	56.25	55.46
2019	$\bar{x}$	54.92	60.19	56.05	57.01	53.67	55.03	51.60	59.09	56.47	56.00
2020	$\bar{x}$	55.60	59.31	55.45	57.14	54.15	52.77	51.80	57.07	57.08	55.60
Total	$\bar{x}$	54.78	60.03	55.60	57.03	53.78	53.72	51.49	58.19	56.57	55.69
		Aa	AB	BC	ABCDb	BCDEa	BCDFa	ABCD EFG	ABCE FGHb	ABEF GH	
	CV	1.78	1.52	1.91	2.24	2.26	3.33	1.69	2.38	0.89	4.85
Daily milk yield per robot (kg)											
2018	$\bar{x}$	1525	1709	1572	1799	1277	1424	1515	1692	1908	1602
2019	$\bar{x}$	1528	1714	1587	1801	1376	1526	1529	1775	1910	1638
2020	$\bar{x}$	1588	1728	1622	1860	1411	1489	1547	1746	1979	1663
Total	$\bar{x}$	1545	1716	1592	1818	1351	1479	1529	1737	1930	1633
		Aa	AB	BCb	ABCD	ABCDE	BCDE Fa	BDEGb	ACDE FGH	ABCD EFGH	
	CV	4.08	3.04	4.70	5.25	5.82	5.74	3.12	4.10	2.64	11.33
Robot free time (%)											
2018	$\bar{x}$	28.68	21.94	26.23	27.25	28.09	22.65	26.97	20.12	18.83	24.53
2019	$\bar{x}$	27.35	21.83	25.37	27.25	24.47	23.73	25.58	19.30	19.24	23.79
2020	$\bar{x}$	26.00	21.46	24.73	26.57	23.26	22.52	24.81	19.72	18.92	23.11
Total	$\bar{x}$	27.42	21.76	25.49	27.05	25.39	22.99	25.84	19.71	19.00	23.85
		A	AB	BCa	BD	BEb	ADFab	BFG	ACDE FG	ABCDE FG	
	CV	6.97	6.74	12.22	10.76	10.98	11.61	9.45	11.36	7.33	15.84
Average days in milk (days)											
2018	$\bar{x}$	185.7	183.4	189.7	195.1	189.1	180.2	201.7	203.1	181.2	189.9
2019	$\bar{x}$	188.7	187.9	191.9	195.7	187.0	180.7	210.2	201.6	180.7	191.6
2020	$\bar{x}$	191.5	192.1	192.3	191.1	178.6	184.7	212.0	190.5	178.5	190.1
Total	$\bar{x}$	188.5	187.6	191.2	194.1	185.3	181.7	207.7	198.8	180.2	190.6
		Aa	B	Cb	D	DE	aCDF	ABCD EFG	ABEF GHb	ABCD GH	
	CV	2.16	3.17	4.86	5.19	4.72	3.79	3.14	4.48	1.35	5.76
Daily milking frequency (no.)											
2018	$\bar{x}$	2.66	2.62	2.51	2.74	2.58	2.83	2.83	2.76	2.79	2.70
2019	$\bar{x}$	2.63	2.62	2.48	2.79	2.65	2.86	2.83	2.79	2.78	2.71
2020	$\bar{x}$	2.61	2.67	2.50	2.80	2.68	2.81	2.82	2.80	2.79	2.72
Total	$\bar{x}$	2.64	2.63	2.50	2.78	2.64	2.83	2.82	2.78	2.79	2.71
		A	B	ABC	ABCDa	CDE	ABCD Eb	ABCEa	ABCEb	ABCEb	
	CV	1.84	1.80	1.55	1.55	2.62	2.42	1.76	1.39	1.29	4.40

CV – coefficient of variation (%); CZ - Czech Republic, FR – France, DE – Germany, IT – Italy, LV – Latvia, LT – Lithuania, NL – Netherlands, PL – Poland, US – United States

AA (aa) – Values that are significantly different within a variable are marked with the same letters P ≤ 0.01 (P ≤ 0.05)

Table 3. Milking parameters according to country and milking year.

Year	Statistics	Country									Total
		CZ	DE	FR	IT	LT	LV	NL	PL	US	
Daily number of refusals per cow (no.)											
2018	$\bar{x}$	2.33	2.46	1.77	1.65	3.64	2.05	3.61	2.09	1.55	2.35
2019	$\bar{x}$	2.39	2.49	1.70	1.69	3.33	2.12	3.53	2.01	1.61	2.32
2020	$\bar{x}$	2.22	2.49	1.66	1.60	3.78	2.10	3.29	2.01	1.56	2.3
Total	$\bar{x}$	2.32	2.48	1.71	1.65	3.57	2.09	3.49	2.04	1.57	2.32
		Aa	Ba	ABC	ABD	ABCDE	ABCD EF	ABCDFG	ABCDEGH	ABEF GH	
	CV	5.04	2.94	6.55	6.01	9.79	6.95	8.3	6.39	5.26	31.28
Daily number of failures per cow (no.)											
2018	$\bar{x}$	4.62	4.38	3.95	4.76	7.19	5.78	4.36	5.99	5.13	5.13
2019	$\bar{x}$	4.68	4.32	3.93	4.58	6.33	6.00	4.41	5.57	5.39	5.02
2020	$\bar{x}$	4.49	4.03	3.61	4.14	6.21	5.83	4.16	5.25	4.78	4.72
Total	$\bar{x}$	4.60	4.25	3.84	4.49	6.58	5.87	4.31	5.61	5.11	4.97
		Aa	aB	ABC	CD	ABCDE	ABCD EF	CEFG	ABCDEGH	ABCDE FGH	
	CV	5.67	4.42	5.29	6.43	10.96	10.25	4.85	6.18	7.32	18.81
Box time per cow per visit (s)											
2018	$\bar{x}$	413	405	424	394	388	400	403	396	419	405
2019	$\bar{x}$	413	405	427	393	399	406	405	402	413	407
2020	$\bar{x}$	418	406	430	396	397	408	410	406	415	410
Total	$\bar{x}$	415	406	427	394	395	405	406	401	416	407
		A	AB	ABC	ABCDa	ABCE	ACD EF	ACD EG	ACHa	BCDE FGH	
	CV	1.25	1.21	2.00	2.41	2.01	1.76	1.19	2.30	2.09	3.06
Milking speed (kg/min)											
2018	$\bar{x}$	2.45	2.54	2.54	2.83	2.24	2.26	2.53	2.56	2.92	2.54
2019	$\bar{x}$	2.47	2.58	2.55	2.82	2.32	2.33	2.54	2.62	3.00	2.58
2020	$\bar{x}$	2.53	2.63	2.58	2.85	2.36	2.39	2.55	2.63	3.07	2.62
Total	$\bar{x}$	2.48	2.58	2.56	2.83	2.30	2.32	2.54	2.60	2.99	2.58
		A	AB	AC	ABCD	ABCDE	ABCDF	DEFG	ADEFH	ABCD EFGH	
	CV	2.52	2.66	2.19	2.05	3.78	3.83	1.97	2.51	3.23	8.50
Daily milk yield per cow (kg)											
2018	$\bar{x}$	28.24	28.26	28.43	31.56	23.83	26.76	29.63	29.04	33.93	28.85
2019	$\bar{x}$	27.83	28.47	28.31	31.58	25.62	27.73	29.63	30.05	33.83	29.23
2020	$\bar{x}$	28.56	29.14	29.23	32.54	26.07	28.2	29.85	30.59	34.68	29.87
Total	$\bar{x}$	28.20	28.61	28.65	31.89	25.17	27.56	29.70	29.89	34.14	29.28
		A	B	C	ABCD	ABCDE	BCDEF	ABCDEFG	ABCD EFH	ABCD EFGH	
	CV	2.89	2.37	3.20	3.49	4.98	4.10	1.72	3.05	2.11	8.86
Milk efficiency (kg/min.)											
2018	$\bar{x}$	1.54	1.60	1.60	1.75	1.42	1.42	1.56	1.59	1.74	1.58
2019	$\bar{x}$	1.54	1.61	1.60	1.73	1.45	1.43	1.55	1.61	1.77	1.59
2020	$\bar{x}$	1.57	1.61	1.63	1.76	1.47	1.48	1.55	1.62	1.80	1.61
Total	$\bar{x}$	1.55	1.61	1.61	1.75	1.45	1.44	1.55	1.61	1.77	1.59
		A	AB	AC	ABCD	ABCDE	ABCDF	BCDE FG	ADEF GH	ABCEF GH	
	CV	2.19	2.09	2.19	2.16	2.95	2.96	2.30	1.87	2.49	7.09

CV – coefficient of variation (%); CZ - Czech Republic, FR – France, DE – Germany, IT – Italy LV – Latvia, LT – Lithuania, NL – Netherlands, PL – Poland, US – United States

AA (aa) – Values that are significantly different within a variable are marked with the same letters P ≤ 0.01 (P ≤ 0.05)

It is significant that the presented results regarding milking speed, milk yield and milk efficiency indicate a favourable upward trend in years 2018-2020, which is a continuation of the previously studied period of years 2012-2017 (Waśkowicz *et al.*, 2014; Piwczyński *et al.*, 2020a).

When analysing the chemical composition of milk, it was observed that the highest fat (4.39%) and protein (3.55%) contents were found in milk obtained from cows in NL (Table 4). On the other hand, the lowest level of fat was recorded in milk in IT (3.84%), and proteins in US (3.11%). The studies showed a significant influence of the milking year on the analysed characteristics of milk composition (Table 1), but the changes in their level in the following years did not express any clear trend. Also, the currently presented results in this respect were similar to those obtained in previous studies (Waśkowicz *et al.*, 2014; Piwczyński *et al.*, 2020a).

Salfer *et al.* (2017) noted yet another important benefit for AMS farms, namely pelleted feed supplementation in AMS box was strongly associated with body condition and thus might cause the increase in milk production. When analysing the rumination activity of cows (measured by the number of minutes per day), it was found that rumination time was the shortest in the US (468.99 minutes), and the longest in the LV (504.86 minutes) (Table 4). The amount of concentrated feed intake depends on many factors, including the palatability of the feed and the individual requirements of a cow. The analysis showed that a cow for the production of 100 kg of milk consumed from 12.96 kg (IT) to 20.05 kg (NL) of concentrate feed.

Table 4. Milking parameters according to country and milking year.

Year	Statistics	Country									Total
		CZ	DE	FR	IT	LT	LV	NL	PL	US	
						Fat content (%)					
2018	$\bar{x}$	3.95	4.04	4.09	3.83	4.18	3.95	4.37	3.91	3.87	4.02
2019	$\bar{x}$	4.00	4.10	4.17	3.86	4.11	3.96	4.41	3.92	3.90	4.05
2020	$\bar{x}$	3.96	4.09	4.16	3.84	4.14	3.95	4.39	3.97	3.89	4.04
Total	$\bar{x}$	3.97	4.07	4.14	3.84	4.14	3.96	4.39	3.93	3.88	4.04
		Aa	AB	AC	ABCD	ADE	BCDEF	ABCDEFG	BCDEG	BCEGa	
	CV	2.22	2.17	2.10	1.45	1.93	2.38	2.31	1.26	1.95	4.44
						Protein content (%)					
2018	$\bar{x}$	3.40	3.43	3.32	3.38	3.37	3.29	3.53	3.38	3.11	3.36
2019	$\bar{x}$	3.43	3.45	3.36	3.40	3.36	3.33	3.56	3.37	3.12	3.38
2020	$\bar{x}$	3.39	3.44	3.35	3.39	3.35	3.29	3.55	3.37	3.11	3.36
Total	$\bar{x}$	3.41	3.44	3.34	3.39	3.36	3.30	3.55	3.37	3.11	3.36
		Aa	B	BCa	D	BEb	ABDFb	ABCDEFG	BFGH	ABCDEFGH	
	CV	1.90	1.73	1.77	1.37	1.65	2.06	1.73	0.76	1.97	3.66
						Rumination time (min./24h)					
2018	$\bar{x}$	462.2	470.0	474.4	456.2	474.6	483.9	476.9	470.3	446.3	468.3
2019	$\bar{x}$	491.8	485.6	500.0	476.7	482.8	501.7	498.8	490.9	472.3	489.0
2020	$\bar{x}$	507.0	505.6	516.2	502.0	507.5	528.9	521.3	510.5	488.3	509.7
Total	$\bar{x}$	487.03	487.06	496.87	478.28	488.31	504.86	499.02	490.58	468.99	487.8
		A	B	ABCa	ABCD	CDE	ABCDEF	ABDEG	DFGHa	ABCDEFGH	
	CV	4.03	3.09	3.65	4.16	3.18	3.98	3.80	3.49	3.99	4.23
						Consumption of concentrated fodder per 100 kg of milk (kg)					
2018	$\bar{x}$	16.07	14.41	14.14	12.73	16.87	13.92	20.44	14.59	14.88	15.34
2019	$\bar{x}$	15.99	14.18	14.18	13.12	16.78	13.79	20.05	14.28	14.68	15.23
2020	$\bar{x}$	15.36	13.84	14.05	13.03	16.11	13.91	19.67	14.01	14.46	14.94
Total	$\bar{x}$	15.81	14.14	14.12	12.96	16.59	13.87	20.05	14.29	14.67	15.18
		A	AB	AC	ABCD	ABCDE	ADEF	ABCDEFG	ADEFGH	ABCDEFGH	
	CV	2.20	1.75	1.92	1.99	3.89	2.88	2.14	1.89	1.49	13.46

CV – coefficient of variation (%); CZ - Czech Republic, FR - France, DE - Germany, IT - Italy LV - Latvia, LT - Lithuania, NL – Netherlands, PL – Poland, US – United States

AA (aa) – Values that are significantly different within a variable are marked with the same letters P ≤ 0.01 (P ≤ 0.05)

The average consumption of concentrate was at the level of 15.18 kg. It should be emphasized that in the years 2018-2020, the average rumination time increased (by 41.4 minutes), while the amount of concentrated feed needed for the production of 100 kg of milk decreased (by 0.4 kg). It is particularly interesting as during this time the daily milk yield of a cow increased by more than 1 kg. This means that breeders in order to satisfy the nutritional needs of cows, instead of concentrate feed, introduced a larger amount of roughage, as evidenced by the longer rumination time. Endres and Salfer (2015), emphasized that in order to obtain the highest milk yield in AMS farms farmers, apart from introducing high-production cows and reducing box time, should also focus on providing good nutritional management.

When analysing the calculated coefficients of variation (CV) of the controlled features according to country, it should be emphasized that they showed a tendency to express low values - in most cases they did not exceed 5%. This proves a significant unification of the parameter values in the subsequent months of data reporting.

Conclusion

Summing up the results of the conducted research, it should be stated that the tested milking parameters were highly significantly influenced by the country where the milking robot was located. The presumptive reason for these differences was the differentiation of the genetic potential of milked cows and the diversity of the feed base. The research showed that the most favourable results in terms of financial efficiency of a farm (milk speed, milk yield, milk efficiency, robot yield) were found in US and IT herds. In years 2018-2020, a favourable trend was observed in terms of the above-mentioned features.

References

Barman, D., Prasad, K., Kumar, S., Ahirwar, M., Saini M., & Kamboj, M. L. (2017). Effect of shifting animals from groups on their social relationship and performance. International Journal of Current Microbiology and Applied Sciences, 67, 1601-1606. https://doi.org/ 10.20546/ijcmas.2017.607.193

Brzozowski, M. Piwczyński, D., Sitkowska, B., & Kolenda, M. (2018). The impact of installation of automatic milking system on production and reproduction traits of dairy cows. Reproduction in Domestic Animals, 53(5), 1123-1129. https://doi.org/10.1111 /rda.13214

Bogucki, M., Sawa, A., & Neja, W. (2014). Effect of changing the cow's milking system on daily yield and cytological quality of milk. Acta Scientiarum Polonorum, Zootechnica, 13(4), 17–26.

Castro, A., Pereira, J. M., Amiama, C., & Bueno J. (2012). Estimating efficiency in automatic milking https://doi.org/10.3168/jds.2010-3912

Czerniawska-Piątkowska, E., Gralla, K., Szewczuk, M., & Chociłowicz, E. (2012). The comparison of yield, composition and quality of cow milk depending on twice-a-day and four-times-a-day milking. Acta Scientiarum Polonorum, Zootechnica, 11(4), 21–30.http://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-c4600b0d-8d1a-4019-98b8-f2f261675c1c/c/ 03-3.pdf

de Koning, K., & Van der Vorst, Y. (2002). Automatic milking – Changes and changes In Proceedings of the British Mastitis Conference, Brockworth, United Kingdom, 68–80. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.583.7769&rep=rep1&type=pdf

de Koning, K. (2010). Automatic Milking – Common Practice on Dairy Farms, In Proceedings of the First North American Conference on Precision Dairy Management, Toronto, Ontario, Canada, 52–67. http://precisiondairy.com/proceedings/s3dekoning.pdf

Deming, J.A., Bergeron, R., Leslie, K.E., & DeVries, T.J. (2013) Associations of housing, management, milking activity, and standing and lying behavior of dairy cows milked in automatic systems. Journal of Dairy Science, 96(1), 344-351. https://doi.org/ 10.3168/ jds.2012-5985

Endres, M. I., & Salfer, J. A. (2015) An evaluation of automated milking systems in the Midwest United States. Journal Dairy Science, 98(Suppl. 2), 114 (Abstract). https://doi.org/10.1016/S0022-0302(20) 30760-8

Grant, R.J., & Albright, J.L. (2001). Effect of animal grouping on feeding behavior and intake of dairy cattle. Journal of Dairy Science, 84(E. Suppl.), E156-E163. https://doi.org/10.3168/jds.S0022-0302(01) 70210-X

Lely International (2019). Retrieved on 30 October 2019, from personal message.

Nixon, M., Bohmanova, J., Jamrozik, J., Schaeffer, L.R., Hand, K., & Miglior, F. (2009). Genetic parameters of milking frequency and milk production traits in Canadian Holsteins milked by an automated milking system. Journal of Dairy Science, 92, 3422-3430. https://doi.org/10.3168/jds.2008-1689

Österman, S., Östensson, K., Svennersten-Sjaunja, K., & Bertilsson, J. (2005). How does extended lactation in combination with different milking frequencies affect somatic cell counts in dairy cows? Livestock Production Science, 96(2), 225–232. https://doi.org/10.1016/ j.livprodsci.2005.01.014

Piwczyński, D., Gondek, J., Sitkowska, B., & Kolenda, M. (2020a). Comparison of results coming from automatic milking system in selected countries in Europe and U.S. Journal of Central European Agriculture, 21(2), 187-196. https://doi.org/ 10.5513/JCEA01/21.2.2559

Piwczyński, D., Brzozowski, M., & Sitkowska, B. (2020b). The impact of the installation of an automatic milking system on female fertility traits in Holstein-Friesian cows. Livestock Science, 240, https://doi.org/10.1016/j.livsci. 2020.104140

Rodenburg, J. (2017). Robotic milking: Technology, farm design, and effects on work flow. Journal of Dairy Science, 100(9), 7729-7738. https://doi.org/ 10.3168/ jds.2016-11715.

Rotz, C., Coiner, C., & Soder, K., (2003). Automatic milking systems, farm size, and milk production. Journal of Dairy Science, 86(12), 4167–4177. https://doi.org/10.3168/ jds.S0022-0302(03) 74032-6

SAS Institute Inc.: SAS/STAT® 94 User’s Guide Cary, NC: SAS Institute Inc. (2014).

Salfer, J. A., Minegishi, K., Lazarus, W., Berning, E., & Endres,

M. I. (2017). Finances and returns for robotic dairies. Journal of Dairy Science, 100(9), 7739-7749. https://doi.org/10.3168/jds.2016-11976.

Sitkowska, B., Piwczyński, D., Aerts, J., & Waśkowicz, M. (2015). Changes in milking parameters with robotic milking. Archives Animal Breeding, 58(1), 1–7. https://doi.org/10.5194/aab-58-137-2015.

Sitkowska, B., Piwczyński, D., Kolenda, M., & Różańska-Zawieja, J. (2020). The milking frequency of primiparous cows in their early stage of lactation and its impact on milking performance. Animal Production Science, 60(3), 436-443. https://doi.org/10.1071 /AN18409.

Taing, W. (2016). The economic viability of automatic milking systems in Australia's pasture-based dairy farm systems: a case study analysis. Melbourne School of Land and Environment. The University of Melbourne, 1–187. https://minervaaccess.unimelb.edu.au/handle/11343/128241.

Tse, C., Barkema H., DeVries T., Rushen J., & Pajor E. (2017). Effect of transitioning to automatic milking systems on producers' perceptions of farm management and cow health in the Canadian dairy industry. Journal of Dairy Science, 100, 2404–2414. https://doi.org/10.3168/jds.2016-11521

Waśkowicz, M., Piwczyński, D., Sitkowska, B., & Aerts, J. (2014) Efektywność stosowania robotów udojowych w wybranych krajach UE i USA [The effectiveness of milking robots in selected EU and US countries]. Przegląd Hodowlany, 6, 27–30. [in Polish] http://ph.ptz.icm.edu.pl/wp-content/uploads/2016/12/3-Wa%C5%9B kowicz.pdf

Wethal, K. B., & Heringstad, B. (2019). Genetic analyses of novel temperament and milkability traits in Norwegian Red cattle based on data from automatic milking systems. Journal of Dairy Science, 102(9), 8221-8233. https://doi.org/10.3168/jds.2019-16625