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Practical aspects of the use of milking robots

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Abstract: The article presents results of monitoring carried out in barns with milking robots. The use of milking robots makes it possible, with proper stocking, to milk cows without human intervention. The analysis included all barns with Lely robots located in the Podlaskie Voivodeship in 2018–2021. In 2018–2019, there were seven such barns, and in 2020–2021 nine. In all barns, high milk yields were obtained of more than 1000 kg compared to the average milk yield obtained from stock of cows under monitoring in the Podlaskie Voivodeship. In 2021, four barns milked more than 9.5 thous. kg, three barns more than 10 thous. kg and two barns almost 12 thous. kg of milk. Fat and protein contents were typical for the breed. Three barns were monitored more closely in 2021, with varying numbers of robot milking stations in barns, i.e. A one, B two and C three milking stations. In 2021, over 700,000 kg was milked per stall in stall A, over 750,000 kg in B and over 850,000 kg of milk in C. The average milk per cow per milking was high, with over 11 kg in barn A, 12 kg in B and 13 kg in C.

Keywords: dairy cow, milk, milk fat content, milk protein content, milk yield, milking robot

INTRODUCTION

The Podlaskie Voivodeship is the Poland's second-largest milk producer (GUS, 2021). From 2010 to 2019, the Podlaskie Voivodeship saw an increase in milk production from 1969.4 to 2822.9 mln litres, or 43.3%. At that time, the increase in the country was smaller at only 18.2%. In 2019, 20% of the national milk volume was produced in the Podlaskie Voivodeship. Many factors contributed to such a significant increase, but according to the authors, two had the most significant impact. The first is the so-called "Turośl experiment" implemented by the Dutch government in the 1990s (Skopiec, 1994). It involved the Dutch running a farm and advising on the modernisation of barns in the area and training of farmers. The second factor was the far-sighted investment policy pursued by local dairies. They have implemented modern technologies, which have allowed them to produce original goods. "Serek piątnicki" was in great demand throughout the country. It allowed a high milk price to be applied at the point of purchase. In this way, farmers in Podlasie established their specialisation in milk production, which translated into high production capacity and profitability.

There has recently been significant technological advancement in milk production (Borusiewicz and Kapela, 2013). Before that, the robotisation of milking in the country in general and in the Podlaskie Voivodeship in particular had been slow (Borusiewicz and Marczuk, 2017; Winnicki, Mielcarek and Jugowar, 2018; Romaniuk, Winnicki and Borek, 2021). It is evidenced by data cited below for barns under monitoring conducted by the Polish Federation of Cattle Breeders and Milk Producers (Pol. Polska Federacja Hodowców Bydła i Producentów Mleka – PFHBiPM). In 2021, milking robots were used in only 28 barns in the Podlaskie Voivodeship, compared to 323 farms with robots in the country, which accounted for 8.7%. The number of cows was also low: 3,210 head, only 10.3% in relation to the country (31,158 head).

The use of milking robots allows for milking cows without human intervention. First of all, automation requires the correct

selection of the number of cows to be milked by the robot (Rotz, Coiner and Soder, 2003; André *et al*., 2010). If the robot load is too high, not all cows will be milked at appropriate intervals (Sitkowska *et al*., 2016). The cost-effectiveness of using milking devices depends primarily on their milking capacity (Aerts *et al*., 2022). The use of milking devices on the farm also poses challenges in supplying the equipment with electricity of adequate quality (Czekała *et al*., 2017; Skibko *et al*., 2022) and addressing vacuum fluctuations in the milking installation (Skalska *et al*., 2013). It is particularly relevant in cases where the farm is located in close proximity to an unstable energy source, such as photovoltaics or wind turbines (Skibko *et al*., 2021; Skibko, Hołdyński and Borusiewicz, 2022).

Cow milking efficiency is a complex issue influenced by many factors. These can include but are not limited to the number of cows per robot, the number and time of stall handling, the number of connection attempts or the type of movement (free-forced) (Castro *et al*., 2012; Tremblay *et al*., 2016). Milking efficiency is a critical factor affecting profitability, so research on this issue is most welcome by the agricultural community. The highest milking efficiency is obtained when the ratio of milk volume to time spent by a cow in the robot is the highest (Odorčić *et al*., 2019). Milking efficiency varies with days of lactation and it is the lowest in early lactation, reaches a peak in mid-lactation and then decreases again (Heringstad and Bugten, 2014).

Our research evaluated the effectiveness of milking robots used in barns in the Podlaskie Voivodeship, in particular:
- robots occupancy,
- milk yield, and
- herd management.

MATERIALS AND METHODS

Values that formed the basis for the analysis came from different sources, covered different elements, and were related to different time ranges for each indicator. To limit variation, the study examined:
- robots by the same company – Lely,
- one voivodship – Podlaskie,
- the same period of 2018–2021.

Table 1 shows basic information about nine barns meeting the above conditions. The order of the barns was determined by the year robots were commissioned in the respective herd.

The figures presented in Table 1 were derived from the three sources stated below.

1. Studies which cover evaluation and breeding of dairy cattle. These are annual inspection reports on the dairy cow performance by the Polish Federation of Cattle Breeders and Milk Producers (PFHBiPM).
2. Report "Farm Scan" downloaded from the Lely's IT system on 16 February 2022. The report was provided by Lely. The report contains a number of milking robot performance and cow production indicators for the past month and year relative to the date the report was downloaded. The report included three barns labelled A, B and C; see Table 1. The differentiating factor was the number of milking stations: A – one station, B – two and C – three milking stations.
3. Outcome reports – abbreviated RW-1 and RW-2, provided by PFHBiPM to the farmer after the performance audit. The same barns A, B and C were analysed as in point 2. In barn A, an AR-8 inspection was performed every two months, six inspections during the year; in barns B and C, the AR-4 inspection was provided every month; 11 inspections during the year. The RW-1 report contains general herd data, and the RW-2 contains information on each cow individually. These reports were made available by the herds' farmer-owners to the authors.

RESULTS AND DISCUSSION

PERFORMANCE OF COWS IN HERDS WITH LELY MILKING ROBOTS IN THE PODLASKIE VOIVODESHIP IN 2018–2021

In 2018 and 2019, seven barns met the requirements set out in the methodology, and from 2020 onwards, another two barns. They used: single-stall in three barns, double-stall in four barns and triple-stall in two barns. All herds showed good performance (above 9,000 kg of milk per cow per year in all cases) throughout the four years. Of the 32 annual results analysed, in 11 cases, the average milk yield was up to 10 thous. kg; in 14 cases, it was between 10 and 11 thous. kg; in 2 cases, between 11 and 12 thous. kg and in 5 cases above 12 thous. kg (Tab. 2, Fig. 1–3). The lowest

Table 1. Lely milking robots in the Podlaskie Voivodeship

Herd No.	Milking robot		Number of cows		Herd designation
	year of commissioning	the number of milking places	in the herd in 2021	per post	
1	2011	2	139	70	–
2	2012	1	60	60	–
3	2012	2	110	55	–
4	2013	2	152	76	B
5	2014	2	160	80	–
6	2015	1	70	70	–
7	2015	3	219	73	C
8	2020	3	191	64	–
9	2020	1	72	72	A

Source: own elaboration.

Table 2. Performance of cows in milking herds milked by Lely robots in the Podlaskie Voivodeship in 2018–2021

Herd No.	Capacity (kg)			Content (%)	
	milk	fat	protein	fat	protein
The year 2018					
1	9,716	395	325	4.06	3.34
2	12,038	462	386	3.84	3.21
3	10,006	400	346	4.00	3.46
4	10,752	416	352	3.87	3.27
5	9,124	360	298	3.95	3.27
6	10,180	411	342	4.04	3.36
7	10,751	409	345	3.80	3.21
Podlaskie Voivodeship	8,123	333	277	4.10	3.41
Country	8,298	334	281	4.03	3.39
The year 2019					
1	9,463	380	327	4.02	3.46
2	12,359	461	384	3.73	3.11
3	9,463	389	331	4.11	3.50
4	10,537	424	357	4.02	3.39
5	9,073	348	298	3.83	3.28
6	9,972	392	331	3.93	3.32
7	12,343	463	395	3.75	3.20
Podlaskie Voivodeship	8,479	349	291	4.11	3.43
Country	8,530	347	292	4.07	3.42
The year 2020					
1	10,054	410	337	4.08	3.35
2	12,215	448	375	3.67	3.07
3	10,231	429	359	4.19	3.51
4	10,053	415	344	4.13	3.42
5	9,740	381	317	3.91	3.28
6	10,172	410	352	4.03	3.46
7	12,984	496	421	3.82	3.24
8	10,582	417	365	3.94	3.45
9	10,754	446	362	4.15	3.37
Podlaskie Voivodeship	8,697	358	297	4.12	3.42
Country	8,823	359	301	4.07	3.41
The year 2021					
4	10,284	424	358	4.12	3.48
5	9,630	389	310	4.04	3.22
6	9,737	409	341	4.20	3.50
7	11,974	465	399	3.88	3.33
8	10,299	435	364	4.22	3.53
9	9,899	423	344	4.27	3.47
Podlaskie Voivodeship	8,617	363	296	4.21	3.44
Country	8,837	365	302	4.13	3.42

Source: own study.

yield was recorded in barn 5, below 10,000 kg for all four years. This barn also recorded the lowest milk yield of the entire period analysed (9,073 kg in 2019). However, this was 594 kg higher than the Podlaskie Voivodeship average (8,479 kg). On the other hand, the highest yields were found in barns 2 and 7. In barn 2, three times over 12,000 kg (in 2018, 2019 and 2020) and in 2021, 11,934 kg. In barn 7, the average yield exceeded 12,000 kg on two occasions during the study (in 2019 and 2020) and 11,974 kg in 2021. Thus, it can be concluded that these were high yields, significantly exceeding the average values of the Podlaskie Voivodeship as well as the whole country.

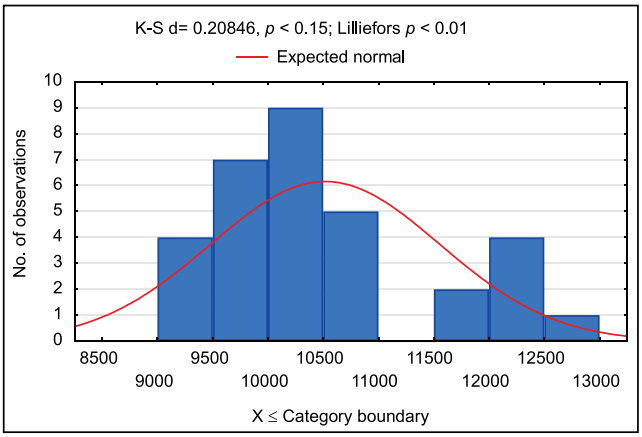
A factor contributing to high milk yields was the increased frequency of milking of high-yielding cows. It was adjusted to the current daily yield of each cow. It is only possible with robot milking. A significant increase in yield occurs when switching from two to three times milking for cows with yields above 8,000 kg. This condition was met in all herds analysed. Additionally, in the production of fat and milk protein, high values were achieved in the farms (Tab. 2). The difference between the average fat yield in the Podlaskie Voivodeship and that in the barns analysed favoured the latter. Only once, in barn No. 5 in 2019, there was a 1 kg lower fat content than the provincial average. In the remaining years (2018, 2020 and 2021), a 23–27 kg higher yield in relation to the provincial average was recorded in barn No. 5. In the best barns (Nos 2 and 7), the difference was more than 100 kg. The protein yield in the barns analysed was also higher than the national average. The difference between the Podlaskie Voivodeship average and the lowest among the barns (No. 5) ranged from 7 kg (in 2019) to 21 kg (in 2018), while the difference between the best barns (Nos 2 and 7) generally exceeded 100 kg.

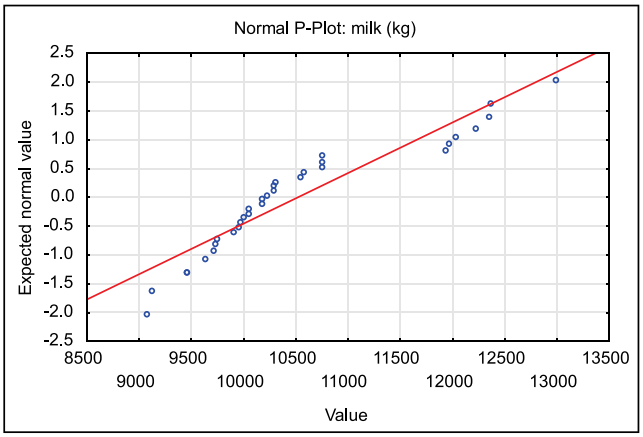
The percentage of fat in milk was different. In 2018, in all seven barns with milking robots, the fat content in milk was lower compared to the average for the Podlaskie Voivodeship. The lowest fat content was recorded in barns No. 7 (3.80%) and No. 2 (3.84%), i.e. in barns with the highest milk yield. A similar relationship occurred in subsequent years. In 2019, only barn No. 3 had a fat content equal to the provincial average (4.11%), while in 2020, barns Nos 3, 4 and 9 had fat contents slightly higher than the provincial average. Additionally, in 2021, in barns 2, 8 and 9, the fat content was slightly higher compared to the provincial and national average. In all years analysed, the lowest fat content was in the herds with the highest milk yields in barns 2 and 7. The negative correlation between the yield and the fat percentage is a natural physiological phenomenon.

The average percentage of protein in milk in both the Podlaskie Voivodeship and the country was very similar year to year. Differences between barns were negligible, ranging from 0.25% in 2018 to 0.44% in 2020. As in the case of fat content, the lowest protein content was found in the barns with the highest milk yield (Nos 2 and 7).

ANALYSIS OF MILKING ROBOT OPERATION

A basic milking box unit is modular. The robot milks cows for 24 h, and its operation can be divided into two parts: the time the cows occupy the stall and the so-called "downtime". The use of robots in selected barns with one (A), two (B) and three (C) milking boxes are shown in Tables 3, 4 and 5. For comparison, the results were converted per milking box. For the farmer, the





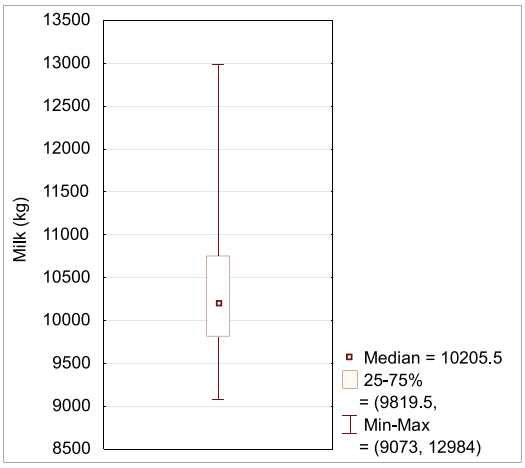
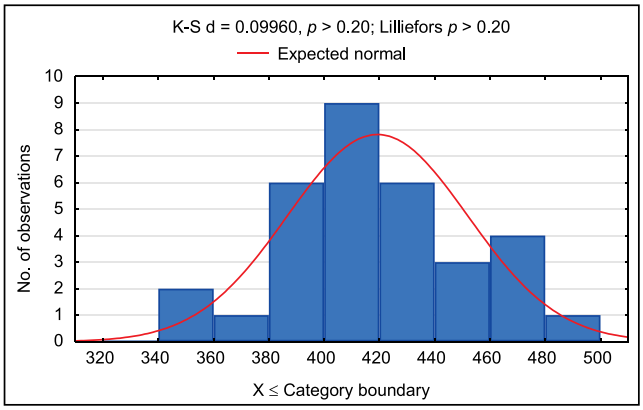
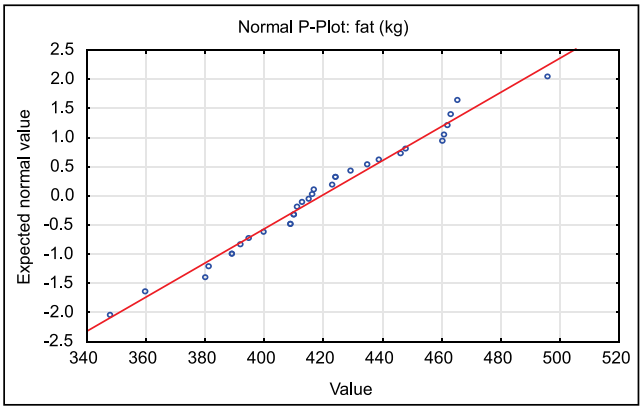


Fig. 1. Milk yield recorded in the analysed herds; summary statistics: milk production (kg), mean = 10,517.593750, variance = 1,075,886.829637, standard deviation = 1,037.249647, skewness = 0.938225, kurtosis = –0.110748; source: own study





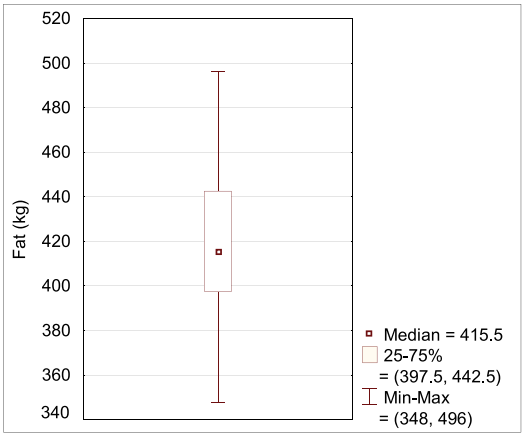
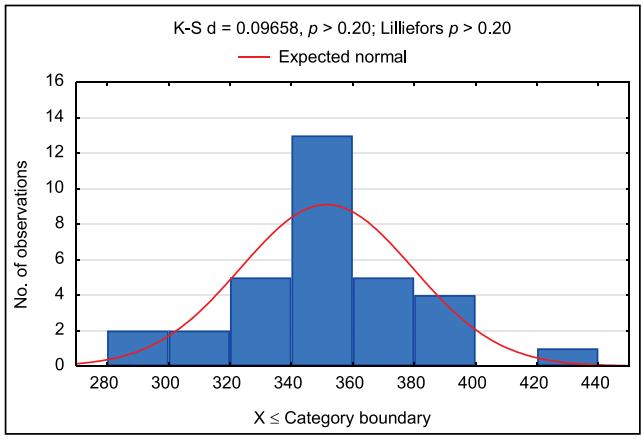
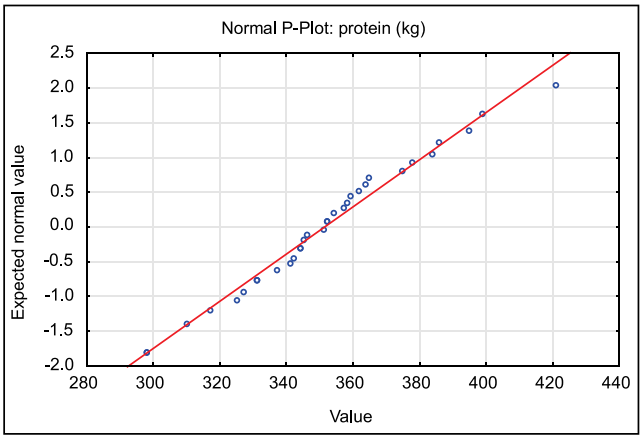


Fig. 2. Fat content in milk obtained from the herds analysed; milk production (kg), mean = 419.343750, variance = 1,067.974798, standard deviation = 32.679884, skewness = 0.107240, kurtosis = –0.071649; source: own study





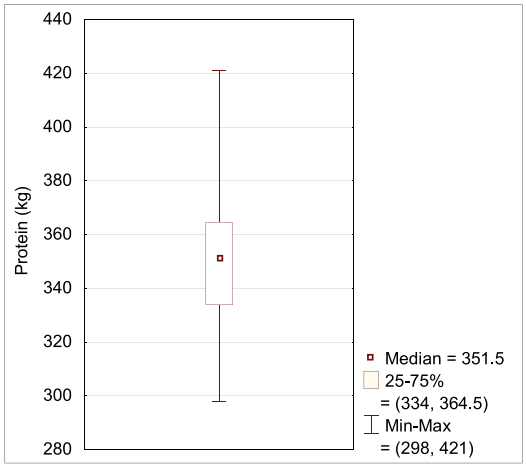


Fig. 3. Protein content in milk obtained from the herds analysed; milk production (kg), mean = 351.500000, variance = 788.387097, standard deviation = 28.078232, skewness = 0.253246, kurtosis = –0.305678; source: own study

primary indicator characterising the robot's efficiency is the number of cows the robot can milk, which determines the herd size per milking stall. The average number of cows annually and in the last month before the data were downloaded from the computer system was almost identical in all three barns (Tab. 3). During the year, there were 64 cows in barn A, 65 in barn C and 66 in barn B. The same was confirmed last month, with 65 cows each in barns A and B and 67 in barn C. In each case, this was higher than the national average of 59 cows.

The results demonstrate maximum robot utilisation. The number of cows milked is derived from the number of milkings performed and the average milking rate in the herd. During a year, the number of milkings per day ranged from 171 in barn B to 182 in barn C. Similar values were recorded for the last month. In the barns surveyed, the number of milkings was 10 or more above the national average.

A frequently used indicator of a robot's performance is the milk yield in a good year. It is the product of the number of cows

Table 3. Basic performance indicators of milking robots in herds of different sizes per milking stall

Indicator	Unit	Value of the last 336 days in the herd				Value of the last 30 days in the herd		
		A	B	C	Lely Center	A	B	C
Number of cows	pcs.	64	66	65	59	65	65	67
Number of milkings per day	pcs.	173	171	182	159	169	175	187
The amount of milk milked per: – 24 hours	kg	1,963	2,074	2,377	1,757	2,212	2,060	2,452
– per year	thous. kg	716	757	867	641	807	752	895
Duration of activity: – cleaning and massaging the teats	s	59	42	41	46	60	42	42
– actual milking	s	283	311	262	280	316	301	259
– the presence of the cow in the milking stall	min	421	434	380	412	458	420	378
The robot's "free time"	%	11.4	9.9	15.7	16.6	5.0	8.2	11.5

Source: own study.

Table 4. Basic characteristics of milking cows

Indicator	Unit	Value of the last 336 days in the herd				Value of the last 30 days in the herd		
		A	B	C	Lely Center	A	B	C
Milking rate per day	–	2.7	2.6	2.8	2.7	2.6	2.7	2.8
The amount of milk milked: – per 1 milking	kg	11.3	12.2	13.0	10.9	13.2	11.7	13.0
– per day		30.9	31.9	36.4	30.8	35.3	32.3	37.6
Out-of-class milk	%	1.3	1.0	1.0	1.9	1.1	0.4	1.0
Percentage of cows with a milking interval of more than 14 h	%	16.4	10.2	9.9	12.7	16.8	6.1	8.3
Feeding of concentrate in the milking box: – residues left behind	%	11.5	10.3	7.8	7.8	12.0	8.9	3.9
– consumption per 100 kg of milk	kg	12.0	11.6	8.0	13.4	10.8	11.9	8.9

Source: own study.

Table 5. Milking characteristics of cows in terms of milking interval and quantity of milk milked

Milking interval (h)	Quantity milked (kg)	Percentage of lactating cows in the herd in particular lactation in barn								
		No. 1			No. 2			No. 3 and beyond		
		A	B	C	A	B	C	A	B	C
>12	≥14	15.1	4.2	8.2	9.6	2.8	4.1	16.4	4.2	4.1
	<14	2.7	6.9	2.7	2.7	5.5	1.3	4.1	2.8	1.3
6–12	–	67.2	87.5	85.7	69.9	77.8	84.3	64.4	81.9	73.4
<6	≥8	8.2	1.4	2.7	16.4	13.9	9.6	15.1	10.1	20.5
	<8	6.8	0	0.7	1.4	0	0.7	0	1.0	0.7
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: own study.

milked and their yield. The lowest daily milk yield was in herd A at 1,963 kg, the highest in barn C at 2,377 kg. It was always more than the national average of 1 757 kg per day. In annual terms, this was: barn A – 716,000 kg·y^{-1}, barn B – 757,000 kg·y^{-1} and barn C – 867,000 kg·y^{-1}. It is assumed that an annual milking of 500–600 thous. kg justifies the use of robots economically.

Higher yields improve profitability of the robot. A high quantity of milk was obtained in all barns. The cows' average time in the milking stall varied between barns (Tab. 3). The shortest time cows stayed in the stall was in stall C, where the time-averaged 380 s·y^{-1} and an average of 378 s in the last month. In contrast, in barns A and B, the stay was longer and varied slightly over the periods analysed.

The human influence concerned the teat cleaning and massage time and was determined to be about 1 min in stall A and about 40 s in stalls B and C. Cows in barn C were milked the fastest, with the actual milking time about 280 s.

"Downtime" consists of the following:

- changing cows in the box,
- blocking of stalls by cows "not designated" for milking (Lely uses so-called free access – no waiting area with selection gates),
- cleaning and disinfecting of milking equipment (2–3 times a day).

According to Lely's recommendation, "free time" should be 10–15% of the day time or 140–210 minutes. During the year, the robot's "free time" ranged from 9.9% in barn B through 11.4% in barn A to 15.7% in barn C. In the last month analysed, it decreased in all barns. It can therefore be concluded that the "downtime" was within the range recommended by Lely.

The farmer determines the interval between milking and the milking rate based on the cow's milk yield in the herd. Lely recommends that no more than 12 kg and a maximum 14 kg of milk should be collected per milking. Across the country, the average daily milk yield was 30.8 kg per day. In the herds analysed, such a yield was recorded in herd A (30.9 kg), and a higher value occurred in herd B (31.9 kg) and C (36.4 kg). In the last 30 days analysed, there was an increase in herd A to 35.3 kg, in B to 32.3 kg and in C to 37.6 kg per day. The milk obtained per milking was also high (Tab. 4). It was true for all three barns and both periods analysed. It means that the milking rate of 2.6 to 2.8 times per day was too low to provide the cows with the comfort associated with milking. This situation is related to exceeding the number of cows per milking stall. Another indicator that shows the inadequacy of the number of cows per milking stall is the percentage of animals with a milking interval of more than 14 hours. During the year, barns B and C accounted for around 10%, and barn A even 16.4%. In the last analysed month, the

percentage of cows with a long milking interval decreased in barns B and C, while it remained high in barn A (16.8%).

The out-of-class milk (impoundment) generally amounted to about 1% of milk collected and was lower than the national average of 1.9% (Tab. 4).

There were differences between the herds analysed regarding the amount of concentrate feed consumed during milking per 100 kg of milk produced. An outstanding result was obtained in herd C, only 8.0 kg. Much higher feed consumption was recorded in herds B (11.6 kg) and A (12.0 kg). However, these results are still better than the national average of 13.4 kg.

Table 5 shows the distribution of milking frequency in relation to milk quantity. A division into five classes was adopted, taking into account the interval between milking and the amount of milk per milking. An interval of 6 to 12 h (i.e. 4 and 2 milkings), a long interval of more than 12 h (up to 2 milkings) and a short interval of fewer than 6 h (more than four milkings per day) were taken as "normal". The long interval accounted for a high yield above 14 kg and a low yield below 14 kg. The short interval accounted for milkings above 8 kg and below 8 kg.

Another factor considered in the study was the number of lactations: first, second and third and onwards. The frequency of "normal" intervals was lowest in herd A and was valid for all lactations. The first lactation recorded the best results: herd B with 87.5% and C with 85.7%.

Deliberately long intervals between milkings (more than 12 h) are used for drying. The effectiveness of this procedure is milking below 14 kg. Such cases ranged from 1.3% (in herd C in lactations 2 and 3 and beyond) to 6.9% (in herd B in lactation 1). Few cows yielding more than 14 kg of milk were in herd B (from 2.8% in lactation 2 to 4.2% in lactations 1 and 3 and onwards) and herd C (4.1% in lactations 2 and 3 and onwards, and 8.2% in lactation 1). In contrast, there were many such cows in herd A: in lactation 1 – 15.1%, in lactation 2 – 9.6% and in lactation three and onwards – 16.4%. It indicates too infrequent milking in herd A.

Short intervals between milkings, less than 6 h, are used for cows with the highest productivity. The arrangements for such intervals were generally correct. Small milkings – less than 8 kg did not occur in barn A in lactation 3 and onwards and in barn B in lactation 1 and 2. Moreover, a small percentage (0.7%) occurred in barn C in all lactations. Only in barn A were there 6.8% primiparous. The advantage of frequent milking is evident when milking over 8 kg. There were fewer such cows in lactation 1, while in lactation 2 and lactations 3 and onwards, the number of such cows was more than 10% and even 20% (barn C cows in lactation 3 and onwards). The results show that it is necessary to take into account the number of cows per milking stall and the actual performance of individual cows.

MANAGING HERDS OF DIFFERENT SIZES

Robotic milking is applied in the case of larger herds and intensive and stable milk production. This is due to the high investment costs for the robot. The optimum number of cows per milking place is over 60. However, the average size of the herd under monitored in the Podlaskie Voivodeship is below 45 cows. Hence, a barn with one milking stall may pose an organisational and economic challenge.

Single stall barn (A)

Table 6 shows the basic values characterising herd A in 2021. The total number of cows during that year was reasonably stable, ranging from 68 to 74. There was more variation in the number of cows milked: for most of the year, these were between 65 and 69. At the end of the year, the number of cows milked was only 53, which affected the daily milk yield by the herd. With a balanced average yield per cow (between 28.3 and 30.7 kg), daily herd production was very stable, ranging from 1934 to 1995 kg (Fig. 4). In contrast, in November (in a herd of 53 cows), despite the highest yield of 31 kg per day, production from the herd was 300 kg lower (i.e. about 15%).

Table 6. Basic data on stock A in 2021

Month	Number of cows			Percentage of cows milked	Number of calving once			Milk production (kg) from	
	milked	dried	total		1	2	total	cows	flocks
1	65	3	68	96	3	–	3	30.2	1,963
2	–	–	–	–	2	1	3	–	–
3	66	2	68	94	1	4	5	29.3	1,934
4	–	–	–	–	2	2	4	–	–
5	65	8	73	89	1	4	5	29.8	1,937
6	–	–	–	–	–	2	2	–	–
7	65	8	73	89	2	9	11	30.7	1,995
8	–	–	–	–	–	5	5	–	–
9	69	5	74	93	1	3	4	28.3	1,952
10	–	–	–	–	–	2	2	–	–
11	53	18	71	75	2	4	6	31.0	1,643
12	–	–	–	–	4	17	21	–	–

Source: own study.

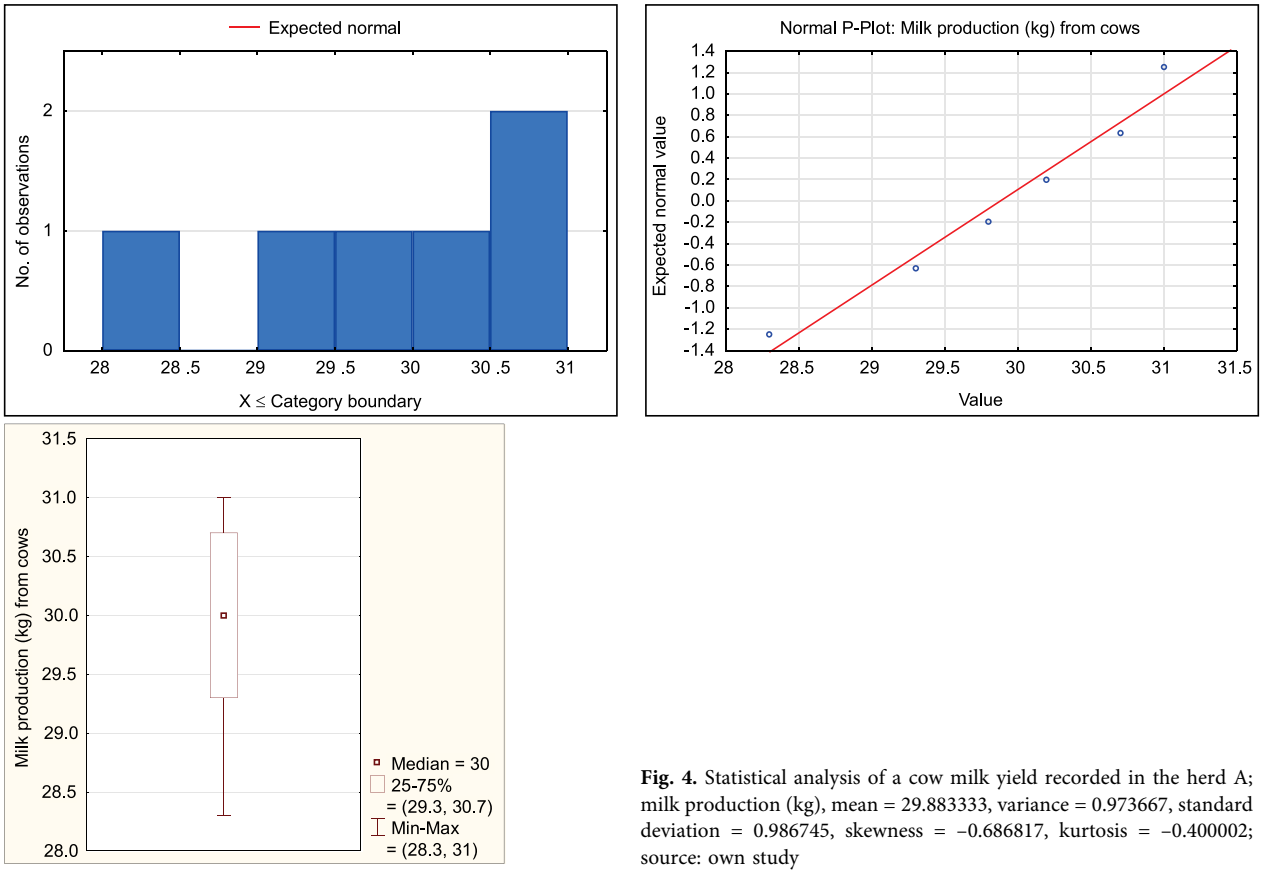
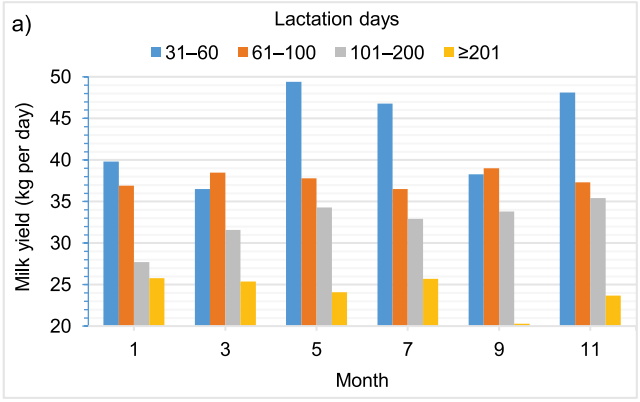


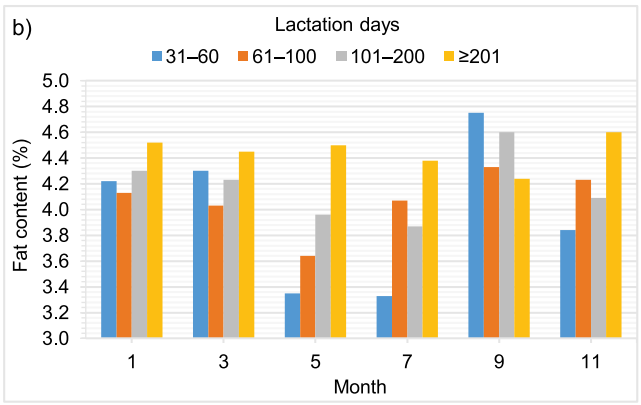
Fig. 4. Statistical analysis of a cow milk yield recorded in the herd A; milk production (kg), mean = 29.883333, variance = 0.973667, standard deviation = 0.986745, skewness = –0.686817, kurtosis = –0.400002; source: own study

Significant differences in the number of calving occurred between particular months. For 10 months, calving ranged from 2 to 6. In the other two months, the number was much higher, with 11 calving in July and 21 in December.

In the cow herd analysed, there is a considerable variation between cows regarding milk yield. The source of this variability boils down to hereditary and physiological factors linked to the lactation phase. The high variability complicates feeding. The necessary variation in feed rations for individual cows is possible by limiting the concentrated feed. It is distributed during milking and per special feed stations. Here, too, there are both economic (concentrate feed is expensive) and physiological constraints as using large quantities of concentrate feed leads to digestive and metabolic disturbances (metabolic acidosis).

Figure 5a shows average daily milk yields by lactation day in the 2021 run. As a rule, cows had the highest yields on days 31–60 of lactation. During this period, exceptionally high yields were





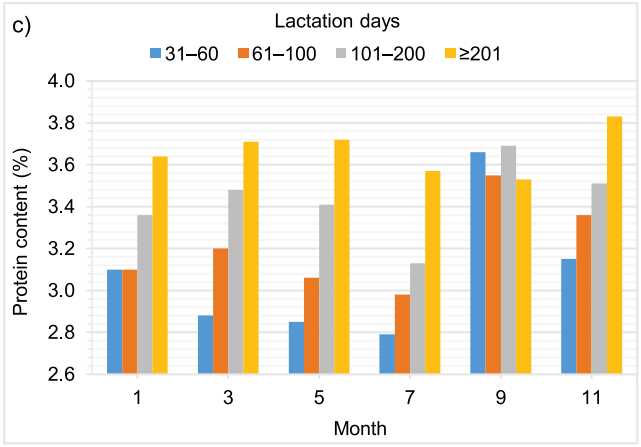


Fig. 5. Basic data describing milk production in barn A, according to lactation stage in 2021: a) average daily yield, b) percentage of fat in milk, c) percentage of protein in milk; source: own study

recorded in May, July and November, 49.4, 46.8 and 48.1 kg of milk per day, respectively. The highest yields were for cows at 61–100 days of lactation in March (38.5 kg per day) and September (39.0 kg per day). The variation occurring is due to individual variability – regular decreases in yield with the course of lactation can be observed.

The fat content in milk followed a different pattern (Fig. 5b). As a rule, the highest fat content was in milk from cows at the end of their lactation. The highest daily milk yield showed the lowest fat content. Such a relationship is a natural physiological relationship. Similarly, there was a negative relationship between milk yield and protein content (Fig. 5). In contrast, the unusual results obtained in September 2021, when both fat and protein contents were very similar in all lactation phases, pose an interpretation challenge (Fig. 5b, c).

Cowshed with two milking places (B)

The number of cows in barn B changed slightly over the year (Tab. 7). In both January and December 2021, it was almost identical, 150 and 149 cows, respectively. There was also little change over the year. The lowest number of cows (147 cows) was in October, and the highest number (154 cows) was in May and June. To evaluate the use of the milking robot, the number of milking cows is important. In this case, the differences were more significant. More cows underwent milking at the beginning of the year (most in April – 138 cows) and fewer at the end of the year (least in December – 122 cows). The difference of 16 cows gives almost 2 h of milking per stall (16 cows · 434 s of cow stay in milking stall – Tab. 3). It indicates how important a parameter on the farm is to have an even number of cows milked throughout the year. It depends on births which occur every month of the year but the number of births varies. The lowest number of births was in April and May (8 each), and the highest was in March and September (18 each). Improvements in reproductive management are needed in this element to achieve an even distribution of calving throughout the year.

Figure 6a shows average daily milk yields according to the lactation phase in the 2021 run. Differences were noted between lactation phases and individual months of the year (Fig. 7). Cows most frequently reached maximum milk yields in the second month of lactation in the first eight months of 2021. Almost identical milk yields in the 31–60 and 61–100 day lactation periods were found in November and December 2021. In contrast, in August and September, the maximum yield was recorded in 61–100 days of lactation. During the year, the daily yield was 40.5 kg on 31–60 days of lactation, while on 61–100 days, it was about 37.5 kg of milk per day. A reasonably even yield was observed on 101–200 days of lactation. It averaged about 33.9 kg of milk per day, with extreme values found in November (32.7 kg) and October (35 kg). At the final stage of lactation (more than 200 days), the average yield was 26.8 kg of milk per day. The difference in yield between months increased, the lowest being in November and the highest in June, respectively 23.4 kg and 30.6 kg.

The results indicate high individual variability in milk yield. Therefore, constant monitoring of individual cow performance is required and adjustments to milking frequency and amount of concentrate fed need to be made. These are elements of the precision farming procedure.

During lactation, the changes in the percentage of fat (Fig. 6b) and protein (Fig. 6c) varied. In both cases, the lowest content was at the beginning and the highest at the end of lactation. The average fat content in the first 100 days of lactation was about 3.80%, in the next 100 days about 4.00%, and at the end of lactation about 4.35%.

The average protein content in milk at the beginning of lactation (days 31–60) was about 3.15%. It increased to about 3.30% on days 61–100, and then increased to 3.5% on days 101–200 to reach about 3.7% at the end of lactation. It is assumed that the balance of energy in feed intake in relation to the amount of milk produced occurs when the protein content in milk is between 3.2 and 3.6%. In the barn analysed (B), the degree of balancing out varied between lactation phases. In the second month of lactation, there was an energy deficit. From the third to

Table 7. Basic data on stock B in 2021

Month	Number of cows			Percentage of cows milked	Number of calving once			Milk production (kg) from	
	milked	dried	total		1	2	total	cows	flocks
1	131	19	150	87	1	10	11	31.6	4,140
2	132	19	151	87	6	3	9	32.1	4,237
3	131	22	153	86	7	11	18	31.9	4,179
4	138	15	153	90	1	7	8	31.7	4,375
5	133	21	154	86	2	6	8	33.0	4,389
6	126	28	154	82	2	14	16	33.9	4,271
7	128	25	153	84	2	12	14	33.1	4,237
8	130	22	152	86	7	9	16	32.3	4,199
9	129	22	151	85	3	15	18	30.4	3,922
10	125	22	147	85	5	7	12	30.8	3,850
11	125	28	153	82	5	7	12	30.2	3,775
12	122	27	149	82	5	12	17	33.0	4,026

Source: own study.

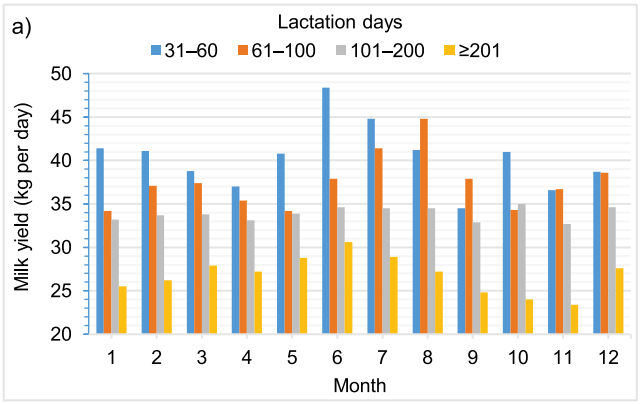


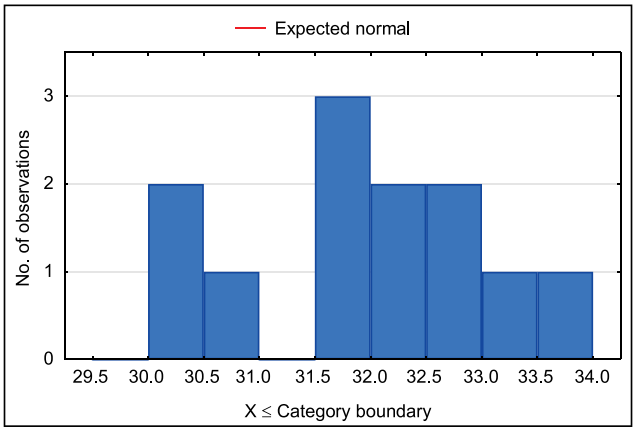
Fig. 6. Basic data describing milk production in barn B according to lactation stage in 2021: a) average daily yield, b) percentage of fat in milk, c) percentage of protein in milk; source: own study

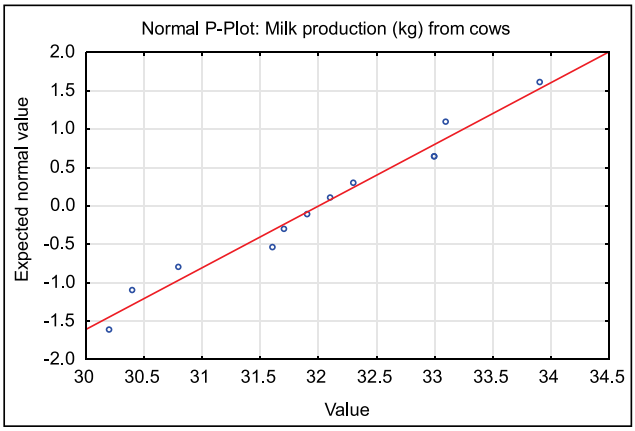
the seventh month of lactation, nutrition was balanced with milk production. In contrast, from the eighth month of lactation onwards, energy overfeeding was recorded.

The results presented show the difficulty to balance nutrition of high-yielding cows. There are two sensitive periods. The first one is at the beginning of lactation (peak performance) and it is combined with the danger of malnutrition. This problem occurs in every herd and increases as herd productivity increases. This issue is the subject of research in many scientific centres. The second period is at the end of lactation and it is accompanied by the danger of overfeeding.

Cowshed with three milking stalls (C)

Barn C was the largest of the facilities surveyed (Tab. 1). In January 2021, the herd consisted of 216 cows, with an increase to 232 cows in December (Tab. 8). Throughout the year, the number





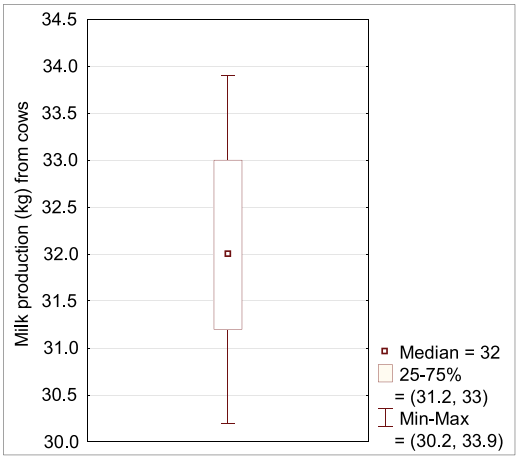


Fig. 7. Statistical analysis of yield recorded in the herd B; milk production (kg), mean = 32.000000, variance = 1.310909, standard deviation = 1.444949, skewness = –0.111204, kurtosis = –0.763225; source: own study

Table 8. Basic data on stock C in 2021

Month	Number of cows			Percentage of cows milked	Number of calving once			Milk production (kg) from	
	milked	dried	total		1	2	total	cows	flocks
1	198	18	216	92	4	10	14	38.9	7,700
2	196	19	215	91	3	8	11	39.8	7,800
3	198	16	214	93	2	4	6	39.7	7,860
4	198	17	215	92	2	6	8	39.1	7,742
5	189	28	217	87	7	11	18	38.2	7,220
6	186	34	220	85	7	17	24	37.1	6,900
7	190	36	226	84	15	16	31	36.0	6,840
8	196	35	231	85	4	19	23	34.3	6,723
9	195	38	233	84	6	18	24	32.4	6,318
10	196	36	232	84	6	19	25	36.2	7,095
11	193	39	232	83	7	14	21	37.6	7,257
12	200	32	232	86	7	16	23	37.9	7,580

Source: own study.

of cows milked was relatively constant, between 190 and 200 cows, and it was below 190 cows only twice – in May (189 cows) and June (186 cows). The percentage of cows milked varied between 83% in November and 93% in March. The number of dry cows changed as well. It was below 20 heads from January to April, and above 30 from June to December. Such large fluctuations did not adversely affect the production, as dried cows do not require additional treatment.

Two leading indicators show the scale of the farm production: the number of calving and the volume of milk collected. There were 228 calvings per year on the farm, including 70 primiparas. As a rule, from 2 to 7 primipara were calved per month. Only in July, there were significantly more primipara – 15 heads. The total number of calving in each month of 2021 also significantly varied. The fewest calvings were in March (6) and April (8). There were significantly more calvings from June to December (more than 20), and the maximum number of calvings occurred in July (31). The herd showed high milk production levels (Fig. 8). The average daily yield per cow was below 35 kg only twice (in August and September). In the other ten months, it was over 36 kg and from February to April it exceeded 39 kg.

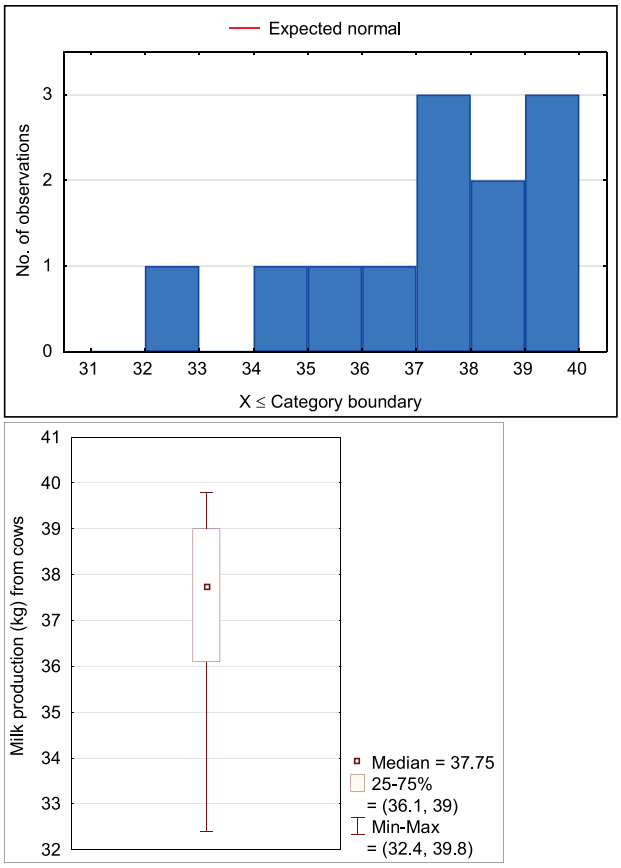


Fig. 8. The statistical analysis results of the cow's milk yield were recorded in herd C; milk production (kg), mean = 37.266667, variance = 5.000606, standard deviation = 2.236203, skewness = –998340, kurtosis = 0.616392; source: own study

Daily milk production from the barn varied. From June to September, it was below 7,000 kg. In the other eight months (January–May and October–December), it exceeded 7,000 kg of milk per day. The difference between the extremes (in September 6318 kg and in March 7860 kg) exceeded 1.5 thous. kg of milk per day.

Figure 9a shows the average daily milk yield per cow by lactation stage over the year. As a rule, cows had the highest yield in the second month of lactation. It was lower in only two months (September–October), as it was <40 kg of milk per day. In the other months of the year, it was >40 kg; in May, it was even 49.1 kg of milk per day. Milk yield was at a slightly lower level from day 61 to day 100 of lactation (in ten months, it exceeded 40 kg per day). A very mild decline in milk yield occurred in the second 100 days of lactation. In six months, the average exceeded 40 kg of milk per day. An apparent decline in milk yields did not occur until after the 200th day of lactation, but these were still high yields – above 30 kg (only in October and November was the decline significant, corresponding to yields of 26.1 kg and 28.8 kg of milk per day).

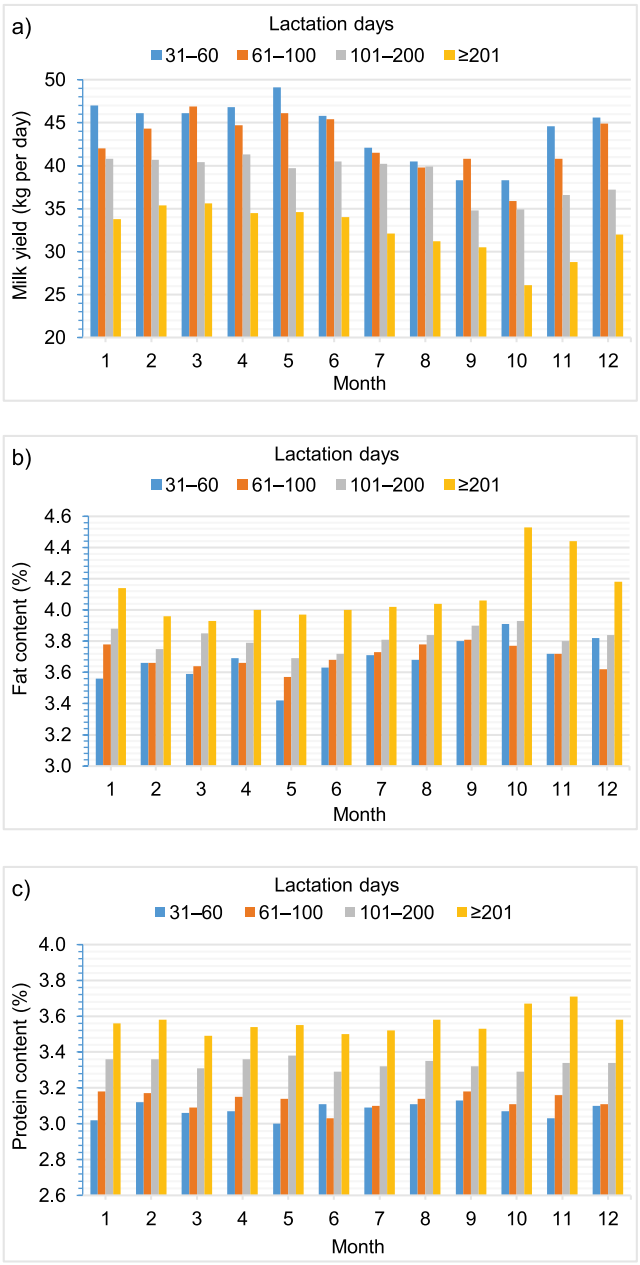


Fig. 9. Basic data describing milk production in barn C, according to lactation stage in 2021: a) average daily yield, b) percentage of fat in milk, c) percentage of protein in milk; source: own study

Herd C is characterised by a low milk fat content (Fig. 9b). In the initial phase (31–60 and 61–100 days of lactation) and the middle phase of lactation (101–200 days), the fat content was below 4%. In the final phase of lactation (201 and onward days), the fat percentage was above 3.90%, with a maximum value occurring in October (4.53%).

Low protein content in milk, below 3.20%, was observed in the first 100 days of lactation throughout the year (Fig. 9c). It indicates inadequate feeding of cows in terms of energy. It is a common problem in herds with high milk yields. In the later part of lactation, from day 101 to the end of lactation, the protein content was mainly standard, i.e. 3.2–3.6%, which means a balance of energy intake with feed relative to the amount of milk.

DISCUSSION

1. At all sites, high milk yields were obtained from cows throughout the study period, on average 780,000 kg of milk per year. The fat and protein content was typical for the breed. The average fat content (in period analysed) was only 0.06% higher than the national average of 4.08%. In the farms analysed, the average fat content was 4.00%, with a standard deviation of 0.16%. However, the extreme values recorded in the individual herds varied considerably and were 3.67 and 4.27%. The average protein content on a national scale (in period analysed) was 3.41% and it was 0.02% lower than the average for the Podlaskie Voivodeship, and 1.77% higher than the average recorded on the farms studied (average protein content in milk was 3.35%, with standard deviation of 0.126%). In the case of protein, the spread of values between herds was also smaller, ranging from 3.07% to 3.53%.
2. The amount of milk collected per robot station was high, on average 10,517.59 kg, which was 124% of the average in Podlaskie Voivodeship and 122% of the national average. Milk production varied significantly between herds and years ranging from 9,073 to 12,984 kg per robot station, with a standard deviation of 1,021 kg.
3. Depending on the herd and month analysed, the number of cows per milking stall was from 53 to 69. On average, 64.54 cows were milked per stall per month, with an average total number of cows in the herd of 74.4 head. A proper planning of cow drying resulted in 86.79% of all cows in the herd milked at one stall.
4. The average amount of milk per milking was high at 33.68 kg, with a standard deviation of 3.41 kg. The amount of milk collected varied both between herds and the months analysed and ranged daily from 28.3 to 39.8 kg per cow.
5. In order to improve the uniformity of milk production from the barn, more attention should be paid to the uniformity of calving during a year. The farms analysed (A, B and C) recorded a total of 458 calvings in 2021, an average of 12.72 calves per month. However, the differences in the number of monthly calvings per year were very large, with only two calvings in June and October and 10 calvings per milking stall in July.

6. In order to improve animal welfare, more attention should be paid to intervals between milkings of high-yielding cows and the composition of their feed. The best solution would be to adjust the time between milkings, and the quantity and composition of the feed independently for each cow, depending on her condition and day of lactation. It will not only optimise the amount of milk collected per unit but also result in milk parameters maintained at the desired level, in particular protein and fat content.

CONCLUSIONS

The authors showed that the herds were characterised by high milk yields, and the milk obtained did not differ significantly in composition from values typical for a given breed of cattle. Nevertheless, some regularities could be observed in all herds analysed (A, B, C). The lowest milk production per cow occurred late summer and early autumn. It may be related to the shortage of nutrients in the forages taken in by the animals. The peak productivity occurs in winter and early spring. Knowledge of these relationships can be used in herd management planning. To increase milk production in cows, the amount of concentrate feed can be increased, but this involves increased production costs. Being aware of the periods of reduced milk production, one can adequately plan months when cows dry out as this occurs mainly in the months of reduced productivity.

While analysing the performance of milking robots used in the barns, it can be concluded that they worked properly. The number of milking stations correlated properly with the herd size. As a result, the daily milking rate was significantly higher than the national average, while the robot's "free time" was reduced.

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