






The productivity of dairy cows on farms using milking robots – based on data from the Podlaskie Voivodship

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Abstract: Robotic milking systems represent one of the key technologies automating milk production, integrating advanced mechanics, vision systems, and data-driven analysis. Their implementation influences labor efficiency, animal welfare, and the overall quality of the obtained raw material. An examination of their adoption in the Podlaskie region provides insight into their significance for the development of local dairy farms between 2019 and 2024. The article presents changes in herd size, milk yield, and milk quality of cows milked by robots in the Podlaskie Voivodship from 2019 to 2024, comparing them with the results obtained in the conventional milking system. During the study period, the total herd size more than doubled, which indicates the growing popularity of automatic milking technology. Milk yield remained stable until 2023, then increased to 11.18 thous. kg per cow per year in 2024, accompanied by a simultaneous reduction in the differences between farms. The fat and protein content of milk remained relatively stable in the early years, before showing a marked increase in the last year of the analysis and a more even level between herds. In all the parameters studied, robot-milked herds had an advantage over farms using conventional milking, indicating the growing efficiency and quality of production in automated systems.

Keywords: cow, fat yield, herd size, milk yield, protein yield

INTRODUCTION

In recent decades, the dairy sector worldwide has undergone significant changes due to technological advancements, shifting economic conditions, and evolving consumer expectations (Roman, 2020; Zięta, Pietrzak and Malak-Rawlikowska, 2024). Growing competition in the milk market and pressure to improve production efficiency mean that farmers are increasingly turning to solutions that enable the optimisation of breeding processes (García-Méndez, Arriba-Pérez de Somoza-López, 2024). One of the most innovative and rapidly developing areas is milking

automation, which is implemented using milking robots (Jacobs and Siegford, 2012). This technology, which was considered a novelty a dozen or so years ago, available mainly to large farms in Western European countries, is now also gaining popularity in Poland, including in regions with dairy farming traditions, such as the Podlaskie Voivodship (Sobczyński *et al.*, 2013; Sobczyński *et al.*, 2015).

Milking robots, also known as Automatic Milking Systems (AMS), are one of the most advanced technologies in modern agriculture, designed to automate the entire milking process for cows (Borusiewicz *et al.*, 2023). Their design is based on

a combination of precision mechanics, optical sensors, animal recognition systems, and software for collecting and analysing production data (Piwczyński *et al.*, 2020). In practice, this means that a cow approaches the robot at any time of the day, and the device automatically recognises it using a transponder or identification collar, assesses the condition of the udder, performs the milking process, and, at the same time, records several parameters relating to its performance and health (Piwczyński *et al.*, 2021). One of the key elements of milking robots is the vision and sensor system, which enables precise positioning of the milking cups on the teats, as well as real-time monitoring of milk flow and the quality of the raw material obtained (Borne van den, Grinsven van and Hogeveen, 2021). This enables the immediate detection of abnormalities, such as changes in the electrical conductivity of milk (Hovinen and Pyörälä, 2011), which may indicate mastitis (Edmondson, 2017; Fan *et al.*, 2023). Modern robots also enable the analysis of milk composition in terms of fat, protein, lactose, and somatic cell counts, providing the farmer with a comprehensive picture of the herd's condition and the quality of production (Khatun *et al.*, 2023; Ozella *et al.*, 2023).

The benefits of using AMS are multifaceted (Piwczyński *et al.*, 2021). On the one hand, this technology significantly reduces physical labour, freeing the farmer from the need for manual or semi-automatic milking at fixed times (Rodenburg, 2017). On the other hand, it allows for more flexible time management – cows decide for themselves when they want to be milked, which can naturally increase the frequency of milking and have a positive impact on productivity (Kuczaj *et al.*, 2020). In many cases, there is also an improvement in animal welfare, resulting from less stress associated with routine herding to the milking parlour and a more individual approach to each cow (Bustos Mac-Lean *et al.*, 2024). However, it should be emphasised that the implementation of milking robots involves significant investment and organisational requirements. The cost of purchasing and installing a single milking robot can reach several hundred thousand PLN, and its practical use requires the appropriate adaptation of the farm's infrastructure, including the layout of the premises, the feeding system, and the organisation of animal flow (Feuz and Larsen, 2019). Furthermore, the success of the investment depends on the skilful use of the data generated by the system – the farmer should be prepared to take an analytical approach to herd management and respond to signals from the software.

The Podlaskie Voivodship, one of Poland's largest milk producers, is a perfect example of a region where tradition meets modernity (Nowak, 2016). On the one hand, there are numerous family farms with extensive experience in dairy cattle breeding (in Poland, at the end of 2024, 15,634 barns were permanently inspected), and on the other hand, there is a growing interest in investments in modern infrastructure, including milking robots (Dąbrowska, 2017). However, this process is proceeding at different speeds and on different scales, depending on the financial capabilities, farm size, and production strategy of the individual farmer (Madej, 2015).

An analysis of the results from 2019 to 2024 allows us to observe how the introduction of milking robots affects the number of cows in herds, their milk yield, and the quality of the raw material obtained, measured by fat and protein yield. This period encompasses both years of stable development and moments of significant change in herd structure and production dynamics, making it an intriguing subject for research on the

effectiveness of implementing modern technologies in agricultural practice.

This study aims to present in detail the trends and changes occurring on farms in the Podlaskie Voivodship using automatic milking systems during the analysed period, as well as to compare their results with those of farms using traditional milking methods. This will not only allow for an assessment of the effectiveness of milking robot technology in local conditions, but also indicate potential directions for further development of the dairy sector in the region, in the context of growing quality, economic, and environmental requirements.

MATERIALS AND METHODS

The initial figures for the analysis of the problem were obtained from GUS (2020–2025) and PFMBiPM (2020–2025).

Data for analysis came from herds and barns evaluated year-round according to methodology approved by International Committee for Animal Recording (ICAR), which meet the condition of a minimum number of milkings per year:

- 11 registered full milkings – in evaluation methods with an interval of '4' (every 4 weeks),
- 8 registered full milkings – in evaluation methods with an interval of '6' (every 6 weeks),
- 6 registered full milkings – in evaluation methods with an '8' interval (every 8 weeks).

The evaluation method for each barn is determined based on the last trial milking of the calendar year. For barns having several evaluation methods in the last trial milking of the year, the method with the prevailing number of cows is the leading method for determining year-roundness. The data came from barns and herds of breeders who gave written permission for publication. Performance evaluation of dairy cows is one of the most important elements of breeding progress, allowing monitoring and improvement of herd quality. Over the past 13 years, the percentage of cows under evaluation has increased by 16% in the country. In 2024, the share of evaluated cows in the total dairy cow population was 36%. For the analysis, barns were selected that used robotic milking. The values given in the tables and figures are the average values recorded in a given year from the dairy cows in a given herd. Each herd was represented as an average value for the year. This method of presentation eliminated the problem associated with different numbers of dairy cows per year/herd. A larger number of dairy cows merely represents a larger sample from which the average value was determined.

Statistical analysis was also performed. Among the parameters that describe the various distributions, can be distinguished:

- range, the difference between the largest and smallest values in the set;
- standard deviation (s) is calculated acc. to Equation (1):

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (1)$$

where: x_i = single, i -th value, \bar{x} = arithmetic mean of the data, n = sample size;

- standard error (SE) is calculated acc. to Equation (2):

$$SE = \frac{s}{\sqrt{n}} \quad (2)$$

- sample variance (s^2) is calculated as the square of the standard deviation;
- kurtosis (β_2) is calculated acc. to Equation (3):

$$\beta_2 = \frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^n \left(\frac{x_i - \bar{x}}{s} \right)^4 - \frac{3(n-1)^2}{(n-2)(n-3)} - 3 \quad (3)$$

- skewness (Sk) is calculated to Equation (4):

$$Sk = \frac{n}{(n-1)(n-2)} \sum_{i=1}^n \left(\frac{x_i - \bar{x}}{s} \right)^3 \quad (4)$$

RESULTS AND DISCUSSION

Between 2019 and 2024, the number of dairy cows in herds milked by robots in the Podlaskie Voivodship exhibited significant variability both between individual farms and on an annual basis (Tab. S1). In 2019, the average number of cows was approximately 146, with values ranging from 59 to 228. The following year saw a decrease in the average to 130, and the range of values increased to 187, which indicates the diversity of herd sizes. In 2021, the average rose again to just under 136, and in 2022, the average number of cows was 140. Although in 2023 the average number of dairy cows in herds fell to just under 135, the range of values was the largest since the beginning of the analysed period and amounted to 189. The year 2024 brought a further decline in the average to just under 120, but a record maximum herd size of 282 was recorded, with the range increasing to 228.

An analysis of the volatility indicators reveals that the standard deviation remained at a similar level throughout the period, ranging from 54 to 62 dairy cows, confirming the constant diversity of herd size. Skewness values were positive in most years, particularly in 2024, indicating a predominance of smaller herds and the presence of a few farms with exceptionally high stocking densities. Kurtosis was negative in most years, except for 2024, when the positive value may indicate a greater concentration of results around the mean, with extremes also occurring. There is also a visible steady increase in the total number of herds covered by the study – from 14 in 2019 to 36 in 2024 – which may indicate the gradual popularisation of automatic milking technology in the region. The reasons for the variation in the number of cows in the herd from year to year were not verified in the study. It may be due to a number of factors, whether biological (natural reproductive processes), economic (milk prices, the need to sell animals, the ability to purchase new animals) or environmental (e.g., infectious diseases, herd size adjustments to available feed resources).

A steady increase in the total number of herds surveyed is also evident – from 14 in 2019 to 36 in 2024 – which may indicate the gradual popularisation of automatic milking technology in the region.

Figure 1 shows the changes in the distribution of the number of cows milked by robots in the Podlaskie Voivodship from 2019 to 2024, allowing us to see not only the extreme values

but also how the herd structure changed in individual years. A gradual change in the shape of the distribution is evident – from a more even distribution in the early years, with a clear concentration of farms around the average values, to an increasingly stretched distribution in later years, where the share of both tiny and exceptionally large herds is growing. In the early years, the data are close to a normal distribution, with a slight predominance of medium-sized farms. In recent years, there has been a clear shift towards lower values, accompanied by the simultaneous appearance of a few, but very high values, which form long ‘tails’ in the distribution. As a result, the shape of the graph in 2024 is already different – it is asymmetrical, with a dense cluster of values in the lower range and single extremes in the highest range. This graphical representation illustrates the process of herd diversification, where small and medium-sized farms coexist with units of significantly larger scale of production. Podlaskie is a region with an intense concentration of dairy farming and relatively early adoption of AMS. Industry literature from the region highlights the organisation of the robot’s work (occupancy, throughput) as the key to profitability, which favours both large and well-managed smaller barns (Wąs *et al.*, 2011; Borusiewicz *et al.*, 2023). The distributions shown in the article (long ‘tails’) correspond well with this picture of adoption and diversity of farm models.

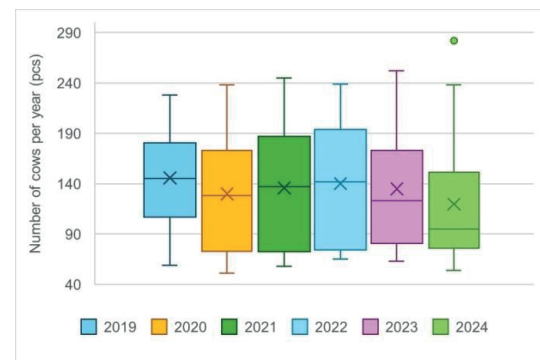


Fig. 1. Distribution of the number of dairy cows milked by robots in the Podlaskie Voivodship since 2019; source: own study

In 2019–2024, milk yield in robot-milked herds in the Podlaskie Voivodship remained relatively stable, although with a marked increase in the last year of the analysis – Table S2. The quantities shown in Table S2 are the averages obtained by the entire herd tested in a given year (this negated the effect of the number of dairy cows in the herd on the test result).

In 2019, the average yield was approximately 10,495 kg of milk per cow per year, and the range of variation between farms was relatively small, from 9,073 to 12,359 kg, corresponding to moderate variation (standard deviation: 1,174.8). The year 2020 saw a slight increase in the average to 10,659 kg, but the spread of results increased slightly, with the maximum yield this year reaching 12,984 kg. In 2021, the average yield decreased to 10,227 kg, with minimum values falling below 8,600 kg and maximum values exceeding 12,800 kg, indicating growing differences between farms. The year 2022 was characterised by a very similar average result (approx. 10,273 kg) and the most extensive range of yields in the study period – the difference between farms was 4,481 kg, with a maximum result of 12,736 kg and a minimum of 8,255 kg. In 2023, the average remained

virtually unchanged (10,268 kg), but variability increased, as confirmed by the highest standard deviation (1,207) in the period under review. This year, the difference between the weakest and best herds reached 4,209 kg. The most dynamic improvement was recorded in 2024, when the average yield increased to 11,177 kg and the maximum yield on a farm reached a record 13,731 kg of milk. At the same time, the standard deviation fell to 948.5, suggesting that the increase in productivity affected a large group of farms, rather than just isolated cases. This is particularly evident in herds No. 5, 6, 12, 13, where, in the comparison of 2019 and 2024, there was a significant decrease in the number of dairy cows, while the average herd productivity increased significantly. Comparing the analysed data, it can be concluded that the average milk yield in 2024 in Podlaskie Voivodship (11,177 kg) was definitely higher than the national average milk yield (9,611 kg).

An analysis of skewness indicators reveals that, in most years, the distribution was slightly skewed to the right, indicating a predominance of farms with below-average productivity, alongside a smaller number of highly productive herds. The kurtosis took values close to zero or negative, indicating relatively flat distributions without a clear 'peak' typical of highly concentrated values. Throughout the period, there is a gradual increase in the total productivity of the herds studied – from 146,923 kg in 2019 to over 402,381 kg in 2024 – which may reflect both an improvement in production results and an increase in the number of cows covered by the automatic milking system.

Figure 2 illustrates the changes in the distribution of milk yield of cows milked by robots in the Podlaskie Voivodship from 2019 to 2024, showing the evolution of the production structure in individual years.

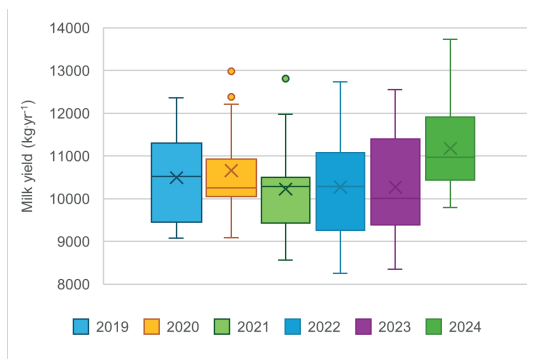


Fig. 2. Distribution of average milk yield in cows milked by robots in the Podlaskie Voivodship since 2019, source: own study

In the first year, the distribution is relatively compact, with most farms achieving results in the range of 9,500–11,500 kg, and extreme values are rare. In subsequent years, especially from 2020 to 2022, the shape of the distribution gradually flattens, indicating increasing diversity in results – there are more farms with both low and high productivity. During this period, the graph begins to show increasingly longer 'tails' towards higher values, reflecting the presence of a small number of highly productive herds. In 2023, the distribution reaches its widest point, with a clear spread in both directions – there is a group of farms with productivity below 9,000 kg and those exceeding 12,500 kg. The last year of the analysis, 2024, brings a significant change in the shape of the distribution – the curve shifts towards higher values and the lower

range of results rises significantly, suggesting an improvement in efficiency in most farms. At the same time, the peak of the distribution becomes more pronounced, and the 'tail' towards the highest values (over 13,000 kg) is shorter than in previous years, which may mean that the differences between farms with extreme results have decreased.

Figure 3 shows a comparison of the average annual yields of cows milked by robots and those milked by conventional methods in the Podlaskie Voivodship from 2019 to 2024, allowing for an assessment of the dynamics of the differences between these two milk production systems. Throughout the entire period, there is a clear advantage in productivity in herds using automatic milking, with the difference remaining within a few hundred kilograms per year in favour of the robotic system.

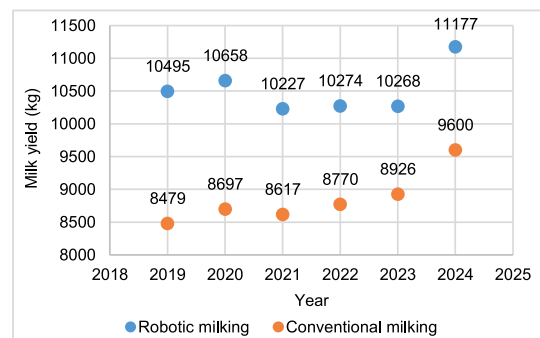


Fig. 3. Comparison of average annual yields of dairy cows milked by robots and conventionally in the Podlaskie Voivodship in 2019–2024; source: own study

In 2019–2020, the difference in milk yields between farms using milking robots and those with conventional milking was approximately 2,000 kg. From 2021, the gap between the two curves begins to widen more clearly – in 2022 and 2023, the yield in robot-milked herds remains stable, while in the conventional system, there are slight fluctuations. Nevertheless, by 2023, the differences in productivity between the analysed farms will decrease. The most significant increase in milk productivity is expected to be seen in both types of farms in 2024, with the difference remaining at a similar level to previous years. This suggests that in recent years, farms have become better adapted to the requirements of working with robots, optimising nutrition and improving herd management. The figure, therefore, shows not only differences in productivity levels but also the rate at which both systems are improving their performance. The results presented are consistent with those of other studies in the literature (Brzozowski *et al.*, 2020; Kowalski, Nowak, and Wiśniewska, 2023), which indicate that transitioning to AMS increases productivity by approximately 10% compared to traditional milking (Crocco *et al.*, 2025).

In 2019–2024, the fat yield in milk from cows milked by robots in the Podlaskie Voivodship remained relatively stable, with a marked increase in the last year of the analysis – Table S3.

In 2019, the average fat yield was approximately 412 kg, with a minimum of 348 kg and a maximum of 463 kg, reflecting moderate variation between herds (standard deviation 35.82). In 2020, the average increased to 421.93 kg, and the range of values widened to 135 kg, with the highest value being 496 kg. In 2021, the average decreased slightly to 420.10 kg, but the maximum value reached was then 500 kg. In 2022, the average decreased

slightly to 416.58 kg, with the most extensive range observed during the study period – 151 kg – and values ranging from 342 to 493 kg. In 2023, the average remained almost identical (416.64 kg), but the variation in results increased, as evidenced by the highest standard deviation (41.55) in the entire period and the presence of both low (342 kg) and high (487 kg) fat values. The most significant increase was recorded in 2024, when the average fat yield rose to 447.47 kg, while the standard deviation decreased to 30.76, indicating a more even level among farms. The maximum value reached 502 kg, and the minimum increased to 397 kg, confirming an overall improvement in milk quality. Comparing the average fat content of milk from cows milked by robot in 2024 in Podlaskie Voivodship (447.7 kg) with the average fat yield of cows in Poland (388) shows a significant difference of more than 15% in favor of Podlaskie barns.

Skewness indicators fluctuated around zero throughout the study period, meaning that the distribution of results was close to symmetrical, with slight deviations towards higher values in some years (e.g., 2020, 2021). The kurtosis indicates a lack of substantial concentrations of results around the mean, and over the last year, a slight flattening of the distribution has been observed. The total amount of fat in the studied herds increased from 5,769 kg in 2019 to 16,109 kg in 2024, which is due to both an increase in milk fat yield and, probably, a larger number of cows in the automatic milking system.

Figure 4 shows the changes in the distribution of fat yield in milk from cows milked by robots in the Podlaskie Voivodship from 2019 to 2024, allowing us to see the evolution of the results structure in individual years. In the early years, the distribution is relatively compact, with a predominance of farms with results close to the average values and relatively short ‘tails’ towards the extreme values. Over time, the distribution line begins to widen, particularly in 2022 and 2023, when a larger number of farms have both low and high fat yields. In 2023, the distribution curve is clearly flattened, indicating a more even distribution of results across a wide range of values. In the last year of the analysis, 2024, the distribution shifts towards higher values, and the minimum results are clearly higher than in previous years. At the same time, the shape of the curve becomes steeper in the middle, suggesting that more farms achieved a similar high level of milk fat yield. This graph indicates a gradual improvement and equalisation of milk quality in terms of fat in herds using automatic milking, and also that in recent years this process has involved not only the best farms, but also average ones.

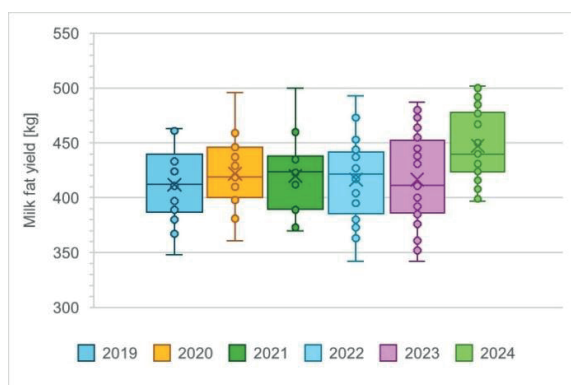


Fig. 4. Distribution of milk fat yield in cows milked by robots in the Podlaskie Voivodship in 2019–2024; source: own study

Figure 5 presents a comparison of the average fat yield in milk from cows milked by robots and conventionally in the Podlaskie Voivodship from 2019 to 2024, showing clear and persistent differences between these systems. Throughout the analysed period, robot-milked herds are characterised by a higher milk fat content than those milked traditionally, and this difference is relatively stable. However, from the first year of the analysis, a slight decrease in the difference between the average milk fat values can be seen. It is worth noting that with conventional milking, fat yield increases year on year, whereas with robotic milking, a slight decrease in value was recorded after 2020, followed by an increase of up to 31 kg in 2024.

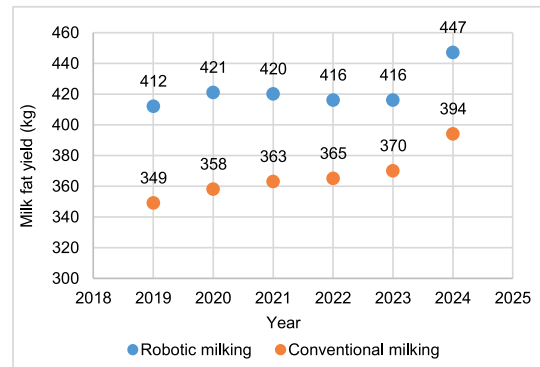


Fig. 5. Comparison of average milk fat yields in cows milked by robots and conventionally in the Podlaskie Voivodship in 2019–2024; source: own study

Between 2019 and 2024, the protein yield in milk from cows milked by robots in the Podlaskie Voivodship exhibited slight fluctuations but showed an apparent increase in the last year of the analysis (Tab. S4). In 2019, the average value was 357.57 kg, ranging from 314 to 408 kg, with moderate variation between farms (standard deviation 28.02). In 2020, the average increased slightly to 357.87 kg, with a maximum value of 421 kg. In 2021, the average decreased to 352.75 kg, but the differences between individual farms were greater – from 310 to 439 kg. The year 2022 saw a slight decrease to 349.88 kg, accompanied by a simultaneous expansion of the range of values to 139 kg, indicating a growing diversity in milk protein production. The average in 2023 was similar to the average in 2021, and the standard deviation reached its highest value in the entire period (41.22), which was the result of the presence of farms with high protein yields (up to 417 kg). In 2024, there was a marked increase in the average to 389.33 kg, accompanied by a simultaneous decrease in variation (standard deviation: 31.26), suggesting an improvement in milk quality across a wider group of farms. Over the entire period, the total protein yield in the studied herds increased from 5,006 kg in 2019 to 14,016 kg in 2024, resulting from both an improvement in quality and a probable increase in the number of cows in the automatic milking system. The average yield of protein in milk in 2024 on the farms analysed (389 kg) was about 15% higher than the national average yield (338 kg).

Figure 6 shows the changes in the distribution of protein yield in milk from cows milked by robots in the Podlaskie Voivodship from 2019 to 2024, illustrating the structure of the results in individual years. In the early years, the distribution was relatively compact, with a predominance of farms achieving values close to the average and short ‘tails’ towards extreme

results. From 2021 onwards, a wider dispersion becomes visible in the graph, indicating the emergence of greater differences in protein yield between herds. The most unusual distribution pattern occurs in 2023 – the line takes on a shape indicating the presence of low and high values, resulting in an apparent flattening and stretching of the graph in both directions. In 2024, the distribution curve shifts towards higher values and its peak becomes more pronounced, reflecting an increase in the number of farms achieving a similar high level of protein content in milk. The visualisation allows us to see the process of gradual equalisation of results after a period of increased volatility, and also confirms that in the last year of analysis, it covered a significant proportion of farms, not only those with the best parameters.

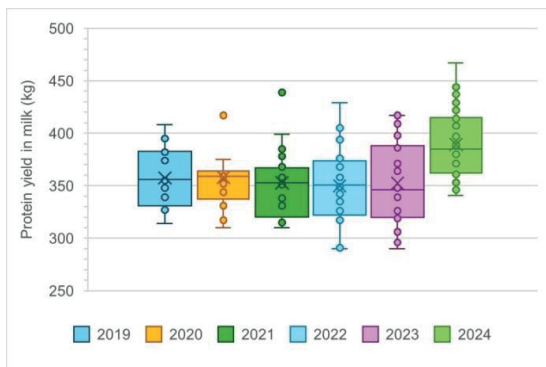


Fig. 6. Distribution of protein yield in milk from cows milked by robots in the Podlaskie Voivodship in 2019–2024; source: own study

Figure 7 shows a comparison of the average protein yield in milk from cows milked by robot and conventionally in the Podlaskie Voivodship from 2019 to 2024, allowing for an assessment of the advantage of one system over the other. Throughout the analysed period, herds using automatic milking maintain a higher average protein yield than herds milked traditionally, although this difference is not significant in most years and decreases until 2023. As with fat yield, protein yield in robot-milked milk decreases from 2021 to 2023, while conventional milking shows a noticeable year-on-year increase. The most pronounced increase in protein content (in both types of milking) is seen in 2024, when the average protein yield in herds increases significantly. The pattern of values suggests that although the

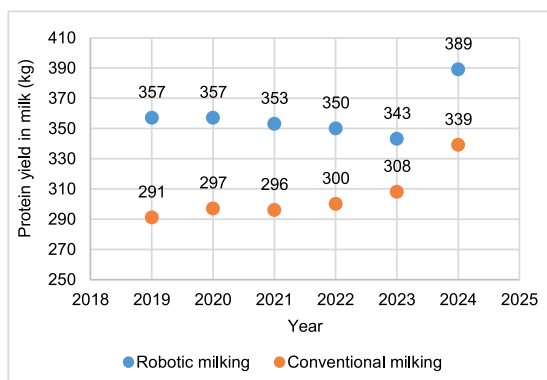


Fig. 7. Comparison of average milk fat yields in cows milked by robot and conventionally in the Podlaskie Voivodship in 2019–2024; source: own study

advantage of automatic milking over traditional milking remains constant, its intensity varies depending on the year of the study.

Publication (Kolenda *et al.*, 2021) shows that AMS yields higher milk volumes but lower percentages of fat and protein compared to conventional systems (dilution effect). At the same time, the absolute amount of fat/protein often does not decrease, but increases. In the analysis by (Brzozowski *et al.*, 2020), the differences were parity-dependent: in multiparous cows, higher yield in AMS was associated with a decrease in % fat by ~ 0.26 p.p. and % protein by ~ 0.05 p.p. (with an increase in milk).

Based on the results presented, it can be concluded that the further development of the dairy sector in the region should be based on several interrelated directions that respond to growing quality, economic, and environmental requirements. First and foremost, it will be crucial to promote automatic milking systems (AMS) on both large farms and smaller family farms, while integrating these systems with herd management software, cloud data analysis, and mobile applications. This will enable precise monitoring of cow health and productivity, as well as a rapid response to any problems (Matera, Boloña and O'Brien, 2024). At the same time, efforts should be made to further improve milk quality by implementing technologies that allow for continuous monitoring of fat, protein, lactose, and somatic cell count, as well as by standardising quality parameters across entire herds and systematically training farmers in nutrition, welfare, and hygiene (Soest van *et al.*, 2024). An important aspect will be to increase the economic efficiency of production by optimising nutrition tailored to the productivity and health of animals, automating auxiliary processes such as feed raking and barn cleaning, and cooperating between farms within producer groups to reduce costs and invest in infrastructure. In the context of environmental requirements, measures to reduce the carbon footprint of milk production are necessary, including effective management of natural fertilisers and greenhouse gas emissions, investment in energy recovery technologies such as agricultural biogas plants, and increasing the share of locally produced feed. The development of the sector should also include the diversification of products and markets through the production of milk with higher quality parameters, as well as organic, high-protein, or lactose-free products.

Additionally, the development of direct sales and local channels will increase margins and reduce dependence on purchase price fluctuations. Another important element is the continuous improvement of farmers' skills, both in terms of AMS operation and maintenance, as well as in data interpretation and herd management, and in the field of sustainable agriculture and compliance with EU regulations, including the requirements of the Green Deal (Muska *et al.*, 2025). All these activities, based on the synergy of automation, precision management, and pro-environmental practices, may be the key to further improving the efficiency and quality of milk production in the Podlaskie Voivodship.

CONCLUSIONS

During the period under review, the number of cows in herds in the Podlaskie Voivodship showed significant variability, ranging from an average of 146 in 2019 to 120 in 2024, with a simultaneous increase in the spread between the smallest and

largest farms. The total number of herds covered by the analysis more than doubled, which indicates the growing popularity of automatic milking technology. Milk yield remained relatively stable at around 10.2–10.6 thous. kg per cow per year until 2023. In 2024, there was a marked increase to 11,180 kg, accompanied by a reduction in the variation between farms, which may indicate an improvement in management and nutrition. Milk fat yield remained at around 412–422 kg until 2023, and in the last year of the analysis, it increased to 447 kg with greater equality of results. A similar trend was observed for protein yield, which ranged between 350 and 358 kg from 2019 to 2023 and increased to 389 kilograms in 2024, accompanied by a reduction in the differences between farms. A comparison of the results with the conventional system showed a consistent advantage for farms using robotic milking in all the parameters analysed, although in some years the gap narrowed slightly. The overall results indicate a gradual increase in production scale, accompanied by improvements in productivity and milk quality in robot-milked herds, particularly evident in 2024, which may be the result of better adaptation by farms to working with automatic technology. Comparing the average yields of the analysed farms with national yields, an increase of about 15% in favor of Podlasie farms is noticeable.

SUPPLEMENTARY MATERIALS

Supplementary material to this article can be found online at: https://www.jwld.pl/files/Supplementary_material_69_Skibko.pdf.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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