

Seasonal and farm-specific variations in milk fat percentage: impact on quality and economic performance in dairy production

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Abstract. This study investigated the seasonal dynamics of milk fat percentage and its economic implications across 83 small-scale dairy farms in the Istog region of Kosovo over one year. A total of 1,616 valid raw milk samples were collected and analyzed twice monthly per farm using the *Gerber* method. The average annual milk fat content was 3.75%, ranging from 2.90% to 4.00%. Statistically significant monthly differences were observed (*Friedman* test, $p < 0.001$), with May showing the highest average fat percentage ($3.807 \pm 0.133\%$) and August the lowest ($3.682 \pm 0.220\%$). While *Spearman's* correlation did not indicate a significant relationship between ambient temperature and milk fat percentage, seasonal comparisons revealed significantly higher fat values in spring than in winter ($p = 0.009$, $rrb = 0.543$). Farm-level analysis showed considerable variation, with fat content ranging from 3.35% to 3.92%, likely reflecting differences in general management practices and potential variations in breed and feeding. An economic model based on €0.075 per 1% fat per liter of milk and an annual production of 36,000 liters per farm revealed income disparities of up to €1,539 per year due to fat percentage differences. These findings underscore the importance of improving farm-level practices and implementing seasonal management strategies to stabilize milk fat content and reduce economic losses, particularly during warmer months when fat levels tend to decline. Future research should further investigate the specific effects of cow breed, feeding regimes, and environmental management on milk composition.

Key words: milk fat, samples, averages, seasonal variation, heat stress, economic impact.

INTRODUCTION

Milk fat is a valuable energy source and largely contributes to the taste and texture of many milk products and other foods (Hoffmann, 2011). The fat content of milk is of economic importance because price formulas for milk are functions of the fat content. Compared to other milk macronutrients, fat is the most variable component in the milk of different ruminants, so compared to cow milk, buffalo milk was richer in fat, lactose, protein (especially caseins), and minerals such as calcium, magnesium, and inorganic

phosphate. (Ahmad et al., 2008). Milk fat concentration differs considerably among bovine breeds. For example, *Jersey* cows typically produce milk with a fat content of around 5.09%, whereas *Holstein-Friesian* cows yield milk averaging 3.79% fat, with crossbred cows often exhibiting intermediate levels around 4.45% (Palladino et al., 2010; Claeys et al., 2014). The *Simmental* milk contained 4.02% fat, and the *Holstein* milk contained an average of 3.72% fat. The superiority of the *Simmental* cows over the *Holstein* cows throughout the year was statistically significant (Khastayeva et al., 2021). Barłowska et al. (2011) reported significantly higher ($p \leq 0.01$) milk fat in Jersey cows (5.41%), while other breeds, such as White-Backed (3.98%) and Polish Red (4.25%) displayed lower fat percentages. National data from Poland also indicate that the Jersey breed produced milk with an average fat content of 5.26% in 2010. In another comparative analysis, milk from *Holstein-Friesian* cows averaged 4.69% fat, whereas Jersey milk reached as high as 7.02% (Czerniewicz et al., 2006). Breed-related differences are not only genetically determined but also reflect the influence of farm structure and milking systems. Studies have shown that tie-stall farms housing various cow breeds tend to achieve higher fat concentrations (4.74%) compared to farms using automatic milking systems dominated by Swedish *Holstein* cows (4.32%) or milking parlors (4.47%) (Priyashantha et al., 2021). These inter-breed and management-related differences underscore the complexity of milk fat variation, particularly in production systems where pricing is closely tied to fat percentage.

Nutrition is the single factor having the greatest influence on the milk production performance of dairy animals. The results demonstrate how different feeding systems can affect the gross and elemental composition of milk. (Gulati, A., 2018). Protein and fat content can also be changed due to the physical form of the forage being fed. Milk fat is more sensitive to dietary manipulation than other milk constituents and has received great attention on nutritional control of milk fat content and fatty acid composition (Olika, 2021). Bovine milk's nutritional quality and processing capabilities are closely associated with milk composition (Sundekilde et al., 2013). Milk from pasture-fed cows (grass and clover) had significantly higher concentrations of fat, protein, true protein, and casein (Callaghan et al., 2016).

Thermal stress expressed a significant influence on milk composition, particularly the fat content. Under conditions of heat stress, milk fat levels can decline markedly by approximately 0.3 to 0.6 percentage points according to various studies. For instance, reductions have been observed from 4.05% to 3.58% (Toledo & Thatcher, 2022) and from 3.61% (spring) and 3.80% (winter) to 3.20% in summer (Kabil et al., 2015). Conversely, during thermoneutral conditions, milk fat percentages tend to remain stable or even increase, supporting the hypothesis that elevated temperatures impair lipid synthesis in the mammary gland. Bauman et al. (2011) reported a consistent decline in milk fat concentration as daily maximum temperatures rose from 8 °C to 35 °C, highlighting the sensitivity of milk composition to climatic conditions. Similarly, O'Brien et al. (2011) emphasized the effects of ambient climate on milk fat content. Seasonal variations in milk composition have also been confirmed by several studies, which consistently link higher milk fat content to colder periods. Heck et al. (2009) and Chen et al. (2014) both identified fat content as a key component affected by seasonal changes. In Ethiopia, Shibru et al. (2009) observed higher fat percentages during the dry season, while Lakew et al. (2019) reported significantly greater total solids in milk collected during the winter months. A large-scale study by Nam et al. (2009), based on

over 160,000 milk samples collected over six years in South Korea, confirmed that milk fat content was significantly higher in winter than in other seasons ($p < 0.05$). Similarly, Smith et al. (2013) found that *Holstein* cows experienced reductions in milk fat percentage under moderate and severe heat stress compared to periods of mild heat stress.

Economic loss due to variations in milk composition alone in the summer months was substantial. In this context, it is imperative to implement a support pricing strategy for dairy farmers during the summer months to overcome financial losses (Thomas & Sasidharan, 2015). As can be observed, numerous animal, dietary, and environmental factors influence milk fat content and yield in dairy cows. Because of the current pricing system, it is critical to reevaluate some of these factors and consider the economic implications of manipulating milk fat content with the ultimate goal of increasing milk fat yield profitably (Santos & De Vries, 2019).

The aim of this study is to analyze the seasonal and farm-specific variations in the milk fat percentage of raw cow milk produced in the Istog region of Kosovo over the course of one year. The research seeks to determine whether environmental temperature and other farm-level factors influence milk fat content and, consequently, the economic performance of dairy farms. This is particularly important in Kosovo, where milk pricing is directly tied to fat percentage, as regulated by Administrative Instruction MA-No. 20/2006.

MATERIALS AND METHODS

Study Area

The study was conducted in the Municipality of Istog in Kosovo. The farms are small farms that mainly breed from 2 to 20 cows and deliver milk to the collection point to generate income for the family as a form of self-employment. The farms are of the tied system where the cows are tied and housed in stalls with dimensions of 80–100 cm wide and 1.75–2 meters wide. Ventilation is mainly natural through windows, with average lighting, while the roof in 90% of cases is made of sheet metal, which allows for the increase of temperatures in the stable in the summer months. Cows are milked twice a day (morning and evening), and this is done in about 95% of them through automatic milkers. Farmers are forced to deliver their milk, with their vehicles, twice a day to the collection point and as soon as possible (at the latest 2 hours after milking), considering that about 90% of them do not have cooling equipment (*lactofreeze*) for milk.

Monthly average temperature data for the Istog region were sourced from the publicly available climate platform Weatherspark.com, which compiles data from multiple meteorological datasets (Weather Spark, 2025). These values represent long-term monthly means and were used as proxies for ambient environmental conditions during the sampling period (January to December). For each calendar month, corresponding temperature averages (°C) were matched with the monthly average of % milk fat values across all farms. This allowed for a comparative assessment of thermal influence on milk composition.

While no on-farm temperature sensors were installed, the regional climate data adequately reflect the macroenvironment affecting dairy herds in the Istog municipality. Months were also implicitly categorized by seasonal temperature characteristics: Winter

(Dec–Feb), Spring (Mar–May), Summer (Jun–Aug), Autumn (Sep–Nov). This alignment permitted the analysis of thermal stress patterns in milk fat fluctuations.

The dominant breed of cattle on all farms surveyed is *Simmental*, representing approximately 60% of the total cow population. *Holstein* cows account for about 30%, while the remaining 10% are crossbreds. Due to practical constraints, detailed breed-level data (e.g., exact breed distribution per farm, individual productivity) were not available, which limits the ability to perform breed-specific statistical analyses.

Feeding practices vary significantly by farm size and season. Farms up to 5 cows often allow cows to graze during the spring and summer months, with the duration of grazing depending on the farmer's management preferences. During the winter, feeding is mainly based on roughage such as hay and alfalfa and ground corn (as concentrates). In contrast, farms with 6 to 20 cows generally keep cows indoors all year round in connected housing systems. In the spring, short-term feeding with fresh grass and vetch (*Vicia ervilia*) is common. From summer to winter, the main feed includes roughage hay and alfalfa, while from autumn to spring, the main roughage is corn silage, including, in smaller quantities, hay and alfalfa. In contrast to farms up to 5 cows, these farms constantly use concentrated feed, either home-prepared (corn mixed with soybeans, sunflower meal, and mineral premix) or purchased as commercial milk concentrate.

Although general feeding patterns are known, the lack of standardized feed formulations and accurate nutrient content data limits the possibility of direct statistical correlation between feed type and milk fat percentage. However, the breeds of cows, feeding regimens, and zoo hygienic conditions are likely to contribute to the seasonal and farm-level variations in milk fat content observed in this study. Future research could benefit from collecting more detailed data on individual animal feeding and breed productivity to support more robust statistical modelling.

Sampling Techniques

A total of 1704 milk samples were subjected to the alcohol stability test at the 'Jeta e Re' milk collection point in the period January - December 2022. This test was performed by mixing 2 mL of milk with 2 mL of 75% ethanol and gently swirling the mixture. Only samples that tested negative (i.e., showed no coagulation or flocculation) were considered stable and were included in the subsequent milk fat analysis. After excluding unstable samples, 1,616 samples were retained for fat percentage determination. Thus, 20 mL of milk was taken, which was placed in the 'glass' for sampling, which was immediately placed in the refrigerator at a temperature of 4 degrees Celsius. The analysis for the % fat in the milk samples was carried out on the same day of collection. Since the 1,616 milk samples analysed for fat% % include sample analyses 2 times/farm/month, in the paper, we will present the average values of fat% % of the sample analyses per farm/month, $n = 808$.

Method for analysing % milk fat - Gerber method

To determine the amount of milk fat in the milk as a raw material, we used the Centrifugal Separation of Fat, otherwise known as the 'Gerber Method'. Using a pipette, we first placed 10 mL of concentrated sulfuric acid (density $\rho_{20} = 1.820 \text{ g mL}^{-1} \pm 0.005 \text{ g mL}^{-1}$) in the butyrometer. Immediately after that, through another pipette, we slowly placed 11 mL of milk, allowing a layer to form on top of the acid. After that, we

placed 1 mL. 98% *amyl alcohol* through the pipette. After closing, we took the butyrometer until the white particles disappeared. The inverted butyrometer was placed in a centrifuge and centrifuged at room temperature for 5 minutes at 350 revolutions. After removing the butyrometer from the centrifuge, we placed it in a water bath at a temperature of 65 °C for 10 minutes. The fat % measurement was performed after removing the butyrometers from the water bath, keeping the butyrometers in a vertical position, and taking the reading point at eye level.

Economic Impact Assessment

To evaluate the economic implications of milk fat variation among farms, a simple economic model was used to estimate relative gain or loss based on deviations from the annual average milk fat percentage (3.75%). Farms producing milk with fat percentages above this benchmark were considered to have economic benefit, while those below were classified as experiencing economic loss. The value of milk fat was calculated using a reference price of €0.075 per 1% fat per liter of milk, based on the Kosovo Administrative Instruction MA-No. 20/2006, which regulates milk prices. For each farm, the deviation from the reference level of 3.75% fat was multiplied by this unit price to determine the approximate economic profit or loss. To reflect the profit or loss every month, we multiplied the fat value per month by 3,000 liters, while for annual calculations, the multiplication was done by 36,000 liters. These values were visualized using a categorical column chart, grouping farms into three categories: Profit (> 3.75%), Break-even (= 3.75%) and Loss (< 3.75%). The analysis was performed using *Microsoft Excel*, and the results are presented as numbers and percentages of farms in each category. A summary of the monthly sample sizes and corresponding temperature data is presented in Table 1

Table 1. Number of Dairy Farms and Milk Samples Analyzed per Month, and Monthly Minimum, Average, and Maximum Air Temperatures (°C) in the Istog Region, Kosovo

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Farms (no)	70	69	71	75	81	78	60	54	58	60	62	70
Samples (no)	140	138	142	150	162	156	120	108	116	120	124	140
Min Temp (°C)	-3	-2	1	6	10	13	15	15	11	7	2	-2
Avg Temp (°C)	0	2	6	11	16	19	22	22	17	12	6	1
Max Temp (°C)	4	7	11	17	21	25	28	28	23	17	11	5

Statistical Analysis

Statistical analyses were performed to assess monthly, seasonal, and farm-level variations in milk fat percentage and their economic implications. Descriptive statistics, including mean, standard deviation, minimum, maximum, skewness, and kurtosis were calculated for each month to evaluate the distribution and variability of fat content in raw milk. To assess the influence of environmental factors on milk composition, *Spearman's* rank correlation test was used to examine the relationship between milk fat percentage and temperature parameters (minimum, average, and maximum monthly temperatures), given the non-parametric characteristics of the data.

Comparisons across months and seasons were performed using the *Friedman* test to detect statistically significant differences in milk fat percentage. Where the assumptions of normality and homogeneity of variance were met, the *Bonferroni* post hoc test was applied for multiple pairwise comparisons.

RESULTS AND DISCUSSION

The results of the % milk fat analyses throughout the months of a calendar year are presented in Table 2.

Table 2. Descriptive Statistical Parameters of Monthly Milk Fat Percentage in Raw Milk Samples from Dairy Farms in the Istog Region

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Valid	70	69	71	75	81	78	60	54	58	60	62	70
Mean	3.716	3.794	3.793	3.793	3.807	3.761	3.793	3.682	3.76	3.697	3.712	3.716
Std. Dev.	0.221	0.169	0.168	0.163	0.133	0.156	0.169	0.22	0.169	0.231	0.234	0.221
Skewness	-1.66	-2.24	-2.22	-2.28	-0.18	0.11	-0.60	-1.50	-0.60	-1.63	-1.65	-1.66
Kurtosis	3.948	7.779	7.724	8.392	-0.66	-0.95	-0.006	2.946	-0.10	3.527	3.508	3.948
Minimum	2.9	3	3	3	3.5	3.4	3.3	3	3.3	3	3	2.9
Maximum	4	4	4	4	4	4	4	4	4	4	4	4

From the analysis of all samples ($n = 1,616$) for % milk fat, the values range from 2.9% as the lowest value to 4% as the highest value. Compared to the results of % milk fat in the research of other authors, it turns out that the minimum values are similar, while the maximum values are somewhat lower than in the results of other authors. Thus, it is reported that milk fat comprises 2.4–5.5% of raw milk, depending on the cow's species and lifestyle (Herold, 2011); the fat content of milk from cattle reared in developed countries is in the range of 3.4–5.1% (Walstra et al., 2006) and that milk contains fats from 3.8 to 5.5%. (Fox et al., 2015).

The *Friedman* test was conducted to determine whether there were statistically significant differences in milk fat percentage across 12 months, and the test yielded statistically significant results ($p < .001$). The significant result of the *Friedman* test justified conducting post hoc analysis using Conover's pairwise comparisons with *Bonferroni* correction. Out of the 66 possible month-to-month comparisons, three were found to be statistically significant ($p_{bonf} < 0.05$). Specifically, May showed significantly higher milk fat percentages compared to January ($p = 0.006$), August ($p = 0.044$), and December ($p = 0.006$). These findings imply that May represents a peak period in fat content among the months evaluated, whereas January, August, and December represent periods of comparatively lower fat levels. The remaining comparisons did not yield statistically significant differences after *Bonferroni* adjustment, suggesting relatively stable fat content during those intervals. The overall effect size, as measured by *Kendall's W*, was low, indicating that while some monthly differences exist, the magnitude of variation is not strong across all months.

The fat percentage gradually increases from January (3.716%) to May, reaching its peak in April and May, the fat content drops in June and reaches its lowest in August (3.67) and increases again in September and stabilizes through to December (Fig. 1).

To assess the relationship between milk fat percentage and environmental temperatures across months, *Spearman's* rank-order correlation was applied. The correlation coefficients were calculated between fat percentage and three temperature parameters: minimum (low), average, and maximum monthly temperatures. The results revealed very weak and statistically non-significant correlations. None of these results reached the threshold for statistical significance ($p < 0.05$), and all coefficients were close to zero. These results imply that milk fat content is likely influenced more by other biological or management-related factors, such as breed, feed quality, and lactation stage, rather than by ambient temperature alone.

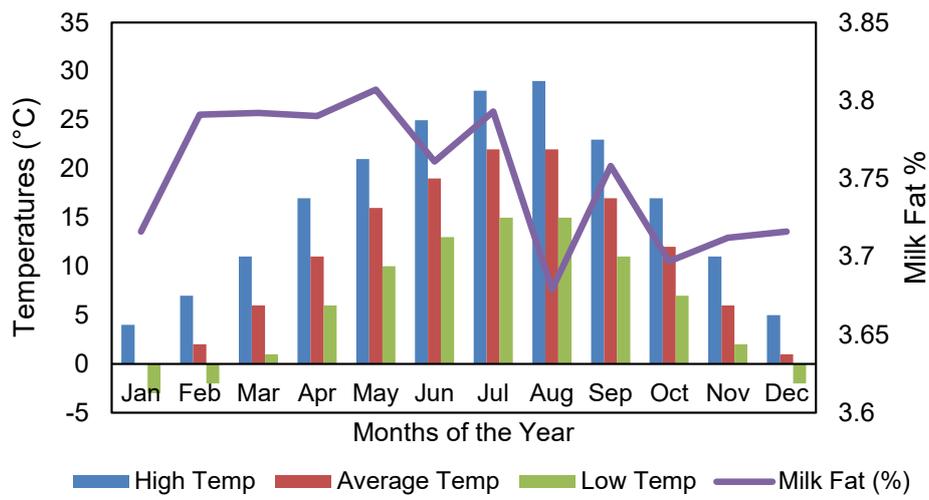


Figure 1. Monthly Variation of Milk Fat Percentage about Minimum, Average, and Maximum Ambient Temperatures.

The observed monthly variation in milk fat percentage aligns with established literature on the influence of seasonal and management-related factors on milk composition. Heck et al. (2009) report that milk fat concentration increased from a minimum of 4.10 g per 100 g in June to a maximum of 4.57 g per 100 g in January, while Cimen M. et al. (2013) reported that in summer months (July and August), the milk fat rates were lower than the test value (3.2%).

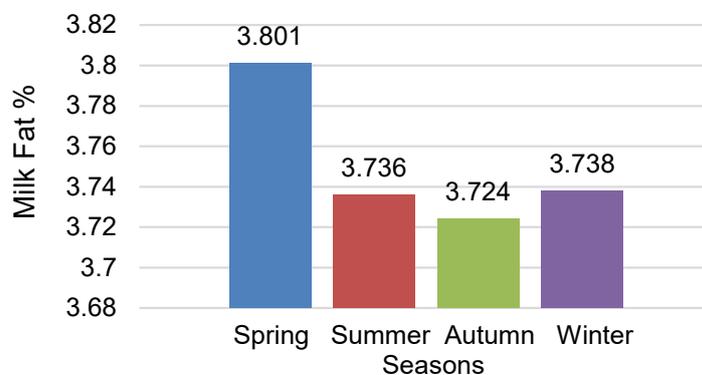


Figure 2. Seasonal Variation in Milk Fat Percentage Across Spring, Summer, Autumn, and Winter.

Descriptive statistics for milk fat percentage were calculated across four seasons: Spring, Summer, Autumn, and Winter. The highest mean fat % was observed in Spring (3.801%), followed by Winter (3.738%), Summer (3.736%), and the lowest in Autumn (3.724%). (Fig. 2). The seasonal distributions varied in dispersion, with the lowest standard deviation in Summer (0.116) and the highest in Winter (0.173). Post hoc analysis confirms that Spring is the only season with a statistically higher milk fat % compared to Winter ($p = 0.009$), even after multiple comparison correction. Although uncorrected p -values suggested differences between Summer and Autumn as well, they were not significant after *Bonferroni* adjustment.

The results obtained during our research can be supported by the works of other authors, both in the general aspect of the role and seasonal impact on the % of milk fat, while some works have presented different results in the specific aspect. Thus several studies have confirmed the negative impact of elevated temperatures on milk fat percentage in dairy cows. For example, Joksimović-Todorović et al., 2011 reported that higher rate of milk fat was recorded in spring in relation to summer period the level of significance being $p < 0.01$ In the *Czech Fleckvieh* and *Holstein* breeds, milk fat content was significantly lower in summer (3.71 and 3.91 g per 100 g, respectively) compared to winter (Hanuš et al., 2016). Results showed the mean value of fat % in four seasons (winter, spring, summer, and autumn) are 3.6 ± 0.055 , 3.27 ± 0.053 , 3.1 ± 0.058 and 3.4 ± 0.049 , respectively. Milk fat level was lower in the summer season compared to any other season, but winter showed the highest amount of milk fat (Kabil et al., 2015); The milk fat were the highest in the winter and the lowest in the summer period (Yildirim & Cimen, 2009); fat and protein percentages of milk samples were significantly ($p < 0.05$) lower during the hot season compared to the cold season. (Bahashwan, 2014), and similar results can be found in many research studies by other authors.

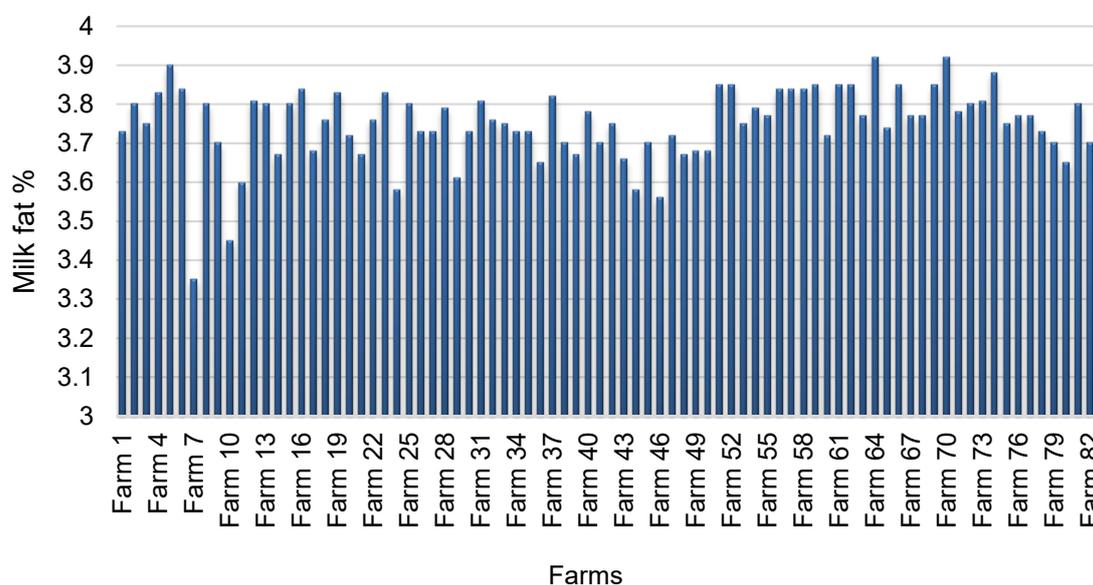


Figure 3. Average Milk Fat Percentage (%) per Farm Across the Studied Dairy Farms.

When it comes to the average % of milk fat per farm, the lowest average value was 3.35% (farm no. 7), while the highest average value was 3.92% (farm no. 70), with an overall average for all farmers of 3.75% (Fig. 3). Through the Kruskal-Wallis test, statistical differences ($p < 0.05$) are found in the distribution of milk fat percentage between the farms. While many farms maintain stable fat percentages in their raw milk, a few experience greater variability, potentially due to farm-specific factors like nutrition, breed, and management practices. Significant differences in mean milk fat percentages across different farms suggest the influence of diverse factors on milk composition. These findings underscore the need for adaptive management practices and further research to identify and mitigate the causes of variability, ensuring consistent and high-quality milk production.

Differences in fat % between months of the year and between different farms reflect on the economic factor of farmers. Thus, farmers with a higher % of fat milk benefit from more income, while farmers with a lower % suffer significant economic losses. Fig. 4 summarizes farmers' economic benefits or losses based on their milk fat percentages. The benchmark is the overall average of 3.75%. Farms producing above the benchmark are assumed to have economic benefits, while those producing below it have economic losses.

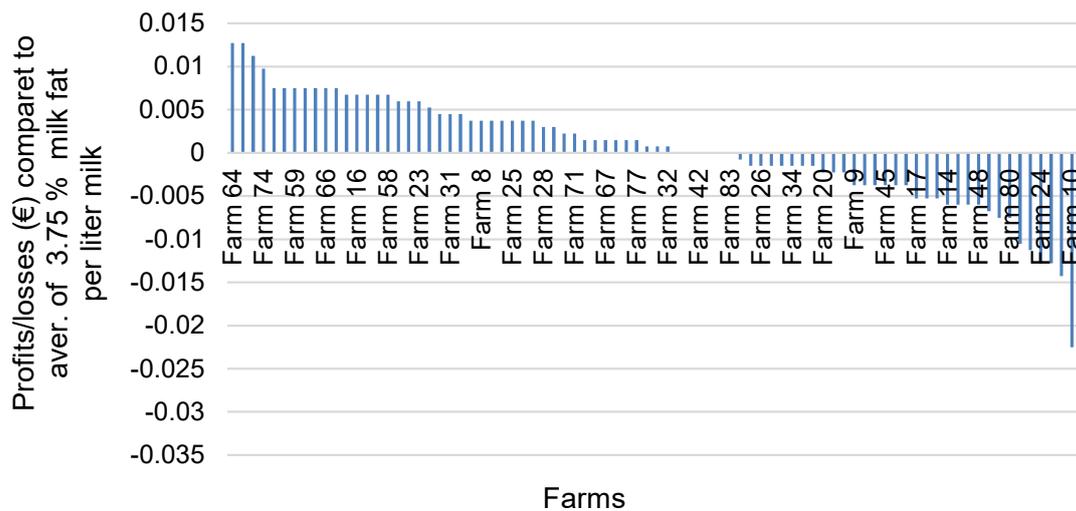


Figure 4. Estimated Profits and Losses (€) per Liter of Milk per Farm Based on Milk Fat Percentage Compared to the Reference Value of 3.75% Fat.

The figure illustrates the diversity in milk fat production across the farms and, consequently, the economic benefits or losses based on the average value of 3.75% fat. It results in those 7 farms, or 8.43%, having a fat percentage equal to the overall average, 42 farms, or 50.60%, producing above the average, securing economic benefits. However, 34 farms, or 40.96%, are underperforming concerning fat percentage, likely facing financial challenges.

An economic analysis was conducted to assess the financial implications of variations in milk fat content among 83 small-scale dairy farms. Based on a standardized pricing model of €0.075 per 1% fat per liter, and assuming a yearly milk delivery of

36,000 liters per farm, the impact of milk fat percentage on farm income was quantified. The reference fat percentage was set at the average value of 3.75%, resulting in a baseline annual income of €10,125 per farm. Farms producing milk with fat percentages above 3.75% experienced profit gains, while those below this threshold incurred economic losses. The highest profit was recorded by Farm 64 and Farm 70, both with an average fat content of 3.92%, translating into an annual income of €10,584, a gain of €459, or +4.53% compared to the reference. In contrast, Farm 7, with a fat content of 3.35%, recorded the largest economic loss, with an annual income of €9,045 and a deficit of €1,080, equating to a loss of 10.67% below the average baseline. Overall, the relative difference in income between the top-performing and the lowest-performing farms amounted to €1,539 per year, or 15.2% of the reference income. This significant disparity underscores the critical economic importance of optimizing milk fat content through effective breeding, feeding, and farm management strategies.

If we specifically evaluate the economic benefits or losses over the months of the year, it results that the highest average fat percentage was observed in May (3.807%), yielding the highest monthly revenue of €856.5, which is approximately €17.20 more than the annual average income. This reflects a 2.06% increase in fat content compared to the baseline. Other months with positive deviations include February, March, April, and July, all showing elevated fat content and consequently higher profits. In contrast, August exhibited the lowest fat percentage (3.682%), resulting in the lowest income of €828.6, corresponding to a loss of €10.71, or 2.09% below the average. Months like October, January, and November also showed slight losses due to below-average fat values.

Analyzing the impact of seasons on farmers' economic performance, it turns out that spring recorded the highest average fat percentage at 3.801%, followed by winter (3.738%), summer (3.736%) and autumn (3.724%). These changes, although numerically moderate, translate into significant economic impacts when projected over large volumes of milk, especially in pricing systems that reward higher fat content. Although these values may seem modest, when aggregated across many farms and over time, the economic impact is considerable.

CONCLUSIONS

This study investigated monthly and seasonal variations in the fat percentage of raw milk collected from 83 dairy farms in Kosovo, analyzing a total of 1,616 milk samples. The results revealed statistically significant differences in milk fat content across months and seasons. Specifically, milk collected in May exhibited a significantly higher fat percentage compared to January, August, and December. At the seasonal level, spring samples showed a higher milk fat content than winter, as confirmed by post hoc analysis following *Friedman* testing.

Although differences in ambient temperature across the months were documented, a statistically significant correlation between temperature and milk fat percentage was not established based on the current dataset. Therefore, while temporal trends were observed, the specific environmental or management-related causes of fat variation could not be definitively isolated.

Furthermore, the study demonstrated that these variations in milk fat content translate into measurable economic differences for farmers, given that milk pricing in Kosovo is linked to fat percentage. Farms with higher average fat values received correspondingly higher estimated monthly income, highlighting the financial relevance of milk quality monitoring.

Future research should aim to include and control for additional variables such as cow breed, feeding practices, housing conditions, and herd size to better elucidate the factors influencing milk fat content

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