Makarijoski, B., Dimitrovska, G., Joshevska, E. (2025). Implementing new predictive functional model for milk fat value in Macedonian white brined cheese production. Agriculture and Forestry, 71 (1). 37-47. https://doi:10.17707/AgricultForest.71.1.03

DOI: 10.17707/AgricultForest.71.1.03

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IMPLEMENTING NEW PREDICTIVE FUNCTIONAL MODEL FOR MILK FAT VALUE IN MACEDONIAN WHITE BRINED CHEESE PRODUCTION

SUMMARY

In the production of Macedonian white-brined cheese, milk fat content is a crucial determinant of the final product's quality, texture, and taste. Accurate prediction and management of milk fat levels during cheese production are essential for maintaining consistency, optimizing yield, and ensuring consumer satisfaction. This study presents the implementation of a new predictive functional model specifically designed to estimate milk fat value in the production of Macedonian white-brined cheese. The model integrates various factors, such as the initial composition of raw milk, processing conditions, and key technological parameters that influence fat retention and distribution throughout the cheese making process. By using a combination of statistical analysis and machine learning techniques, the model enables a more precise and real-time prediction of milk fat content, addressing challenges related to seasonal variations in milk composition and other unpredictable factors in dairy production. Data from local dairies were used to validate the model's performance, and results demonstrate its accuracy in predicting milk fat values with a high degree of reliability.

The study's most significant findings demonstrate the variation and trends in milk fat content across four cheese variants (A, B, C, and D) during the ripening process. The results show that Variant D consistently maintained the highest milk fat values throughout the ripening period, with significant differences ($p<0.05$) compared to the other variants. By the 60th day of ripening, Variant D had a milk fat content of 25.41±0.02%, which was 2.3% higher than Variant C, the variant with the lowest fat content.

The predictive functional model achieved high R^2 values for all variants, ranging from 0.9673 to 0.9997, indicating its robustness in estimating milk fat

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.
Recieved:17/10/2024 *Accepted:10/01/2025*

dynamics. Variant A achieved an R^2 of 0.9997, demonstrating near-perfect alignment between the model's predictions and experimental data.

The implementation of this model has the potential to streamline production processes by reducing the need for frequent laboratory analyses and allowing producers to make real-time adjustments during manufacturing. Furthermore, it contributes to enhanced product standardization, better resource management, and overall improvement in cheese quality. This predictive model offers a novel tool for dairy producers in N. Macedonia and beyond, aiming to improve the efficiency and quality control in white-brined cheese production.

Keywords: white brined cheese, milk fat, quality control, functional model

INTRODUCTION

White-brined cheese is a popular cheese type in many parts of the world, which has been enjoyed for centuries, particularly in Mediterranean cuisine. It belongs to the group of cheeses that ferment in brine solution in anaerobic conditions. This product is characterized with acid salty flavor, no rind, usually white color, but sometimes with yellowish tint, anaerobic brine fermented in plastic cans and pieces which are usually in form of cubes with dimensions 10x10x10 cm, (Velevski, 2015). According to the Codex Alimentarius (Codex Stan 208-1999), white brined cheese belongs to the category of "Cheese in Brine." This category is defined as follows: "Cheese in Brine" refers to cheeses that are ripened and stored in a brine solution, which contributes to their characteristic texture and flavor. These cheeses typically have no or only a very thin rind and may range in texture from soft to semi-hard.

The significance of milk fat in cheese-making is identified by the findings of numerous studies in dairy science and food chemistry. Milk fat remains a critical factor in cheese-making, particularly in influencing flavor, texture, and overall sensory quality of the end product, (McSweeney *et al.*, 2013). New studies, such as those by Franceschi *et al.*, (2024), emphasize the importance of fat, casein, and protein content in the quality of dairy products, and their impact on coagulation properties, which are crucial in determining cheese yield and texture.

Milk fat is one of the most dynamic and variable components found in various types of milk. Maintaining the required level of milk fat value is crucial in all varieties of cheeses, and this is achieved through the milk standardization process. Numerous factors play significant role in determining the content of milk fat in white cheese, with the most prominent influences being the composition of the milk, particularly the casein-to-fat ratio, and also the technological processes used in cheese production, (Bojanić-Rašović *et al.*, 2013).

Research by Haenlein and Wendorff (2006) highlights the multi-faceted contributions of milk fat to cheese quality, emphasizing its role in flavor development, enhancement of taste, and texture modification. Furthermore, investigations by Fox *et al.*, (1998) explain the intricate biochemical processes through which milk fat constituents interact with microbial enzymes during cheese ripening, thereby influencing flavor maturation and textural evolution. The influence of milk fat on white cheese quality is significant and multifaceted. Milk fat contributes to the flavor profile of cheese. Higher fat content often results in a richer, creamier taste. In white cheese varieties fat content can enhance the buttery or nutty notes, contributing to a more enjoyable eating experience, (Waldron *et al.*, 2020). The fat content affects the rheology and texture of the cheese, but produced a limited effect on taste and aroma. Milk fat value can influence the appearance of white cheese. Higher fat content often results in a richer color and a more attractive appearance, as a significant factor in consumer appeal (Guinee and McSweeney, 2006).

The numerous compounds in cheese aroma are derived mainly from three major metabolic pathways occurring during cheese ripening: catabolism of lactose, lactate, and citrate, lipid and protein catabolism. Milk fat contains volatile compounds that contribute to the aroma of cheese. Higher fat content can lead to a more complex and pronounced aroma, which can enhance the overall sensory experience of consuming white cheeses, (Arias-Roth *et al.*, 2022). Milk fat is a source of energy and essential fatty acids. While higher fat content contributes to the calorie and fat content of cheese, it also provides a richer source of nutrients. The concentration of milk fat in cheese holds significant influence over crucial aspects such as taste, aroma, consistency, microstructure, and the biochemical and rheological characteristics of the final product. The complex interactions between these variables highlight how crucial it is to closely monitor and regulate the amount of milk fat during the cheese-making process (Guinee *et al*., 2000).

Fox *et al.*, (2017) further emphasizes the nutritional significance of milk fat in dairy products, stating, 'The composition and properties of milk fat secure a high nutritional and biological value to the products. The synergy between milk fat and proteins contributes not only to the taste and texture of cheese but also to its overall nutritional profile.

The primary aim of this research is to design and implement an innovative predictive functional model for estimating milk fat content in the production of Macedonian white-brined cheese. This study seeks to address challenges associated with milk fat variability, ensuring a consistent and high-quality final product.

The main objectives are as follows: to analyze the dynamics of milk fat content during the ripening process of cheese produced under different production conditions and to develop and validate a predictive functional model that accurately estimates milk fat levels based on critical factors, including initial milk composition, processing parameters, and technological conditions.

The significance of this research lies in the practical applications of the predictive model. It serves as:

•A tool for quality control: Helping producers monitor and maintain consistent cheese quality.

•A process optimization resource: Reducing dependency on frequent and costly laboratory analyses by enabling real-time adjustments during production.

•A driver for standardization: Facilitating greater consistency and uniformity in white-brined cheese production.

•A broader innovation: Offering insights and methodologies that can be applied to the wider dairy industry, supporting resource efficiency, sustainability, and the development of innovative dairy products.

MATERIAL AND METHODS

Sample Collection and Transportation. This study utilized four variants of Macedonian white-brined cheese, designated as Variants A, B, C, and D. Cheese samples were sourced directly from four different dairy processing facilities located in various regions of North Macedonia (Figure 1), ensuring diversity in production techniques.

To maintain the integrity of the samples, they were transported under temperature-controlled conditions on 5°C to the Certified Laboratory for Milk and Dairy Product Quality (LB Lact) in Plovdiv, R. Bulgaria. This laboratory is certified under international standards, ensuring the reliability and accuracy of all testing procedures.

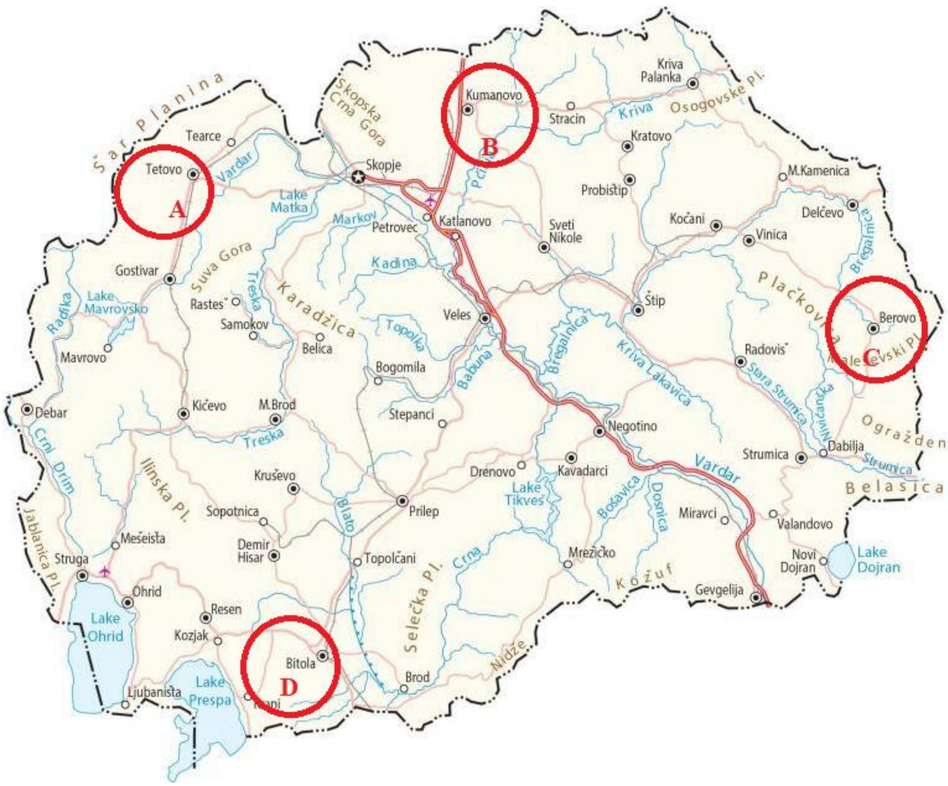

Figure 1: Map of researched area

Milk Fat Content Analysis. The milk fat content (%) in the cheese samples (Figure 2) was measured on the 8th, 20th, 30th, 40th, and 60th days of ripening according to ISO 3433:2008.

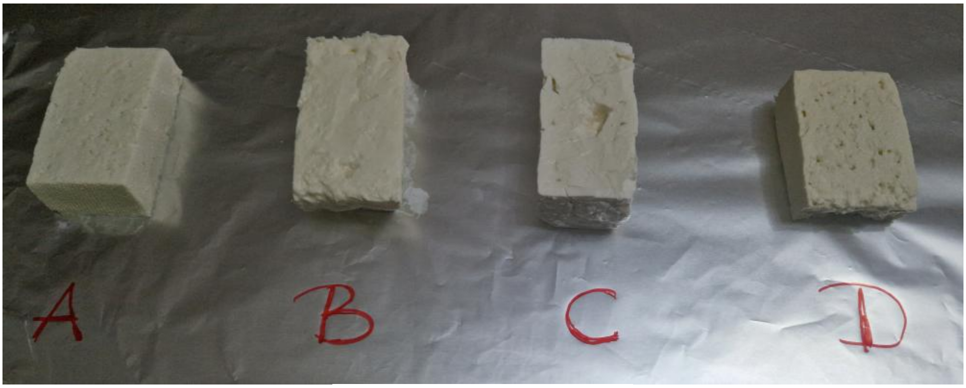

Figure 2: Cheese samples

RESULTS AND DISCUSSION

The comparative analysis made between the examined cheese samples for milk fat value is shown in table 1.

Table 1: Dynamics of Milk fat value in examined cheese samples

Milk fat value (%)				
Period of examination	Cheese Variant A	Cheese Variant B	Cheese Variant C	Cheese Variant D
Day 8	23.88±0.07[a]	23.80±0.10[a,b]	22.67±0.05[c]	24.60±0.05[d]
Day 20	24.10±0.10[a]	23.90±0.10[b]	22.88±0.05[c]	24.80±0.10[d]
Day 30	24.36±0.15[a]	24.0±0.10[b]	23.0±0.10[c]	25.07±0.05[d]
Day 40	24.57±0.05[a]	24.13±0.05[b]	23.03±0.05[c]	25.19±0.01[d]
Day 60	24.63±0.20[a]	24.18±0.03[b]	23.11±0.02[c]	25.41±0.02[d]

**Differences of values with different superscripts in the same row are statistically significant at level p<0.05;*

During the ripening process, significant differences p<0.05 in milk fat content were observed among the four cheese variants. On the 8th day, Cheese Variant D had the highest milk fat percentage (24.60±0.05%), while Cheese Variant C had the lowest value (22.67±0.05%). After 20 days of ripening, the milk fat content ranged between 22.88±0.05% for Variant C and 24.8±0.10% for Variant D. As ripening progressed, on the 30th day, a noticeable increase in fat content was recorded across all variants, with values ranging from 23.0±0.10% to 25.07±0.05%. This upward trend continued on the 40th day, with milk fat percentages between 23.03±0.05% and 25.19±0.01%.

By the 60th day, the milk fat content had stabilized, showing values between 23.11±0.02% and 25.41±0.02%, with Variant D consistently maintaining the highest milk fat level. Notably, Variant D had 0.78%, 1.23%, and 2.3% higher fat content than Variants A, B, and C, respectively. These findings were statistically significant ($p<0.05$) for most of the tested periods, suggesting that differences in technological processes and production conditions played a critical role in milk fat retention.

The higher milk fat content in Variant D can be attributed to variations in the raw milk composition, particularly the lack of milk fat standardization in Variants A, B, and D. In contrast, Variant C was produced using standardized milk fat (3.2%), which likely explains the greater deviations in fat content observed between the variants during ripening.

The gradual increase in milk fat content across all variants throughout the ripening period is consistent with findings from other studies. For example, Ivanov *et al.* (2016) reported an average fat content of 24.5±0.3% in Bulgarian white cheese after 45 days of ripening. Similarly, Chomakov *et al.* (2000) documented fat values ranging from 21% to 25% in white brined cheese produced from cow's milk. Further, Bojanić-Rašović *et al.* (2010) found an average fat content of 23.86% in Montenegrin white brined cheese, influenced by factors such as breed, feeding practices, and environmental conditions. Our findings align closely with those of Naydenova *et al.* (2013), who reported milk fat values between 22% and 23.25%, and Popović Vranješ *et al.* (2011), who identified fat content between 21.97% and 23.97% in Sjenica cheese. Additionally, Velevski (2015) observed milk fat content ranging from 22.34% to 22.40% in three varieties of white brined cheese, further supporting the results obtained in this study. Ismaili (2022) reported milk fat content in Macedonian white-brined cheese ranging from 23.20±0.01% to 25.03±0.03%, which aligns closely with the findings of this study. These values correspond to the range of milk fat percentages observed in the examined cheese variants during the ripening process, supporting the validity of the results obtained. Slightly lower milk fat values in white brined cheese were reported by Milenković (2017), who determined a milk fat content of 20.49±0.77% in cheese produced using industrial techniques. Similarly, Aydemir (2018) found an average milk fat content of 18.44±0.79% in "Beyaz" white brined cheese, while Beev *et al.* (2019) identified an average milk fat content of 16.4±3.071% in Bulgarian white brined cheese. These differences are most likely attributed to variations in the production techniques, conditions and the types of raw materials used in the manufacturing processes.

In this study, a novel functional model was developed to estimate milk fat values over specific time intervals during the ripening process, from the 8th to the 60th day. This model, represented by the equation $y=(AX^2+B)+(CX^2/D*X)$, is designed to apply to all examined variants, providing accurate predictions of milk fat content throughout the fermentation period.

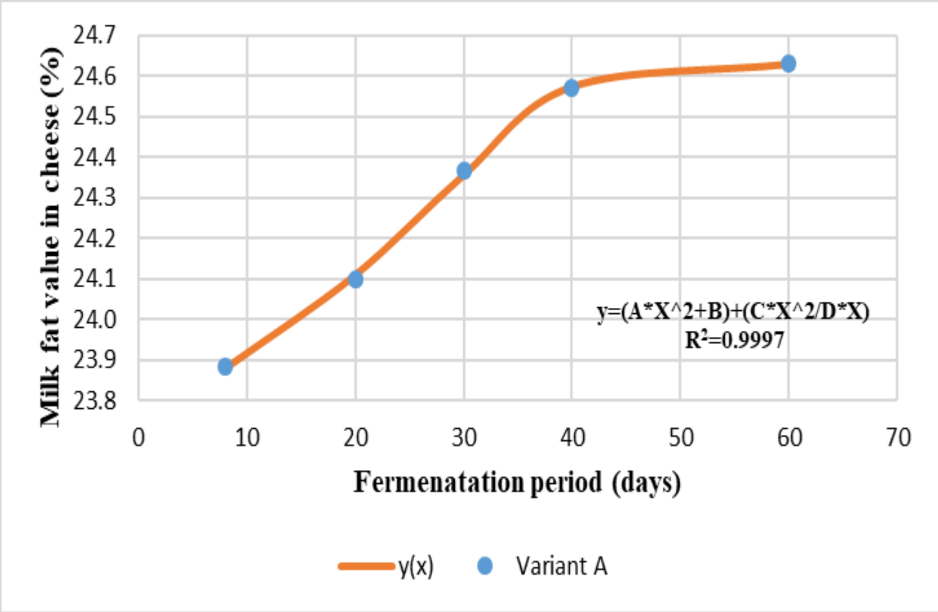

Figure 3: Milk fat value dynamics in cheese Variant A

For Cheese Variant A, the model parameters were determined as A=0.000958, B=23.8245, C=-0.00022, and D=18,322, yielding a highly accurate prediction with an R^2 value of 0.9997, indicating near-perfect correlation between the model's predictions and the experimental data. As shown in Figure 3, the dynamics of milk fat values in Cheese Variant A are illustrated with blue data points representing the experimental measurements, while the orange line depicts the predicted values generated by the functional model.

The model's high R^2 value underscores its potential as a valuable tool for accurately predicting milk fat levels under various production conditions, enhancing the ability to optimize cheese production processes based on technological and environmental factors.

The functional model developed for Cheese Variant B follows the same form, $y=(AX^2+B)+(CX^2/D*X)$, with specific parameters set as A=0.000423, B=23.77, C=-0.000035, and D=6.849. This model produced an R^2 value of 0.9984, confirming its high degree of accuracy and statistical significance in predicting the milk fat dynamics during the ripening process. The close fit between the model's predictions and the experimental data underscores its robustness and reliability. In Figure 4, the milk fat dynamics for Cheese Variant B are illustrated using green data points representing the experimental values, while the blue line indicates the model's predicted trend. The alignment between the experimental results and the model’s curve demonstrates the effectiveness of this predictive tool in approximating the milk fat content during fermentation. The high R^2 value further validates the model, showing its capacity to account for the key variables influencing fat retention and distribution during cheese ripening.

This model is a valuable asset for optimizing cheese production processes and ensuring consistency in product quality.

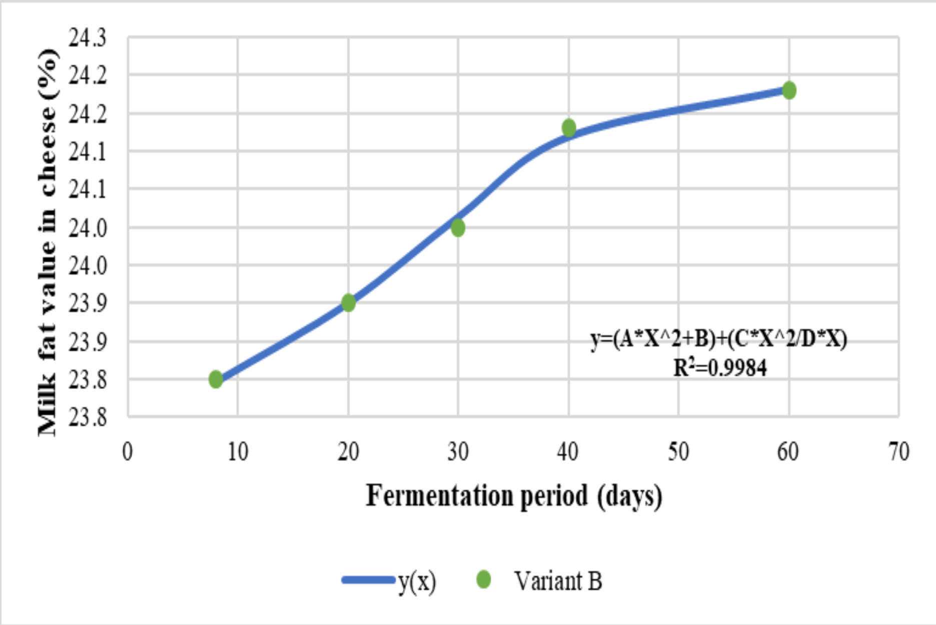

Figure 4: Milk fat value dynamics in cheese Variant B

The newly formulated model is also applicable to Cheese Variant C, represented by the equation $y=(AX^2+B)+(CX^2/D*X)$, with the following parameters: A=0.00051, B=22.68, C=-0.000001, and D=0.08. This model yielded an R^2 value of 0.9673, which confirms its statistical significance and reliability in predicting the dynamics of milk fat content during the fermentation process. In Figure 5, the dynamics of milk fat values for Cheese Variant C are depicted using orange data points that represent experimental measurements.

The blue line illustrates the Y(x) function derived from the predictive model, effectively approximating the parameters for milk fat during the fermentation period. The R^2 value indicates that while the model effectively captures the trends in milk fat content, it also suggests that additional factors may influence the variability in fat retention. This insight highlights the potential for further refinement of the model by incorporating additional variables related to production techniques and environmental conditions.

The same functional model is applicable for Cheese Variant D, characterized by the parameters A=0.00077, B=24.567, C=-0.000139, and D=15.39. This model achieved an impressive R^2 value of 0.9949, confirming its statistical significance and reliability in predicting the dynamics of milk fat content during the fermentation process.

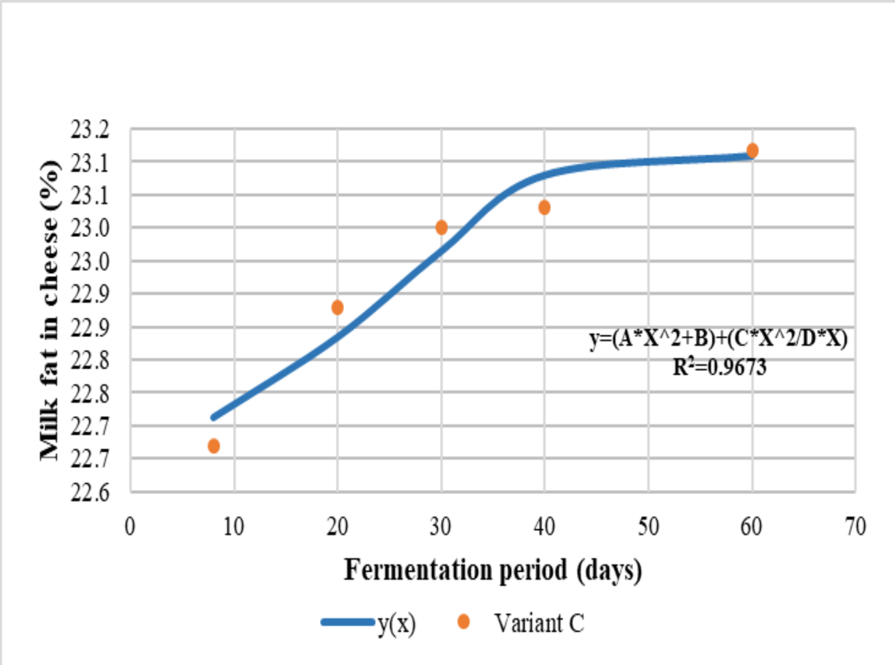

Figure 5: Milk fat value dynamics in cheese Variant C

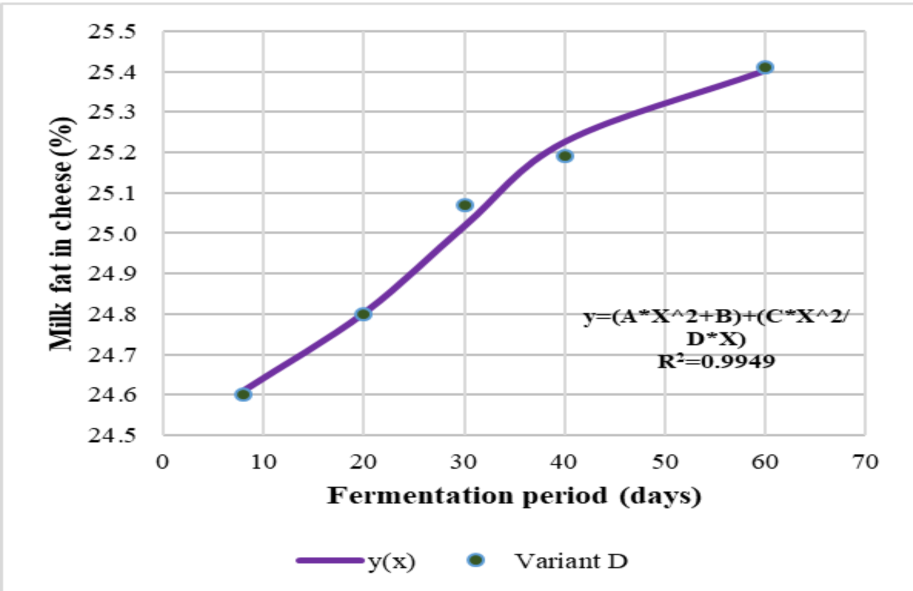

Figure 6. Milk fat value dynamics in Cheese Variant D

In Figure 6, the dynamics of milk fat values for Cheese Variant D are illustrated with green data points obtained from experimental measurements. The lavender line represents the Y(x) function derived from the predictive model, effectively approximating the parameters associated with the investigated phenomenon. The high R^2 value indicates that the model accurately captures the trends in milk fat content, demonstrating its efficacy in reflecting the underlying processes during cheese ripening. This model serves as a valuable tool for optimizing production practices and ensuring consistent quality in cheese products, potentially benefiting producers by facilitating real-time adjustments based on predictive insights.

CONCLUSIONS

The development of a predictive functional model for estimating milk fat values in Macedonian white-brined cheese provides significant insights into the complex processes of cheese ripening. The findings reveal that Cheese Variant D consistently exhibited the highest milk fat content, achieving a remarkable R^2 value of 0.9949. This suggests that specific technological and production conditions significantly impact fat retention during fermentation. Similarly, the strong predictive capabilities of the models for Variants A, B, and C highlight the robustness of this approach, with R^2 values ranging from 0.9673 to 0.9997 across the variants.

The observed differences in milk fat content among the variants, influenced by factors such as initial milk composition and production methods, underscore the necessity for careful management of these parameters to enhance product quality. The models not only provide accurate estimations but also offer a strategic tool for dairy producers aiming to optimize cheese production processes. By incorporating these predictive insights, producers can make informed decisions to enhance the sensory attributes and nutritional profile of their cheese products. In light of the growing demand for high-quality dairy products, these findings align with previous research indicating the critical role of milk fat in determining cheese quality and consumer acceptance. Ultimately, the successful application of this model could facilitate better resource management, improved quality control, and innovation in cheese production, thereby contributing to the sustainability and economic viability of the dairy industry.

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