International Journal of Agriculture and Biosciences 2024 13(4): 800-805.
https://doi.org/10.47278/journal.ijab/2024.213

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Technological Assessment of the Adygeisky Cheese Quality during Ultrasonic Cavitation and Avalanche Streamer Discharge Treatment

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ABSTRACT

This study explores innovative processing methods for dairy raw materials, specifically ultrasonic cavitation and avalanche-streamer discharge, to assess their effects on milk's microbiological safety, structural composition, and suitability for dairy product production. Using milk from various farm animals, we evaluated microbial loads, including exogenous and endogenous microorganisms, and monitored changes during and after treatment. Ultrasonic cavitation of goat and cow milk revealed a significant reduction in microbial content, notably decreasing *E. coli* counts up to 35%, while preserving key physical-chemical properties. This process also promoted fat particle homogenization, enhancing milk's stability. Alternatively, avalanche-streamer discharge alone was ineffective as a pasteurization method. Yet, it efficiently reduced spore-forming bacteria by up to 100-fold with optimized exposure, potentially increasing microbiological safety together with ultrasonic cavitation. This combined technique offers a promising alternative to conventional pasteurization, reducing nutrient degradation while preserving milk's fatty acid profile and organoleptic qualities. Further studies revealed that cavitation processing changed certain milk traits relevant to cheese production. Cavitation-induced calcium agglomeration may contribute to stronger protein matrices in "Adygeisky"-type cheese but requires further study due to potential textural impacts. Overall, both ultrasonic cavitation and avalanche-streamer discharge showed potential to increase dairy processing efficiency, product quality, and safety, paving the way for novel. These heat-free pasteurization strategies retain milk's nutritional integrity and enhance its suitability for high-protein dairy products.

Keywords: Ultrasonic cavitation and avalanche-streamer discharge, Cow's milk, Goat's milk, Histological studies

Article History
Article # 24-876
Received: 07-Oct-24
Revised: 25-Oct-24
Accepted: 05-Nov-24
Online First: 07-Nov-24

INTRODUCTION

Improving product quality, particularly dairy products, is a key strategy for competitive products to enter the global market. Additionally, in the context of import substitution, research prioritizes the creation of technological sovereignty in food security (Borodulin et al., 2021; Nina et al., 2023). The Russian Federation's forecast for scientific and technological development up to 2030 places special emphasis on biotechnological products as a means of preserving resource potential, enhancing population life expectancy, and preserving the nation's healthy gene pool (Gamlath et al., 2020; Vorobiev et al., 2023). According to the FAO, milk production worldwide is increasing due to China, America, Europe, Africa, Greece, and Turkey (Krasulya et al., 2022). Milk production in the Russian Federation is also increasing, thanks to state subsidies and the support of extensive holdings and farms.

Cow's milk is the basis of production, but the state is interested in increasing the share of milk from other farm animals. The dairy goat breeding industry has been overgrown (Kanina et al., 2022). The production of milk and dairy products implies a well-planned, proven technology, including operations to obtain high-quality and safe products. The main task in preserving food systems is decontaminating pathogenic microorganisms, thereby increasing the shelf life of food systems (Krasulya et al., 2021). The dairy industry employs various energy-

Cite this Article as: Kanina KA, Borodulin DM and Kupriy AS, 2024. Technological assessment of the adygeisky cheese quality during ultrasonic cavitation and avalanche streamer discharge treatment. International Journal of Agriculture and Biosciences 13(4): 800-805. https://doi.org/10.47278/journal.ijab/2024.213

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Intensive raw milk processing methods, including thermalization, finalization, pasteurization, sterilization, and ultra-pasteurization. These methods alter the mineral composition of milk, particularly calcium, vitamins, salt, and amino acids (GOST 5867-90, 2001). Therefore, it is important to develop new (alternative) methods of milk processing. These methods enhance the shelf life of milk and dairy products, maintain their biological value, and enhance their structural, mechanical, and taste attributes. GOST 3625-84 (2010) made a significant contribution to the study of alternative methods of high-pressure milk processing (Desole et al., 2024), ultrahigh pressure treatment by GOST R 53438-2009 (2001), light pulse treatment by Voeten et al. (2018) UV radiation was studied by Gorbatov et al. (1982). This enabled us to pinpoint each method's benefits to the food systems. And identify the disadvantages that prevent each method from being used. There is practically no information in information sources about the physical methods of exposure to ultrasonic acoustic cavitation and avalanche-streamer discharge on milk and dairy products. Therefore, it is an urgent topic for research.

MATERIALS & METHODS

The research was conducted at the Federal State Budgetary Educational Institution of Higher Education, "Russian State Agrarian University—Moscow Agricultural Academy, named after K.A. Timiryazev. For this study, we used milk from black-and-white cows and Zaanen goats to see how high-frequency acoustic cavitation and avalanche-streamer discharge changed milk and dairy products' physical, chemical, technological, and structural-mechanical properties. The RSAU-MAA's educational and production livestock complex, named after K. A. Timiryazev in Moscow, breeds cows and goats of these breeds. We determined the quality indicators of milk and dairy products under control conditions.

After the bactericidal phase ended, we processed the milk in 3–4 hours while controlling the thermal load on the milk. We used the UST device "Activator"-150 (manufacturer, Russian Federation) for high-frequency cavitation processing (HFCP). An electric submersible device generated the high-frequency effect, performing the treatment at a pulse action rate of 55 pulses per minute. The processing time spans 5, 10, 15, 20 and 30min, with a separate interval of 17min. We chose this time interval to account for changes in raw milk's composite physical, chemical, and sensory characteristics. The HFCP device operates on the following principle: It places the processed material between the electrodes of the working capacitor and then generates a high-frequency electromagnetic field. The material's molecules begin to oscillate under the influence of the field, resulting in friction and heat generation inside the material. The material maintains the temperature at a set value for the required duration.

We used a device to ensure an electric charge would burn (the source is an electric discharge plasma), and we treated milk in a pulse-periodic mode. The voltage pulses used in the high-frequency receipt processing apparatus are characterized by a brief duration ranging from 0.5 to 1.0 microseconds (mcs). The pulses' impact power exceeds 120 megawatts (MW). This pulse front ensures a rapid and effective impact on the processed material.

The cheeses were produced by GOST 32263-2013 Soft Cheeses guidelines. We used the following raw materials to produce "Adygeysky" cheese: The preparation of raw cow's milk follows GOST R 52054-2003, "Raw cow's milk: Technical conditions." We prepare the raw goat's milk in compliance with GOST 32940-2014, "Goat's milk: Technical conditions." Following TU 9229-179-04610209-2008, the curd milk whey was processed. Technical documents confirm that the established procedure has approved calcium chloride in the food industry. GOST R 51574-2018 regulates food salt. The drinking water should adhere to SanPiN 2.1.3684-21 standards. For the research, we obtained milk curd whey from a Moscow dairy plant under actual production conditions, adhering to all regulatory documentation requirements (GOST 34352-2017, "Milk whey—raw materials"). We conducted whey sampling by the guidelines provided in GOST 33957-2016, "Milk whey and its derivatives," specifically the acceptance rules, sampling procedures, and control methods.

We used a Brookfield device to determine cheese's structural and mechanical parameters and their mixtures. Before starting the study, we set the following parameters: the load on the sample was 5 grams; the measuring probe's movement speed was 2.5mL/s; and the depth of its immersion in the sample was 15 millimeters. During the analysis, we measure the force required to deform the sample before the specified end of the study. The applied load causes the test sample to deform while the magnitude of this load remains constant. We measured three different points of the sample using probe immersion to obtain more accurate results. Using this research method allows us to obtain detailed information about cheeses' structural and mechanical properties, which is important for evaluating the quality of the product and its behavior under various conditions (for example, during slicing, packaging, or transportation).

RESULTS & DISCUSSION

Milk from various farm animals has a high nutritional and biological value; therefore, it is a source of microorganism development, both exogenous and endogenous (Seyfali et al., 2024). This study demonstrates that milk from different farm animals carries significant nutritional and biological value, making it a fertile environment for exogenous and endogenous microorganisms. During the milk processing phase, researchers determined the number of microorganisms in native, unprocessed milk, reaching $5.29*10^2$ CFU/cm^3. The method of provocative testing introduced microorganisms from the *Escherichia coli* group into the milk. The milk content was 3.26CFU/cm^3. When ultrasonic cavitation was used to process goat and cow's milk over 5, 15, 25, and 30min, the changes in microbiological parameters led to a 35% drop in the vegetative form of microorganisms. The drops were 24, 26, and 30%, respectively. The decrease in

bacteria in the Escherichia coli group is the primary cause. At the same time, raw milk's physical and chemical parameters remain the same, except for the size of fat particles. They undergo a crushing process of homogenization. Milk production is characteristic of maintaining a homogeneous structure in the food system (Kashtiban et al., 2024).

Researchers have investigated the effect of avalanche-streamer discharge as a potential method of pasteurizing milk, evaluating its effect on the product's microbiological background (Nina et al., 2023). Our results showed that applying the avalanche-streamer method has no significant effect on the total number of microorganisms in milk, making its use for pasteurization technologically impractical. However, we found that treating milk with electronic complexes, ozone, and free oxygen formed after avalanche-streamer exposure effectively destroys spore bacteria. With a processing time of 30s, the number of spore bacteria decreases by 10 times, reaching 100CFU/cm^3. An increase in the exposure time to 60s leads to a further decrease in the number of spore cells by another 10 times, reaching a value of 10CFU/cm^3. A further increase in the time of avalanche-streamer exposure does not significantly reduce the number of spore cells, and their number stabilizes at the achieved level. Based on the data obtained, it can be concluded that an increase in the avalanche-streamer exposure time over 60 is technologically impractical since it does not lead to additional destruction of spore bacteria in milk (Nina et al., 2023) (Fig. 1).

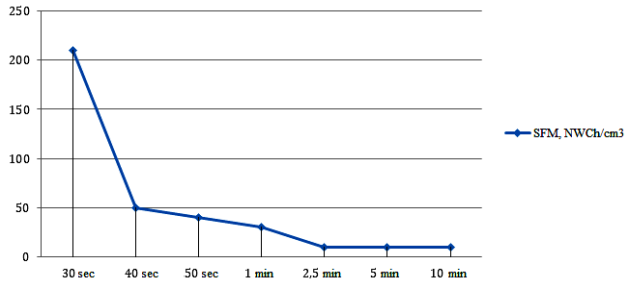

Fig. 1: Change in the number of spore-forming microorganisms (SFM) during avalanche-streamer discharge treatment.

The study's findings indicate that using avalanche-streamer exposure as an independent method to achieve a pasteurization effect in raw milk is impractical (Kanina et al., 2022). Therefore, we cannot recommend this method as the sole means to ensure the microbiological safety of milk. Nevertheless, the study revealed an interesting fact about reducing spore-forming microorganisms in milk under avalanche-streamer effects. This finding opens up new possibilities for using this method with other milk processing methods, such as high-frequency ultrasonic cavitation. When avalanche-streamer exposure and ultrasonic cavitation are used together, they can effectively kill more bacteria and spore-forming microorganisms in milk (Mehany et al., 2024). Such a combined approach can provide a high level of product microbiological safety while avoiding the need to use harsh heat treatment modes, which can adversely affect milk's taste and nutritional value. The obtained research results pave the way for innovative milk processing methods that combine avalanche-streamer effects with other physical methods, such as ultrasonic cavitation, to achieve a pronounced antibacterial effect (Vanga et al., 2020). Some researchers report that these methods (high-frequency acoustic cavitation and avalanche-streamer discharge) affect the fat fraction of the food system and trigger the oxidation process. Therefore, it is important to study the fatty acid composition of the raw material after processing. It is known that the omega-3 and omega-6 fatty acids are more susceptible to oxidation. Their loss during processing will indicate the beginning of the oxidative process (Chughtai et al., 2021).

The information in (Fig. 1) shows that treating milk with avalanche-streamer discharge did not have a significant impact on the fatty acid composition or the process of burning milk fat (lipolysis). This means that the main characteristics of milk fat fraction, such as the ratio of saturated and unsaturated fatty acids (Fig. 2) and the degree of fat oxidation, remained virtually unchanged after processing. The preservation of the initial fatty acid composition and the absence of signs of lipolysis intensification are important for the continued use of processed milk in the technological process of producing various dairy products (Gautam et al., 2024). This is because the fatty acid composition and the degree of fat oxidation directly affect the organoleptic properties, nutritional value, and shelf life of finished products. So, the results showed that processing milk with an avalanche-streamer discharge does not change the fat fraction in a way that is not desirable. It also keeps the milk's original properties, which must be processed further into different dairy products (Aaliya et al., 2021).

The Zaanen breed goats treated with avalanche-streamer discharge yielded the same quality raw materials. It has been established that vegetative cells of microorganisms are present in raw milk. This exposure is not effective in terms of the pasteurization effect, which is confirmed by the raw milk obtained from cow's milk studies (Gamlath et al., 2018).

The structure of milk and dairy products is determined by the constituent components that make up its composition. These are fats, proteins, and macro- and micro-substances in Brownian motion. We observe an air "collapse" of particles when an ultrasonic wave passes through the medium (milk). During the "collapse," suspended particles collide, while particles of a smaller structure are formed - the homogenization effect (Fig. 3b).

With prolonged powerful exposure, fat particles form agglomerates due to the energetically beneficial effect (Fig. 4a & 4b). We can observe calcium accumulations in milk (Fig. 4) through the same mechanism of agglomerate formation. During cavitation processing, calcium from raw milk takes on a visibly larger size compared to unprocessed milk. Presumably, this can create both positive effects in the production of cheeses, for example, the creation of additional disulfide bonds and thereby strengthening the protein matrix, and negative ones by the presence of a "chalky consistency", which will affect the commercial characteristics of the product. This phenomenon requires further research.

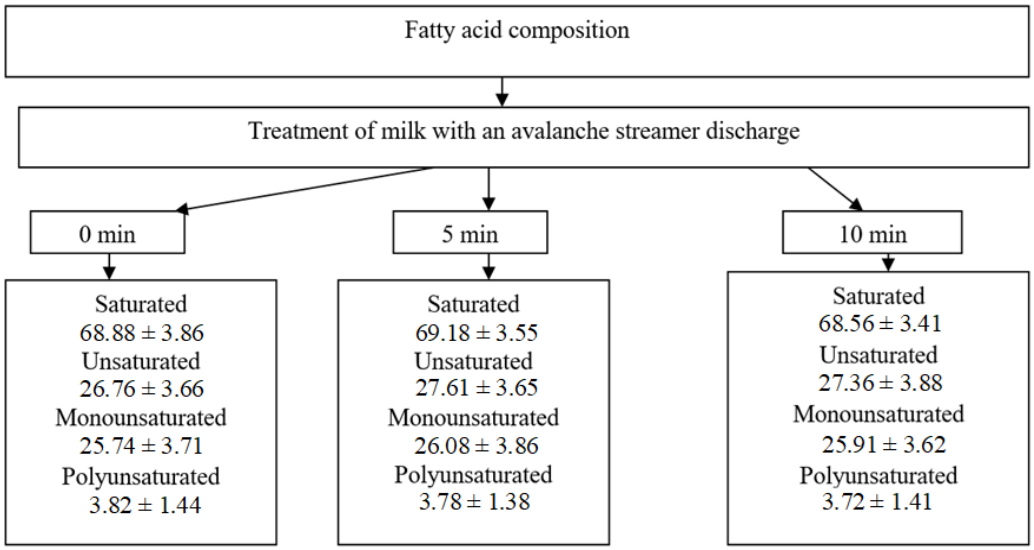

Fig. 2: The composition of fatty acids of cow's milk treated with avalanche-streamer discharge.

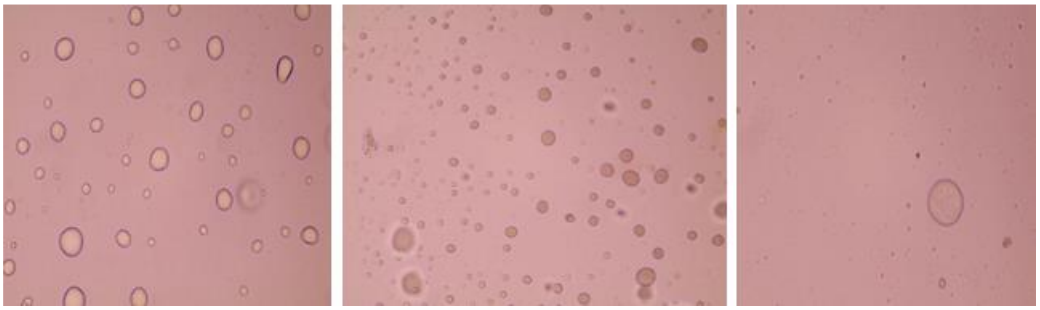

Fig. 3: Milk homogenization, followed by the formation of agglomerates a) milk - without processing, b) homogenization effect, and c) formation of agglomerates.

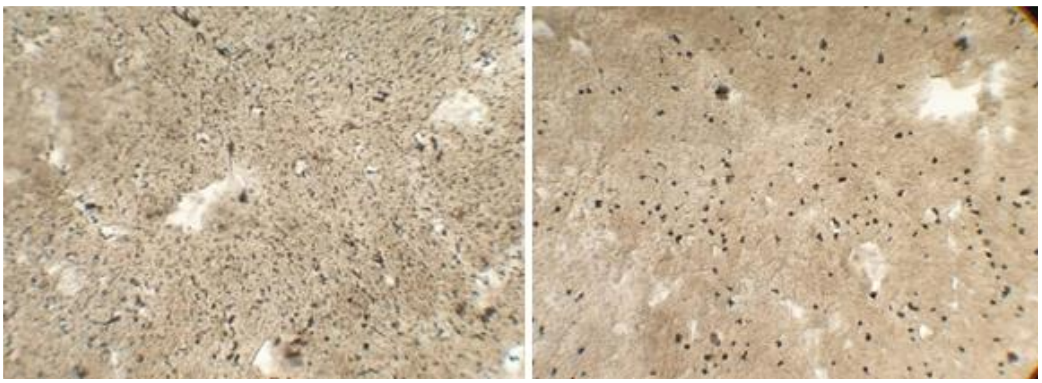

Fig. 4: Histological studies of the cheese "Adygeysky": a) without processing, and b) with high-frequency cavitation processing.

In addition, the physical and chemical parameters of secondary dairy raw materials were studied with various cavitation exposures, and it was found that with increasing exposure, whey components decrease, which leads to a decrease in viscosity in the food system (Table 1). Table 1 shows the physical-chemical parameters of the processed cheese samples. The data obtained were analyzed and showed that the changes in the measured values relative to the control point were not significant, and the use of cavitation treatment of the used dairy raw materials did not negatively impact the final product.

Table 1 shows that the cheese yield is mainly influenced by the components of raw milk and, to a somewhat greater extent, by acoustic cavitation, which, in our opinion, is associated with the coagulation of whey proteins (Huppertz et al., 2019; Chughtai et al., 2021). There is also a decrease in the mass fraction of moisture due to evaporation under high-frequency vibrations. Generally, the yield of cheese with processed milk based on it, high-frequency acoustic cavitation, and avalanche-streamer discharge were higher than raw milk (Table 2). From this, it is worth concluding that the above-mentioned treatments positively affect the technological characteristics of high-protein products. A complete denaturation and coagulation of whey proteins can explain the positive effect. Studies of cheeses' structural and mechanical characteristics (Table 3) confirm this. Furthermore, the formation of additional bonds results from the expansion of calcium agglomerates (Hong et al., 2021; Sergeev et al., 2021). The developed samples were also examined for physical-chemical parameters during the shelf life of the recommended of "Adygeisky" cheese type. We noted that all changes were uniform, and all samples maintained the prescribed shelf life.

Table 1: Physical-chemical parameters of the "Adygeysky" cheese

Indicators	Cow's milk, whole, unprocessed	Cow's milk, whole processed	Goat's milk, whole, unprocessed	Goat's milk, whole, unprocessed	Mixture (60*40), whole, unprocessed	Mixture (60*40), skimmed processed	Cow's milk, skimmed, processed	Goat's milk, skimmed, processed
Fat (%)	18.15	18.14	17.60	17.50	22.0	0.70	0.50	0.60
Protein (%)	15.52	15.53	17.24	17.25	15.82	15.22	15.52	16.58
Moisture (%)	65.00	64.00	64.00	63.00	62.00	82.00	82.00	81.00

Table 2: Technological parameters of Adygeysky cheese

Indicator	Cow's milk, whole, unprocessed	Cow's milk, whole processed	Goat's milk, whole, unprocessed	Goat's milk, whole, unprocessed	Mixture (60*40), whole, unprocessed	Mixture (60*40), skimmed processed	Cow's milk, skimmed, processed	Goat's milk, skimmed, processed
Cheese output, %:	205 g-4 l	207.8-4l	182.5 g-4 l	208.7-4l	132.5-4 l	133.4-4 l	79.15-2 l	81.22-2 l

Table 3: Structural and mechanical characteristics of raw and processed milk cheese

Indicator	Cow's milk, whole, unprocessed	Cow's milk, whole processed	Goat's milk, whole, unprocessed	Goat's milk, whole, unprocessed	Mixture (60*40), whole - unprocessed	Mixture (60*40), skimmed, processed	Cow's milk - skimmed, processed	Goat's milk, skimmed, processed
Penetration pressure, g/cm^2	976.00	980.00	844.00	894.00	1289.00	1300.00	1402.00	1468.00
Deformation, mm	9.90	14.40	10.40	9.01	13.20	11.20	15.00	15.00
Work, MJ	10.40	15.50	15.60	13.20	13.70	13.50	17.90	18.40
Final load, g /cm^2	976.00	980.00	842.00	895.00	1290.00	1335.40	1400.90	1468.10

Conclusion

In summary, the dual approach benefits the production of cheeses with acid coagulation by using avalanche-streamer discharge and high-frequency acoustic cavitation. At the same time, the 45kHz mode, with a processing time of 17 min, is optimal, which affects the structure of cheeses, organoleptic parameters, physical-chemical parameters, and technological parameters.

Acknowledgement: The research described in this article was carried out with the support of the Russian Federation's Ministry of Science and Higher Education per agreement № 075-15-2022-317, dated April 20, 2022, on providing a grant in the form of subsidies from the Russian Federation's Federal budget. The state provided the grant to support establishing and growing a world-class scientific center named "Agrotechnologies for the Future".

Author's Contribution: Author Kanina K.A. is the main and corresponding author respectively. Authors Kanina K.A., Borodulin D.M., and Kupriy A.S. conceived and designed the experiment. Authors Kanina K.A. and Kupriy A.S. performed the study. Author Borodulin D.M. supervised and coordinated the study. Authors Kanina K.A., Borodulin D.M. and Kupriy A.S. prepared the manuscript draft. All authors critically revised the manuscript and approved the final version.

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