Effects of Cold Plasma Technology on Physical and Nutritional Properties of Milk and Milk Products

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Cow's milk is consumed worldwide and its composition includes water, lactose, fat, proteins, and vitamins/minerals. To ensure food safety and extended shelf-life, traditional methods like pasteurization and sterilization have been used for a long time. However, these methods can negatively affect milk quality by causing browning, vitamin loss, and flavor changes. As a result, consumers are now interested in less processed dairy products that retain maximum nutrition, safety, and long shelf-life without extensive heating. Novel food preservation technologies such as high hydrostatic pressures, pulsed electric fields, ultrasounds, and cold atmospheric plasma have gained attention. Cold plasma is a non-thermal technique that uses ionized gas to pasteurize milk, effectively eliminating microorganisms while maintaining milk quality. It can be optimized to reduce bacteria without significant quality loss, but non-optimized processes can lead to issues like lipid oxidation, protein aggregation, and off-flavors. Cold plasma offers advantages such as short processing times, effectiveness at room temperature (beneficial for heat-sensitive products), and low-energy requirements in the food industry.

Mode of action of cold plasma:

The effectiveness of cold plasma treatment is based on the production of various reactive species, including ultraviolet radiation, reactive oxygen species (such as ozone, hydrogen peroxide, singlet oxygen, peroxyl radicals, and hydroxyl radicals), and reactive nitrogen species (such as nitric oxide, peroxynitrite, and peroxynitrous acid). These reactive species have significant effects on the physical, chemical, and microbiological properties of milk and dairy products. One important change caused by cold plasma treatment is the deformation of microbial cell surfaces, damage to intracellular genetic material, and ultimately cell death through lysis. Additionally, the plasma-reactive species, including free radicals, have the potential to inactivate enzymes by modifying amino acids through oxidation, sulfonation, and hydroxylation reactions. Cold plasma specifically targets the secondary structure of enzymes, inhibiting their binding and catalytic activities. Plasma-produced reactive oxygen species can also interact with lipids in foods and cause lipid oxidation. This can lead to undesirable changes, especially in dairy products with high fat content, such as cream and butter. Reactive oxygen species primarily target the methyl groups of fatty acids, with fatty acids containing double bonds being more sensitive to oxidation.

There is a possibility of an increase in product acidity due to chemical interactions between reactive species like hydrogen peroxide and nitric acid formed during plasma production. However, studies have shown mixed results, with some observing no change in acidity. These discrepancies may be attributed to differences in the plasma source used and the specific process parameters applied in different studies.

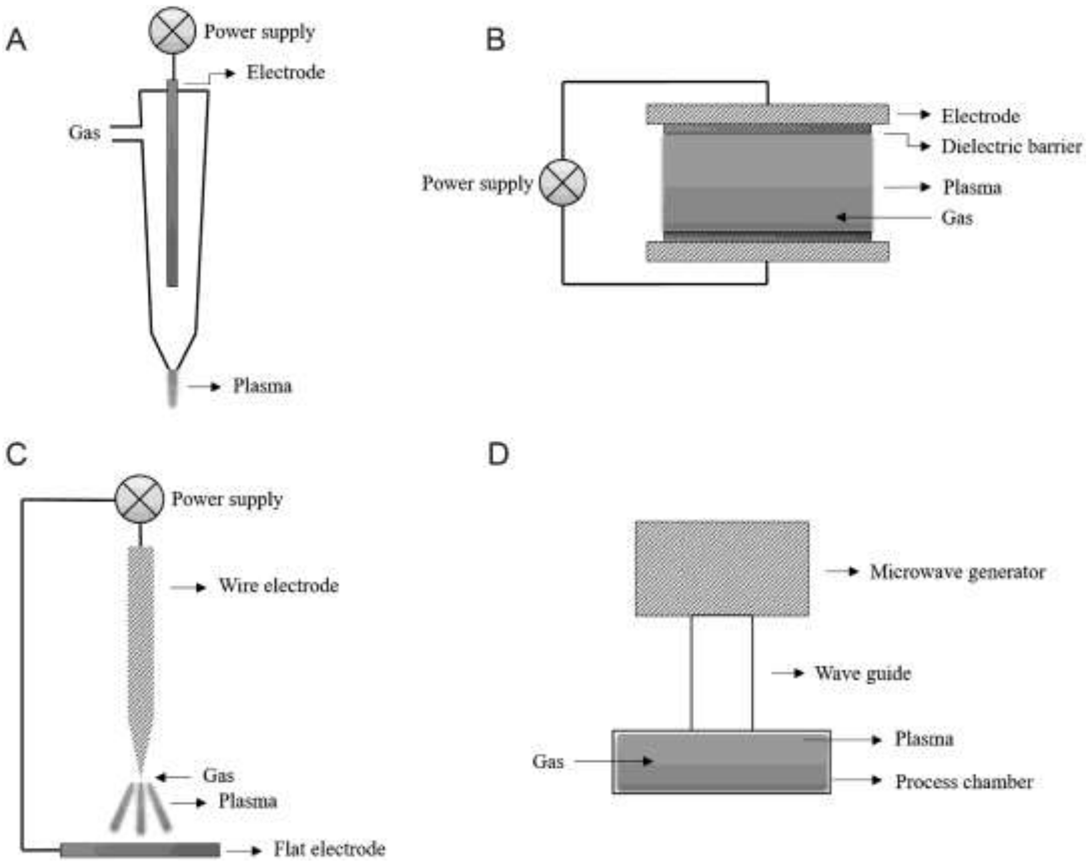

Fig.1. Different Cold Plasma Systems: (A) Plasma Jet, (B) Dielectric Barrier Discharge, (C) Corona Discharge, and (D) Microwave Disc

Physical Properties

Milk is an emulsion containing fat and protein compounds in a watery environment. Its viscosity, which affects mouthfeel and is used as a quality control measurement, depends on its composition and processing conditions. Research has shown that viscosity decreases with higher temperature and moisture content, and increases with higher fat, lactose, protein, and mineral contents. Factors such as pasteurization temperature, pasteurization time, and homogenization pressure also influence viscosity. Skim milk has a viscosity of about 1.56mPas at room temperature, while whole milk has a viscosity of about 2.00mPas. Cold plasma treatment has been observed to slightly reduce milk viscosity, likely due to protein and lipid oxidation. Studies have shown that mild plasma treatment can lead to lower viscosity and flow consistency index in milk. However, the effect of cold plasma on viscosity can vary depending on factors such as treatment time, voltage, and flow rate. Longer treatment times, higher voltages, and higher flow rates can result in increased viscosity. The optimization of viscosity can be achieved by adjusting the plasma conditions.

The color of milk is an important sensory characteristic that influences consumer preferences and is closely linked to the quality of dairy products. The total color difference (ΔE) is a commonly used metric to quantify the visual perception of color differences between two samples. In a study, plasma-treated milk exhibited ΔE values of 0.91 and 1.58 when treated at flow rates of 6 and 3 ml/min, respectively. However, another study reported no significant change in color after plasma treatment of raw milk for up to 15 minutes. In a separate investigation, milk samples treated with DBD at 80 V for 120 seconds showed ΔE values ranging between those of UHT (36.02) and pasteurization. Similarly, for milk powder, ΔE values were below 1.5 after 120 seconds of plasma treatment. To minimize color changes in dairy products, it is recommended to keep the treatment time below 5 minutes. Additionally, to prevent nonenzymatic reactions in milk that result in increased yellowness, it is suggested to use working gas with low oxygen concentration to avoid oxidation of fat and proteins.

The size of particles, particularly fat globules, in milk plays a significant role in determining its flavor, mouthfeel, and emulsion stability. When whole chocolate milk is subjected to cold plasma treatment for 5 minutes, the resulting milk particles exhibit increased surface areas and reduced volume diameters compared to untreated milk. The presence of reactive oxygen species (ROS) in cold plasma processing can lead to mild oxidation of proteins, resulting in increased carbonyl groups and surface hydrophobicity, as well as a reduction in free SH groups. This protein oxidation can cause protein aggregation. Similar findings were observed in a study on whey beverages treated with cold plasma processing.However, if cold plasma treatment exceeds 5 minutes, it can lead to further protein oxidation due to the increased generation of ROS, resulting in larger particle sizes. On the other hand, a higher flow rate (30 ml/min), which increases gas velocity, can cause smaller particle sizes.In summary, cold plasma treatment of milk can impact particle size by influencing protein oxidation and gas velocity. Treatment times longer than 5 minutes can result in protein oxidation and larger particle sizes, while higher flow rates can lead to smaller particle sizes due to increased gas velocity.

Nutritional Properties

Milk proteins, which make up about 32 g/L to 38 g/L in whole milk, play a crucial role in determining the physical, chemical, and sensory characteristics of milk products. When subjected to a 70 kV DBD atmospheric cold plasma treatment for 15 minutes, there was a mild oxidation of proteins, as indicated by an increase in protein-bound carbonyl groups compared to the control sample. This oxidation was measured using a spectrophotometer and resulted in approximately 3 AU2 Abs, whereas the control sample had an approximate value of 0.25 AU Abs. In the case of non-fat dry milk, a study showed that there were no significant changes observed in the amino acid profile when subjected to cold plasma treatment. However, it should be noted that if low pressure (16Pa) or nitrogen gas is used in the treatment, which does not generate reactive oxygen species (ROS), there may be no significant impact on the proteins. On the other hand, if air, high voltage (60 kV), and long treatment times exceeding 30 minutes are applied, there can be mild oxidation or significant protein aggregation due to the higher concentration of generated ROS. Therefore, to minimize changes in proteins during cold plasma treatment, it is important to tailor the treatment conditions accordingly.

In a study it was found that using an encapsulated DBD plasma source on milk resulted in a change in the concentration of butyric acid (0.6 g/L of milk) compared to the control (0.7 g/L of milk) after a 10-minute treatment. In another study by Korachi et als evaluated fat oxidation in milk using an atmospheric plasma discharge system. They reported a one percent decrease in the concentration of short-chain fatty acids (63.6%) during the first 5 minutes of treatment, which increased to 65.8% after 10 minutes. When milk was treated with a low-pressure (16Pa) plasma system, there was a loss of fat during the plasma processing. Higher levels of reactive oxygen species (ROS), including OH radicals and atomic oxygen, are associated with increased fat oxidation. To minimize fat oxidation, it is suggested to lower the voltage and limit the treatment time to below 10 minutes, as this reduces the concentration of ROS. Additionally, using a working gas with a lower concentration of oxygen, such as pure nitrogen, can also help decrease fat oxidation.

There is limited research available regarding the effects of cold plasma treatment on lactose in cow's milk. In one experiment, a DBD-type plasma system was applied to raw milk, and the lactose content was measured. The results showed a significant reduction in lactose content, specifically 44.8 g/L at a flow rate of 3 ml/min, compared to the control sample which had a lactose content of 46.4 g/L. This reduction in lactose content is believed to be a result of the interaction between the OH radical present in the plasma and lactose molecules. The OH radical abstracts a proton from the lactose disaccharide, leading to the formation of a sugar-free radical and subsequent reduction in lactose content.

Conclusion

Cold plasma technology is a relatively new non-thermal technique that holds great potential for processing milk and dairy products. It offers several advantages over thermal methods. When optimized, cold plasma treatment can achieve non-thermal pasteurization or sterilization of milk while minimizing quality changes. However, existing studies on cold plasma have primarily focused on its antimicrobial effects, and there is a lack of comprehensive research addressing the physical, chemical, and sensory properties of the final products. The effects of cold plasma on milk and dairy products are diverse, encompassing microbiological, physicochemical, biochemical, and sensory properties. The type and concentration of reactive species present in the plasma can vary based on factors such as the gas or gas mixtures used, the configuration of the plasma source, and the applied voltage and treatment time. Consequently, different results have been observed in various studies, depending on the method of plasma generation, process parameters, and the specific microorganism species being investigated. Overall, further research is needed to fully understand the changes that occur in milk and dairy products due to cold plasma treatment. More studies are required to elucidate the complex processes involved and to gain a comprehensive understanding of the potential benefits and limitations of cold plasma technology in the dairy industry.

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