Emerging Food Processing Technologies to Improve the Quality of Plant-Based Milk During Processing

Ramya C. S.[1]*, Parvathy Nayana N[1] and Juhi Ranjan[1]
[1] Ph.D. Scholar, Division of Agricultural Engineering, ICAR-IARI, New Delhi
*Corresponding Author: ramyacs8369@gmail.com

Nowadays, the demand for an alternative to animal-sourced milk is high due to medical reason such as lactose intolerance, dairy milk protein allergy, and cholesterol problem and lifestyle choices includes a vegan diet and ready-made healthy beverages. Since then, consumers have tended towards plant-based beverages that have been extracted from oilseeds, nuts, cereals, etc. Plant-based milk substitutes are one of the food groups that are irreplaceable in the vegan food industry because plant-based milk substitutes are used as an essential ingredient in many vegan food products such as plant-based yogurt, cheese, kefir, butter, ice cream, etc. People also choose plant-based milk substitutes because of their rich antioxidant activity and fatty acids which reduce the risk of cardiovascular diseases, cancer, atherosclerosis, and diabetes. However, these substitutes also have various negative effects which include less availability of micronutrients because of the presence of anti-nutritional factors like phenols, which can be overcome by various processing methods such as fermentation.

The production of plant-based milk typically involves several steps: wet grinding, filtration, pasteurization/sterilization, homogenization, aseptic packaging, and cold storage. However, a challenge arises with product stability, as heat treatment can adversely affect sensory and nutritional qualities. Hence, there is a need for novel technologies like ultrasound, pulsed electric fields, ohmic heating, high and ultra-high-pressure homogenization, and cold plasma treatment to enhance stability without the need for additives and to enhance nutritional properties.

High-pressure processing

High-pressure processing is a method of food processing technology, in which the food material is subjected to high pressure ranging from 100 MPa to 600 MPa to eliminate microorganisms and alter the attribute of food materials to achieve the desired quality of food products with minimum loss of nutrients (Gupta & Balasubramaniam, 2011). This technology is also called High Hydrostatic Pressure Processing and Ultra Pressure Processing. The HPP technology works on two principles; Le Chatelier's principle which states that any process accompanied by a decrease in volume is enhanced by pressure and the Isostatic principle which states that the pressure acts equally and homogeneously in all directions irrespective of size and geometry of the particle (Sehrawat et al., 2021).

High-pressure processing has gained significant attention as a technique to achieve considerable microbial inactivation comparable to that of pasteurization. The application of 600 MPa pressure for a duration of 180 seconds significantly reduces the aerobic plate count, coliforms, and yeast count in plant-based milk. Simultaneously, it led to a noteworthy decrease in immunoreactivity within milk. This reduction in immunoreactivity could be attributed to a reduced solubility of milk proteins due to high-pressure processing. Furthermore, it is important to note that high-pressure treatment also demonstrated a lesser impact on the colour change of the milk when compared to pasteurized milk samples. Regarding the dispersive and aggregative characteristics of almond milk, pressure treatment induces relatively more and larger aggregates in comparison to samples treated with heat. This phenomenon can be attributed to the aggregation of macromolecules under high-pressure conditions. The variation in dispersive and aggregative properties observed in high-pressure and heat-treated almond milk was due to differences in protein denaturation, particle coagulation, and aggregate morphological characteristics (Dhakal et al., 2016). Moreover, HPP also increases the emulsion stability and viscosity of the milk samples. Knowledge gained from the studies will help food processors formulate novel plant-based beverages treated with high pressure.

Ultrasound

Ultrasonic devices are utilized as ultrasonic homogenizers to enhance the homogeneity of the emulsion in plant-based milk samples, consequently improving their stability. Moreover, these ultrasonic devices are employed to inactivate microorganisms and thus increase microbial safety. The main mechanism of action of the ultrasound approach resulted from acoustic cavitation, including the formation and collapse of air bubbles in treated systems. In treatment with ultrasound waves, waves with a frequency of over 20 kHz to 100MHz are generated, which in turn affect the cells through cavitation. Bubbles generated by ultrasonic waves attack the cell walls by bursting near them a short time after formation, creating a pressure difference. This can facilitate both extraction and inactivation of microorganisms. Consequently, ultrasound treatment increases the viscosity, particle size, and stability of the emulsion.

Iorio et al. (2018) suggest that the ultrasound treatment could exert a sub-lethal injury on the pathogens, as evidenced by the lag phase in L. monocytogenes or the reduction of the growth rate for E. coli O157:H7, which, combined with the storage under refrigeration, could contribute to increasing the shelf life. High-intensity ultrasounds effectively disrupt peanut cells, increase hydrolysed protein content in milk, improve sedimentation index, prevent phase separation, and improve microstructure with smaller particle and fat globule size. Additionally, ultra-sonication significantly reduces the trypsin inhibitor activity by up to 52% and improves the digestibility of protein in soymilk. This treatment increases the absolute value of ζ-potential and modifies colour parameters (increased a*, but decreased L* and b*). It also mitigates the presence of beany-flavor compounds in soybean milk. Ultrasound can amplify the effect of pH-shift on increasing the thermal stability of coconut milk by modifying the functional properties and structures of coconut milk protein, especially under alkaline pH-shift treatment

Pulsed Electric Field (PEF)

Nowadays, PEF is used for processing different types of beverages. In general, the pulsed electric field is a technique for fluid stabilization through the reduction of fat particle size. This treatment is suggested as an alternative nonthermal technique to increase the shelf life without compromising the quality, nutritional, and sensory attributes of the plant-based milk. In this technique, the food product is usually placed between two electrodes and subjected to pulses that are short at a very high voltage and minimal processing time. The electric fields generate an induction of the membrane potential, which, exceeding a certain value, can cause damage to the cells and even cell death which in turn leads to the destruction of unwanted micro-organisms in plant-based milk.

Pulsed electric field (PEF) treatment profoundly influences the physicochemical, physical, and structural properties of plant-based milk. It greatly reduces the particle size, leading to emulsion with enhanced stability, and reduced phase separation, while also increasing apparent viscosity and changing the consistency index of milk samples. Additionally, PFE treatment improves the physical stability, whiteness index, clarity, and overall appearance of plant-based beverages with a noticeable colour change (Manzoor et al., 2019). However, the important factor to be considered is the PEF treatment time, as an increase in processing time the relative activities of soybean lipoxygenase (SLOX) and peroxidase decreased and the inactivation of *Escherichia coli* and *Staphylococus aureus* increased significantly.

Cold plasma treatment

Cold plasma one of the non-thermal processing technologies, is a well-known technology for reducing the microbial load in foods. Cold plasma has also been reported to maintain quality, reducing both anti-nutritional and allergens. Most allergens and antinutritional factors are proteins, they can be modified, or their structures can be altered by the reactive species. The reactive species produced during plasma generation reacts and bombards with the antinutritional factors and reduces them; or it activates the enzymes that can reduce the antinutritional factor (Lokeswari et al., 2021).

The application of cold plasma treatment in sesame milk resulted in a reduction of anti-nutritional factors such as phytates, oxalates, and lipoxygenase activity. However, it also led to undesired alterations in the physicochemical properties of the plant-based milk. Notably, the application of plasma bubbles effectively decreased the microbial load in plant-based milk (Dharini et al., 2023)

Conclusion

The increasing demand for plant-based milk alternatives, driven by health concerns and lifestyle choices, has given rise to the need for innovative processing methods. High-pressure processing (HPP), ultrasound, pulsed electric fields (PEF), and cold plasma treatment have all shown promise in improving the quality, safety, and nutritional properties of plant-based milk. HPP effectively reduces microbial counts and immunoreactivity while enhancing emulsion stability. Ultrasound treatment improves emulsion homogeneity and microbial safety while reducing allergenicity. PEF treatment modifies physicochemical properties, enhancing stability and appearance. Cold plasma treatment reduces anti-nutritional factors and microbial load. These techniques provide avenues for addressing the challenges in plant-based milk production and expanding the choices available to consumers seeking dairy alternatives.

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