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High-Pressure Homogenization (HPH): Potential Applications in the Development of Functional Dairy Foods

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The homogenization process has long been used by the dairy industry to decrease the size of fat globules, improving the emulsion's stability and enhancing the chemical and physical stability of milk. It considerably affected the quality of dairy products like ice cream, curd, and condensed milk. The use of physical treatments such as homogenization, high-pressure processing, pulsed electric field and ultrasonic has emerged as a novel technology to replace traditional methods to minimise the impact of heat on food components while maintaining microbial safety, preserving nutrients and sensory qualities, and in certain cases, improving techno-functional properties of foods (Alves Filho *et al*., 2020).

High pressure homogenization (HPH) represents a potential non-thermal approach to develop new functional applications. This technology has recently undergone a considerable modification, aiming at investigating new application areas for the food processing business, allowing the building of larger emulsions and the alteration of not just macromolecule aggregates but also some food constituents (Saricaoglu, 2020). HPH involves rapidly increasing a fluids speed through a narrow space valve with extreme pressure intensifiers, which results in depressurization and high shear stress. The fluid cells, particles, and macromolecules are then exposed to enormous mechanical pressure, twisting and deforming them into nano-sized particles. Additionally, HPH causes a decrease in air pressure, which increases turbulence, shear stress, temperature rise, and cavitation. HPH presents interesting opportunities to restructure food proteins, affecting protein conformation, leading to denaturation, gelation, or aggregation and, as a result, producing new products with new or improved texture (Saricaoglu, 2020: Jiang *et al*., 2022).

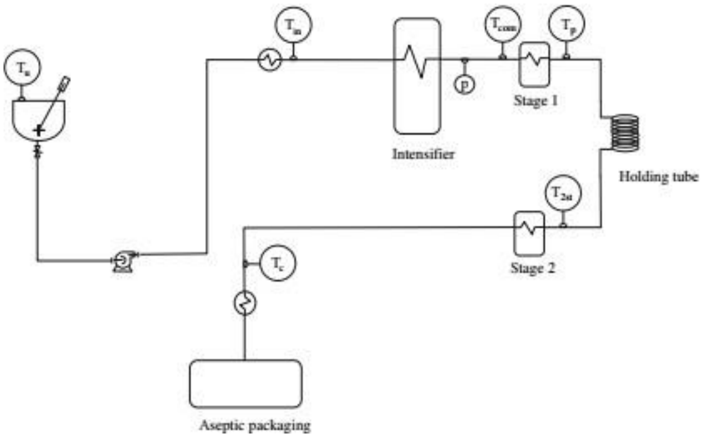

Fig. 1 Schematic diagram of High-pressure homogenization (HPH)

High Pressure Homogenization Process

The HPH system consists of a feed tank, heat exchangers, pressure intensifiers, first and second-stage homogenization valves, holding tube, cooling system, and aseptic packaging system (Fig 1). During HPH, the raw fluid, depending upon processing objective (pasteurization or commercial sterility) or desired unit process (e.g., emulsification), is either pre-chilled or heated to certain initial temperature using conventional heat exchanger. Subsequently, the fluid is pressurized to desired target pressure (up to 300 MPa). Then, the fluid is depressurized through a set of homogenization valves. Often in the first HPH valve, the fluid is depressurized from target pressure to about 10-20 MPa. Then, the fluid passes through a hold tube of a certain length. This will provide sufficient residence time for the processed fluid at the target process temperature to ensure microbiological safety of the processed product. A second homogenization valve is often used to break any particles that might have aggregated since discharged from the first homogenization valve and also used to bring the fluid to atmospheric pressure. The fluid also experiences great shear, cavitation, and turbulence, and such mechanical effects are put to work for mixing, dispersion, emulsification and structuring, particle size reduction and inactivating microorganisms (Sergio *et al.*, 2017). The processed fluid is then cooled and aseptically packaged.

Impact of HPH on food

The use of high-pressure processing is environmentally sustainable since it doesn't require the addition of chemicals and addresses specific difficulties with food product quality and productivity without affecting the product's overall characteristics (Ahmed *et al*., 2019; Wu *et al*., 2019). Depending on the circumstances of the reaction, high pressure treatments can change the secondary, tertiary, and quaternary structures of enzymes to increase the number of hydrophobic sites, reveal amino acid and sulfhydryl groups, and induce modifications in enzyme functionality and enzyme inactivation (Saricaoglu 2020).

Fig 2. Schematic illustration representing attributes of high-pressure homogenization in the food sector (Malik *et al*., 2023)

Application of HPH in Dairy Products

Most HPH application is still, in many ways, restricted to small-scale or laboratory settings. Because they operate at the highest possible pressure levels with flow rates that are less than what is needed for industry and, in some situations, high energy consumption, commercially available HPH units have limited industrial use.

Milk

HPH is frequently used in fermented milk for a number of reasons, including (1) regulating sensory attributes without sacrificing shelf life and nutritional quality; (2) enhancing the activity of probiotics, and (3) altering the functional characteristics of Lactic Acid Bacteria (LAB). HPH is advised for usage to sterilize and homogenize milk in a single step since it reduces the microbial load of milk (Kiełczewska *et al.*, 2021). Furthermore, it has been found that the HPH of milk changes the components of phosphorus, nitrogen, and calcium from being soluble to insoluble, which improves the coagulation qualities of the milk (Burns *et al*., 2015). The milk that was treated at 200MPa and 30°C had the highest shelf life (about 21 days), suggesting that the high pasteurisation treatment had a greater thermal effect on the milk. Lowering the microbial load to 3.50 log cfu/m, UHPH was found to be equally effective as high pasteurised milk at reducing total bacteria and psychrotrophic lactococci (Pereda *et al*., 2007).

Yoghurt

Yogurt's gel strength is enhanced by HPH at 200–300 Mpa at an inlet temperature of 30 or 40°C when compared to conventionally homogenised milk. Particle size was decreased by increasing the homogenization pressure, resulting in finer, whiter emulsions with better physical segregation resilience (Hernadez & Harte, 2008)

Cheese

Ultra-high-pressure homogenization (UHPH; 100 to 330 MPa; 30°C inlet temperature) reduced the whey's protein content while increasing the curd's wet yield and moisture content. It also reduced the size of the fat globules. Moreover, single-stage UHPH at 200 and 300 Maps enhanced the rennet's capacity for coagulation as well as its sensory or functional attributes (Lodaite *et al*., 2009).

Ice cream

The frozen dessert's texture has been improved using HPH. It was found that the texture of ice cream made from an 8% fat mixture homogenized at atmospheric pressure (18 MPa) was comparable to that of ice cream made from a 5% fat combination homogenized at 100 MPa. Therefore, HPH presents a great deal of potential for improving the textural qualities of frozen desserts that are lower in fat (Hayes and Kelly, 2003a; Innocente *et al*., 2009)

Probiotics

The metabolic activity of microorganisms can be positively impacted and modulated by HPH. The functional characteristics of probiotic microorganisms, such as hydrophobicity, interaction with the small intestine, resistance to simulated gastric conditions, auto-aggregation, and stomach-duodenum passage, have been altered through HPH (50 MPa) treatments. Additionally, the microorganisms exhibit higher microbial viability compared to refrigerated product storage (Patrignani and Lanciotti, 2016; Bevilacqua *et al*., 2016). Additionally, HPH controls and improves the probiotic, fermentative, and bio functional properties of a number of Lactobacillus species as well as their viability throughout processing and storage.

Conclusion

HPH was first used to homogenise and stabilise emulsions, such as milk, more effectively. However, recent developments in valve design have made it possible to raise operating pressure, expanding the range of potential uses include pasteurisation, sterilisation, stabilisation of emulsions and suspensions, structural modifications of entire matrices and specific biomolecules. However, more research on the industry's use of HPH is necessary since it can aid in the development of dairy products whose quality is comparable to that of fresh dairy products. Additionally, advancements have been achieved in the utilisation of HPH to lower the microbial load and adjust the activity of specific enzymes. For functional dairy products with heat-sensitive bioactive components, HPH is the recommended option over heat treatment due to its observable effects. The current heat treatment methods used in the dairy industry for pasteurisation and sterilisation are thought to eventually be replaced by this technology in future.

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