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High-Speed and High-Pressure Homogenization Techniques for Optimization of Food Processing, Quality, and Safety

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Abstract

The current review presents the advantages and health benefits of the fast growing homogenization techniques for improving food processing using the high-speed homogenization (HSH) and the high-pressure homogenization (HPH) to overcome the main problems encountering food manufacturers, merchandizers and end consumers which are the short shelf-life or non-conformity of food products. HSH and HPH are considered as an efficient alternative tool to thermal processes that cause many undesirable effects such as nonenzymatic browning (NEB), off-flavor or degradation of bioactive components. HPH treatment contributes to microbial load reduction and enzyme inactivation with increase of functionality in terms of health effect by increasing bioavailability by favoring the release of bioactive compounds, modified structures of biopolymers with improvement of novel interactions within particles networking. Homogenizers vary according to the purpose needed to achieve. Laboratory Homogenizers provide research and development (R&D) scientists with more experimentation options and capabilities for emulsions, dispersions, cell rupture, and liposomes with the capability of innovations, improve existing products, and more efficient manufacturing. While the Pilot and Industrial Homogenizers offer unique flexibility to meet every customer's particular requirements in reproducing the same product quality as developed in the laboratory with increasingly higher levels of plant integration with complete automation, controls and data acquisition. Many laboratory and industrial applications were cited here to highlight the significance of this powerful technology.

Keywords: High-speed Homogenization; High-pressure Homogenization; Food Processing; Food Quality; Food Safety

Abbreviations: CH: Conventional Homogenization; EU: European Union; HM: Human Milk; HPH: High-pressure Homogenization; HPP: High-pressure Processing; HSH: High-speed Homogenization; HTST: High-temperature Short-time; MPs: Myofibrillar Proteins; MSKF: Mango Seed Kernel Fat; NEB: Nonenzymatic Browning; OHC: Oil Holding Capacity; PA: Pasteurized; PG: Polygalacturonase; PLC: Programmable Logic Controller; PME: Pectinmethylesterase; POD: Peroxidase; PPO: Polyphenol Oxidase; PSD: Particle Size Distribution; RTE: Ready-to-eat; SEM: Scanning Electron Microscope; SPI: Soy Protein Isolate; TCC: Total Carotenoid Concentration; TEM: Transmission Electron Microscopy; TPC: Total Polyphenol Concentration; UHPH: Ultra-high-pressure Homogenization; UHT: Ultra-high Temperature;

WHC: Water Holding Capacity; XRD: X-ray Diffraction.

Introduction

"Homogenization" is defined as a fluid mechanical process utilizing pressure to push a fluid through a small orifice to disintegrate the particles or droplets for a purpose of reducing their size to create a stable dispersion or emulsion and is used to disrupt cells for applications in biotechnology. "Homogenizer" is defined as equipment that processes the homogenization, by which a substance's particles are dispersed and remain uniform and equally representative of the sample at large. Homogenizers yield several effects as the powerful ability to kill pathogens; lyse cells; reduce, micronize, or nanosize particles; and create highly stable emulsions, liposomes, and dispersions. Homogenizers can be classified as: mechanical (which use turbulent agitation, stirring, shearing and/or impact to effectuate the breakdown and mixture of substances. Specific examples of mechanical homogenizers include bead mills, rotor-stator homogenizers, high shear mixer homogenizers, and high speed homogenizers), pressure (which force pressurized suspensions through small tunnels or holes in order to disrupt their bonds. Specific examples of pressure homogenizers include high and ultra-high pressure, but there are also low-pressure homogenizers), and ultrasonic (which combine extreme sonic pressure waves with low temperatures in varying types of vessels to form microbubbles that eventually implode as in cavitation), resulting in size reduction and blending) homogenizers [1].

High-Speed Homogenization (HSH)

High-speed homogenization (HSH) is the process of homogenization under the effect of varying speed without alteration of pressure. HSH was used to increase emulsification stability of myofibrillar proteins (MPs) at lower speeds (8,000 to 14,500 rpm). Excessive HSH speeds (20,500 rpm or higher) resulted in aggregation of MP molecules, which was not favorable in emulsifying properties [2]. HSH is widely used in the food industries to mix foods and form protein-stabilized emulsions, where the mechanical forces with the hydrodynamic effects destroy the material on its entrance into the narrow gaps between the rotor and the stator. Processing MP-olive oil emulsion using HSH at 8,000 rpm increased the oxidative stability and shelf-life of the produced emulsion. Through investigation of the physicochemical properties of structured low-fat MP emulsions processed by different HSH speeds, it was concluded that processing speed of 14,500 rpm succeeded in making considerable modification of protein structures with improved emulsifying characteristics. Many protein-stabilized emulsions such as soybean protein isolate and whey protein were successfully processed using HSH [3].

High-Pressure Homogenization (HPH)

High-pressure homogenization (HPH) and high-pressure processing (HPP) are important applied technologies in food industries, where high pressure is used. However, HPH has its mechanism based on shear stress distribution instead of reducing volume with increasing pressure in HPP. The superior efficiency of HPH was recorded on the optimized extractability and stability of phytochemicals in various food matrices. In general, the use of HPH slightly improved or maintained the extractability of the phytochemicals with mild thermal processing [4]. HPH has wide range of applications in protein, milk, beverage, and emulsion preparations, where the material runs quickly in the cavity with definite structure and the mechanical forces applied simultaneously which have varying effects such as convection, cavitation, oscillation under high frequency and high-speed shearing. These significant mechanical forces act on the large emulsion droplets to be broken into smaller ones, making the HPH as the most convenient emulsifying technique to prepare protein stabilized fine emulsion. Processing emulsions containing 20% oil at 100 and 200 MPa showed superior oxidative stability as a result of utilization of higher amount of oil and protein surface load at the interface [5]. Oxidative stability is considered as one of the important quality parameters which could be determined by different applicable methods [6].

The high-pressure homogenizer (HPH) at pressure 20–100 MPa has the ability to process fluid matrices and the purpose to reduce particle size with increase stability of emulsions to avoid creaming and coalescence phenomena in the dairy, beverage, pharmaceutical, and cosmetic industries. HPH has the dual action of reducing microbial load with increasing the quality parameters, nutritional and sensory attributes of food products. HPH presented great benefits for both research and industrial fields and supported many vital EU projects. HPH had its first utilization for cell disruption of dense microbial cultures and recovery of intracellular bio-products which had promising results which activated scientific works for improving food quality and safety in mild temperatures [7]. In food processing, mild non-thermal processes are recommended to avoid the thermal processing contaminants emerging during thermal treatments of food stuff with high health risks [8-10].

Laboratory HPH Versus Pilot and Industrial HPH

Laboratory HPH provides research and development (R&D) scientists, with a wide range of experimentation options and capabilities for formulation of emulsions, dispersions, cell rupture, and liposomes. Whereas, Pilot and Industrial Homogenizer presents a complete facility to satisfy customer's requirements in reproducing the same product quality which has been verified and developed in the laboratory with increasingly higher levels of plant integration with complete automation, controls and data acquisition. To meet these requirements, the Pilot and Industrial Homogenizers are PLC controlled with a touchscreen industrial computer to meet the highest levels of customers' requirement in regulatory compliance and plant integration [1].

HPH has many objective applications in food science and technology as following [11]:

- Preservation and safety by reduction of microbial load and inactivation of enzymes. HPH is considered as a powerful alternative to thermal processes that, mostly, cause undesirable effects such as nonenzymatic browning (NEB), off-flavor or degradation of valuable components. HPH with pressures more than 100 MPa considerably achieve microbial load reduction and enzyme inactivation.
- Improvement of extraction and functional properties of proteins, fibrous materials and bioactive components with increased bioavailability and health effects.

Some Practical Applications of HSH and HPH

Toffee confectionery with nutritional ingredients like apple pulp, pectin, sugar, glucose syrup, skim milk powder, mango seed kernel fat (MSKF) as a butter replacer, was processed using normal blending compared with high-speed homogenization (HSH) as a novel technique in food processing at 1000 rpm for 10 min. HSH proved its high efficiency to produce toffee with superior quality parameters and consumers' acceptance [12]. HSH and HPH were used in processing tomato residue fibers to investigate their effects on the fiber structure after derosination and deproteinization. To investigate the efficiency of the tested methods, physicochemical parameters including expansibility, WHC, OHC, particle size distribution, SEM, TEM and XRD were examined. HSH succeeded in breaking raw fibers to microstructure particles of about 60 µm, while HPH succeeded in reforming fibers to constitute a novel network structure. Microfibrils released with nanostructure of elementary fibrils observed by TEM. Both HSH and HPH could alter the nanostructure of the fibers as indicated by XRD patterns with increasing the soluble fiber content by about 8% [13].

Optimized high-pressure homogenization (HPH) parameters for not-from-concentrate combined peach and carrot juices, based on a two-step comprehensive model using factor analysis and analytic hierarchy process methods were achieved. HPH with pressures over 200 MPa resulted in more amounts of the bioactive components (carotenoids and polyphenols). In general, HPH showed the potential to enhance the liberation of bioactive compounds in health-promoting combined juice [14]. The effect of HPH (100–200 MPa) on the quality and shelf life of apple juice was investigated with evaluation of microbiological, polyphenol oxidase (PPO), peroxidase (POD), polygalacturonase (PG) and pectinmethylesterase (PME) activity, particle size distribution (PSD), viscosity, turbidity, vit. C, individual polyphenols, total polyphenol concentration (TPC), antioxidant activity, and color of fresh and HPH-processed apple juice. The highest reduction in microorganisms (1.4 log) and oxidoreductase activity (~20%) was observed at 200 MPa, while hydrolases did not change significantly. HPH resulted in considerable disintegration of tissue with decreasing viscosity [15]. The highest extractability with an increase of 20–40% in the total phytosterol of almond beverage was achieved by using the Ultra-high-pressure homogenization (UHPH) treatments at 200 and 300 MPa [16].

UHPH produced milk with similar microbial, sensory and physicochemical characteristics to pasteurized (PA) and UHT milks. Results showed the potency of the UHPH technology to reduce the vitamin destruction, obtaining milk with higher nutritional properties than heat-treated milk. UHPH treatments performed at 300 MPa produced sterile milk after obtaining similar or better characteristics than UHT milk in color, particle size, viscosity, buffer capacity, ethanol stability, propensity to protein hydrolysis, and lower scores in sensory evaluation for cooked flavor [17,18]. Donor milk processed in human milk (HM) banks is a safe and valuable resource for preterm newborns that are hospitalized, but is reduced in major immunological components due to thermal inactivation. Regarding HPH processing, at a pressure of 250 MPa and inlet temperature of 20°C, the process showed good potential to reduce coliforms to undetectable levels [19]. HPH produced fat stabilization effect and safe drinking milk with a single operation and applying sub-pasteurization temperatures [20].

Conclusion

High-speed and high-pressure homogenization techniques were discussed with definitions and applications with cited results from review of literature in brief, based on the scientific experimental methods carried out using the homogenization technology with its different patterns ranging from simple to more sophisticated, starting from high-speed, high-pressure, and ultra-high-pressure homogenization accompanied with analytical methods investigating the yield, quality, and safety of extracts along with physicochemical quality parameters and bioactive components which supported the utilization of this powerful technology as a vital promising technology on both of the laboratory and industry scales to improve the extractability and maintaining the stability of phytochemicals with increasing functional properties for health benefits.

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