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Influence of hydrodynamic cavitation on the rheological properties and microstructure of formulated Greek-style yogurts

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ABSTRACT

With limited applications of acid whey generated during the manufacture of Greek yogurts, an alternate processing technology to sidestep the dewheying process was developed. Milk protein concentrate (MPC) and carbon dioxide-treated milk protein concentrate (TMPC) were used as sources of protein to fortify skim milk to 9% (wt/wt) protein for the manufacture of Greek-style yogurts (GSY). The GSY bases were inoculated and fermented with frozen direct vat set yogurt culture to a pH of 4.6. Owing to the difference in buffering of MPC and TMPC, GSY with TMPC and MPC exhibited different acidification kinetics, with GSY containing TMPC having a lower fermentation time. The GSY with TMPC had a titratable acidity of 1.45% lactic acid and was comparable to acidity of commercial Greek yogurt (CGY). Hydrodynamic cavitation at 4 different rotor speeds (0, 15, 30, and 60 Hz) as a postfermentation tool reduced the consistency coefficient (K) of GSY containing TMPC from 79.4 Pa·s^n at 0 Hz to 17.59 Pa·s^n at 60 Hz. Similarly for GSY containing MPC, K values decreased from 165.74 Pa·s^n at 0 Hz to 53.04 Pa·s^n at 60 Hz. The apparent viscosity (η_{100}) was 0.25 Pa·s for GSY containing TMPC and 0.66 Pa·s for GSY containing MPC at 60 Hz. The CGY had a η_{100} value of 0.74 Pa·s. Small amplitude rheological analysis performed on GSY indicated a loss of elastic modulus dependency on frequency caused by the breakdown of protein interactions with increasing cavitator rotor speeds. A steady decrease in hardness and adhesiveness values of GSY was observed with increasing cavitational intensities. Numbers of grains with a perimeter of >1 mm of cavitated GSY with TMPC and MPC were 35 and 13 grains/g of yogurt, respectively, and were lower than 293 grains/g observed in CGY. The water-holding capacity of GSY was higher than that observed for a commercial strained Greek yogurt. The ability to scale up the process of hydrodynamic cavitation industrially, and the ease of controlling events of cavitation that can influence final textural properties of the product, make this technology promising for large-scale industrial application. Overall, the current set of experiments employed in the manufacture of GSY, which included the use of TMPC as a protein source in conjunction with hydrodynamic cavitation, could help achieve comparable titratable acidity values, rheological properties, and microstructure to that of a commercial strained Greek yogurt.
Key words: hydrodynamic cavitation, carbon dioxide, Greek yogurt, milk protein concentrate

INTRODUCTION

The per capita consumption of yogurt in the United States increased from 1.13 kg in 1980 to 6.76 kg in 2013 (USDA, 2014). The increased per capita consumption since 2010 is partly believed to be from the increasing popularity of Greek yogurt (**GY**). A widely used process for the manufacture of GY involves the concentrating of fermented milk solids by dewheying. The process of dewheying in a modern industrial setup employs centrifugal separators like the Quark centrifuge. The acid whey generated from the dewheying process has limited applications owing to its high mineral and lactic acid load. To sidestep the dewheying process, fortifying milk base with high protein milk ingredients is a choice available to GY manufacturers. The GY manufactured by the fortification route is known as Greek-style yogurt (**GSY**) in the industry. The alternative make process does offer technological challenges in terms of increased fermentation time and altered rheological and microstructural properties. In a study by Desai et al. (2013), sour taste was found to be the dominant sensory defect, whereas increased graininess, higher viscosity, and cohesiveness and decreased melt-away dominated the microstructural and rheological defects in GSY.

In the present study, a 2-pronged strategy was applied to address acidity, rheological, and microstructural de-

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Table 1. Composition of CO_2-treated milk protein concentrate (TMPC) powder and milk protein concentrate powder (MPC)[1]

Powder	TS (%, wt/wt)	Protein (%, wt/wt)	Ash (%, wt/wt)	Calcium ($mg \cdot g^{-1}$)
TMPC	96.59	71.92	4.84	12.8
MPC	95.37	67.88	6.73	19.2

[1]Values are the means of data from triplicate analysis.

fects associated with the manufacture of GSY. Protein fortification by carbon dioxide (CO_2)-treated milk protein concentrate (**TMPC**) in GSY manufacture could potentially address higher acidity levels on account of its lower buffering when compared with control milk protein concentrate (**MPC**). The CO_2 treatment of milk before and during the process of UF and diafiltration employed in the manufacture of TMPC would partially demineralize milk, leading to the removal of micellar calcium phosphate (**MCP**) along with serum minerals. The use of hydrodynamic cavitation (**HC**) as a postfermentation tool was hypothesized to improve the rheological and microstructural properties of GSY. Hydrodynamic cavitation is a process having parallels to acoustic cavitation, with differences arising in the principle of cavity formation. Hydrodynamic cavitation uses velocity and pressure differentials generated by the flow of yogurt inside the cavitator toward the formation of cavities (Gogate and Bhosale, 2013). Pressure differential generates bubbles in low-pressure zones that collapse as they enter a high-pressure zone inside the cavitator. This collapse leads to the release of vast amounts of energy that could potentially influence protein interactions altering rheology and microstructure of GSY. Moreover, grains (that could potentially be a source of graininess) that are formed in GSY could serve as seed nuclei for the bubble to form, expand, and collapse, leading to a product with reduced grains that could lead to a product with superior mouthfeel (Earnshaw, 1998). To prove this hypothesis, the objective of this study was to determine the influence of TMPC as a protein source and hydrodynamic cavitation as a processing step on the chemical, rheological, and microstructural properties of GSY.

MATERIALS AND METHODS

MPC/TMPC Manufacture and Composition

The manufacturing procedure and composition (Table 1) of MPC and TMPC powders from pasteurized skim milk (72°C for 15 s) are described by Marella et al. (2015). Low heat nonfat dry milk was obtained from Associated Milk Producers (AMPI Inc., New Ulm, MN).

Preparation of Formulated Greek-Style Yogurts

Pasteurized skim milk was obtained from the Davis dairy plant of South Dakota State University. Nonfat dry milk and MPC or TMPC was added to skim milk at 50°C. The MPC or TMPC was added to contribute 6% (wt/wt) protein of the total 9% (wt/wt) protein in the GSY base formulation. The TS, protein, fat, lactose, and ash content of the GSY base along with the composition of a strained commercial GY purchased from a local grocery store is given in Table 2. The GSY base formulations mixed in a high-speed mixer were heated to 90°C for 10 min in a steam chest followed by cooling to 42°C. Frozen direct vat set yogurt culture (YC-X11) obtained from Chr. Hansen Inc. (Milwaukee, WI) was added at the rate of 0.02% (vol/vol). The pH of yogurt bases was measured every hour using a pH meter (CyberScan pH 110, Eutech Instruments, Singapore) to generate acidification profiles. Fermentation was arrested on reaching a pH of 4.6 by placing GSY in an ice bath followed by overnight storage in a cold room maintained at <5°C. All chemicals and reagents were purchased from Fisher Scientific (Pittsburgh, PA) unless otherwise indicated.

Hydrodynamic Cavitation

An 8-inch APV hydrodynamic cavitator (SPX Flow Technology, Pasteursvej, Silkeborg, Denmark) was used for the HC of yogurts. The cavitator had specially designed rotors with indentations that influenced the flow trajectory of yogurts inside the cavitator. A total of 66 indentations were placed equidistant from each other on the 200-mm (8-inch) rotor. The speed of rotor that determines the extent of cavitation was controlled with a variable frequency drive attached to a 10-HP motor. The gap between the rotor and stator was 3 mm. The GSY was fed into the cavitator through a positive displacement pump. Four different rotor speeds of 0, 872, 1,745, and 3,490 rpm corresponding to frequencies of 0, 15, 30, and 60 Hz were used to generate cavitation during yogurt flow through the device. For cavitation at 0 Hz, yogurt was passed through the cavitator with an inactivated rotor. Cavitation was carried out at 8