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Physical properties of a frozen yogurt fortified with a nano-emulsion containing purple rice bran oil

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ABSTRACT

The objectives of this study were to develop and evaluate a frozen yogurt (FY) fortified with a nano-emulsion containing purple rice bran oil (NPRBO). NPRBO with fat droplets size range of 150–300 nm was mixed with the FY ingredients to produce a frozen yogurt containing NPRBO (FYNRO). Plain frozen yogurt (PFY), frozen yogurt with sodium caseinate (FYSC) and FYNRO had similar hardness. The apparent viscosity of the FYNRO mix was similar to the PFY mix with values of 0.19 and 0.17 Pa·s, respectively. The FYNRO micrograph showed a more compact and dense structure compared to FYSC and PFY. This study demonstrated that FY could be fortified with NPRBO.

1. Introduction

Frozen yogurt (FY) is a dessert characterized by having the textural properties of ice cream combined with the acidic taste of yogurt (Marshall, Goff, & Hartel, 2003). In general, its processing consists of mixing natural stirred yogurt with stabilizers/emulsifiers and sugar, then freezing the mix in a conventional ice cream freezer (Tamime & Robinson, 2007). FY popularity has increased and continues to grow. A FY with live cultures attractiveness to consumers includes providing a low fat replacement for ice cream and probiotic benefits if the live cultures are present in the yogurt in counts of $>10^6$ CFU/g (Lopez, Medina, & Jordano, 1998).

Rice bran oil (RBO) has been used for centuries in Asian countries due to its health benefits, and its popularity is increasing in the US (Orthoefer, 2005). RBO is balanced in saturated, monounsaturated, and polyunsaturated fatty acids (AHA, 2012). RBO, which is also rich in bioactive compounds such as tocopherols, tocotrienols and gamma oryzanol, has been linked with health improvement by lowering serum cholesterol and having antioxidant functionality in humans (Kerckhoffs, Brouns, Hornstra, & Mensink, 2002; Most, Tulley, Morales, & Lefevre, 2005; Soheir, 2010). Recently, a new rice variety harvested in the US called "purple rice" is gaining more attention due to the higher concentrations of natural antioxidants including α-tocopherol, γ-tocotrienol, and γ-oryzanol present in the oil extracted from purple rice bran (Jang & Xu, 2009). Purple rice bran oil (PRBO) is an excellent source of natural antioxidants and adding nano-emulsions of purple rice bran-oil (NPRBO) to products including frozen yogurts may improve the nutritional profile of the products by substantially increasing their natural antioxidant content (commercially available frozen yogurts contain about 0.047 mmol/100 g) (Halvorsen et al., 2006). The food industry has interest in nano-emulsions due to their benefits including functional performance in food processing; for example, they can be thoroughly mixed with foods such as yogurt (Anton, Gayet, Benoit, & Saulnier, 2007; Hu, Johnston, & Williams III, 2004; Jafari, He, & Bhandari, 2006; Tadros, Izquierdo, Esquena, & Solans, 2004). The addition of oil into a dairy product such as FY or ice cream can affect its physicochemical characteristics such as oxidation, melting point, texture,

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pH, and viability of lactic cultures. Therefore, the objectives of this study were to produce a nano-emulsion containing PRBO, and to determine the effect of addition of the nano-emulsion on the physicochemical characteristics of FY.

2. Materials and methods

2.1. Production of frozen yogurt fortified with nano-emulsion containing purple rice bran oil (NPRBO)

A nano-emulsion containing PRBO (NPRBO) with a droplet size range of 150–300 nm was prepared using a mixture of PRBO (10 g/100 g) extracted from purple rice bran (*Blanca Isabel* variety, Rush Rice Products, L.L.C, Louisiana, USA), sodium caseinate (5 g/100 g) provided by American Casein Company (Burlington, NJ, USA), and water (85 g/100 g). The mixture was sonicated for 5 min using an ultrasonic processor (500 Watt Model CPX 500, Cole–Parmer Instrument Co. Vernon Hill, IL, USA) fitted with a 22 mm tip diameter at 82% amplitude with 2 × 1 pulses (with 1 s delay between pulses) to produce a micro-emulsion according to the method of Wan, Bechtel, and Sathivel (2011). Then the micro-emulsion was subjected to ultra-shearing at 26,000 rpm for 10 min using Ultra Shear M Homogenizer (OMNI International, USA) to obtain a nano-emulsion. Samples were held in an ice bath at 4 °C during sonication and ultra-shearing to prevent lipid oxidation (Chemat et al., 2004). Particle size distribution and mean droplet diameter of the NPRBO was measured by a Dynamic Light Scattering (DLS) device (Zetasizer Nano-ZS, Malvern Instruments Ltd, Worcestershire, UK) according to Qian and McClements (2011).

FY containing a nano-emulsion of purple rice bran oil (FYNRO) was compared to control FY containing emulsion materials without purple rice bran oil (FYSC) and plain FY (PFY). The yogurts were produced by direct inoculation following the formulations presented in Table 1. All equipment, implements, and containers were sanitized with a 200 ppm sodium hypochlorite (Eurochem International Corporation, Atlanta, GA, USA) solution before use. Pasteurized whole milk (Great Value®, Bentonville, AR, USA) was obtained from a local store. Grade A non-fat dry milk (NFDM) was obtained from Dairy America, Fresno, CA, USA. Extra fine granulated sugar was obtained from Domino Foods, Inc., Yonkers, NY, USA. Maltodextrin (M040) (0.15 g/100 g protein, 96 g/100 g carbohydrates, 0 g/100 g fat) and PGX stabilizer (83.6 g/100 g carbohydrate, 5.72 g/100 g total ash, 2.04 g/100 g protein, and <0.1 g/100 g fat) having 84.74 g/100 g dietary fiber were obtained from Danisco, Inc., Madison, WI, USA. Starter cultures of *Lactobacillus bulgaricus* (LB) and *Streptococcus thermophilus* (ST) were obtained from Chr. Hansen, Milwaukee, WI, USA.

Table 1
Frozen yogurt formulations.

Ingredient	FYNRO[a,e]	FYSC[b] (control)	PFY[c] (control)
Whole milk (kg)	7.56	7.56	7.56
NPRBO[d] (g)	620.00	–	–
Sodium caseinate solution (g)	–	620.00	–
Sucrose (g)	1362.00	1362.00	1362.00
M040 Maltodextrin (g)	363.20	363.20	363.20
Stabilizer (g)	20.00	20.00	20.00
NFDM (g)	399.52	399.52	399.52
Lactobacillus bulgaricus (mL)	2.00	2.00	2.00
Streptococcus thermophilus (mL)	2.00	2.00	2.00

[a] FYNRO = Frozen yogurt containing nano-emulsion of purple rice bran oil.
[b] FYSC = Frozen yogurt containing emulsion material without purple rice bran oil.
[c] PFY = Plain frozen yogurt.
[d] NPRBO = Nano-emulsion containing purple rice bran oil.
[e] Both the FYNRO emulsion and the FYSC solution contain 5 g/100 g sodium caseinate.

Yogurt mixes were prepared as described in Table 1. Whole milk was placed in 8 L stainless steel containers. Dry ingredients such as NFDM, sucrose, maltodextrin, and stabilizer were added to milk while-constantly manually stirring the mixture. NPRBO and sodium caseinate solution were added in order to form FYNRO and FYSC mixes, respectively. NPRBO was added at a ratio of 310 g of NPRBO to each 3.78 kg of the base yogurt mix to produce the FYNRO mix and to provide approximately 7% of the RDI (recommended daily intake) of vitamin E in every cup (120 g portion size) of FYNRO. All mixes were heated to 60 °C for 1 min to increase the incorporation of the ingredients before homogenization. The yogurt mixes were then homogenized in a two stage homogenizer (Model 300 DJF 4 2PS, Gaulin Mfg. Co., Wilmington, MA, USA) at 13.79 MPa for 15 s and then pasteurized at 72.78 ± 1 °C for 30 min. After pasteurization, mixes were rapidly cooled in a water bath to 40.55 ± 1 °C before inoculation of LB and ST at a 1 mL/3.78 kg milk usage rate of each. Following inoculation, samples were transferred to an incubator (Model 815 Thermo Scientific, Two Rivers, WI, USA) and maintained at 43 ± 1 °C and constantly measured the pH of the mixtures until the pH dropped to 4.6. It took approximately 4 h to reach the final pH. Yogurt mixes were quickly cooled in an ice bath and stored overnight at 4 °C in a cooler. Yogurts were manually stirred prior to freezing using a stainless steel perforated milk stirrer (Nelson Jameson, Marshfield, WI, USA) in order to break the gels formed during incubation. Stirred yogurt mixes with a semi-liquid consistency were frozen in a batch freezing machine (Taylor 430-12, Taylor Co. Rockton, IL, USA) in 7.56 kg batches. The frozen yogurt batches were packed and tightly sealed in 1.86 kg containers (Reynolds Plastics, Richmond, VA, USA). Containers were labeled and then placed in a freezer at −22 °C for hardening and storage.

2.2. Rheological properties of yogurt mixes before freezing

Viscosity, flow behavior and viscoelastic properties of yogurt mixes at 5 °C (Isik, Boyacioglu, Capanoglu, & Nilufer Erdil, 2011) were determined using an AR 2000 ex Rheometer and Universal Analysis software (TA Instrument, New Castle, DE, USA) with fitted plate geometry using 40 mm diameter plates. A 200 μm gap was used to determine the flow behavior of the samples (2–3 g). The shear stress was measured at shear rates from 0.00185 to 116 s^{-1}, which are normally used for the measurement of the rheological properties of power law fluids (Singh & Heldman, 2008). The flow behavior was modeled using the Power Law model (Eq. (1)) since samples did not present a yield stress:

$$\sigma = K\,(\dot{\gamma})^{\eta} \tag{1}$$

Where σ is shear stress (Pa), K is the consistency index (Pa·s^{η}), $\dot{\gamma}$ is shear rate (s^{-1}) and η is the flow behavior index. Logarithms were taken for σ and $\dot{\gamma}$ and a plot of log σ versus log $\dot{\gamma}$ was constructed. The resulting line yielded the magnitude of log K (intercept) and η (slope). The viscosity at a shear rate of 116 s^{-1} was reported. Frequency sweeps were conducted at angular frequencies between 0.1 and 15 rad s^{-1}, with a 200 μm gap. The elastic modulus (G') and the viscous modulus (G'') of the samples were obtained using the Universal Analysis software.

2.3. Texture analysis of frozen yogurts

Texture (as hardness) of the FYNRO, FYSC and PFY was determined according to Soukoulis and Tzia (2008). For determination of hardness, samples were packaged in cups with 65 mm diameter and 30 mm height. Samples were then transferred from −22 °C to −15 °C and held for 24 h before analysis. A texture analyzer