Research Article

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Effect of cocoa butter replacement with a β-glucan-rich hydrocolloid (C-trim30) on the rheological and tribological properties of chocolates[†]

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Abstract

BACKGROUND: The food industry has been facing the challenge of developing low-fat and low-calorie food products due to rising health awareness of consumers. To meet this consumer demand, an oat β-glucan-rich hydrocolloid (C-trim30) was evaluated as a cocoa butter substitute in chocolates. The effects of C-trim30 on the rheological, tribological, and textural properties of chocolates were investigated.

RESULTS: The viscosity of molten chocolates increased with increasing levels of C-trim30. Flow behaviors analyzed using the Casson model showed that the Casson viscosity and yield stress increased with increasing concentration of C-trim30 in the chocolate. Tribological tests on a ball-on-flat tribometer showed a reduction in boundary coefficients of friction, with increasing C-trim30. In addition, hardness of chocolates showed that replacement of cocoa butter with C-trim30 produced chocolates with softer texture.

CONCLUSIONS: The cocoa butter replacement with C-trim30 up to 10% produced soft chocolates with improved boundary lubrication properties. Also, the chocolate prepared by replacing the cocoa butter with C-trim30 resulted in a product with a lower caloric value and increased health benefits from the oat β-glucan.

Keywords: chocolate; β-glucan; hydrocolloid; rheology; tribology

INTRODUCTION

It is widely recognized that a diet high in fat results in a number of undesirable health problems to humans, including obesity and heart-related disease. It is therefore recommended that people choose foods with low fat as prescribed in the new food guide pyramid published by the United States Department of Agriculture.[1] With this nutritional trend, food products low in fats and calories are of great interest in the current market.[2] According to National Health and Nutrition Examination Surveys,[3] the percentage of energy intake from fat decreased from 37 to 33% for adults aged 20–74 years between 1971 and 2000. This is still higher than the fat intake recommended by the World Health Organization, which suggests that the total fat intake should be less than 30% of the total calories, and saturated fat intake should not be more than 10% of total calories. Therefore, continuing efforts to reduce fat intake will be required to prevent heart-related diseases and improve the health of people.

C-trims, with the 'C' for calories, are β-glucan-rich hydrocolloids that are produced by steam jet-cooking and fractionating oat bran concentrates.[4] These natural materials contain high concentrations of β-glucan, ranging from 15 g to over 50 g kg^{-1}, that provide health-enhancing benefits. In addition, C-trims can be used as viscous thickeners to control the texture and rheology of foods.[5] C-trims have been used in the production of low-calorie foods with elevated levels of β-glucan, including cookies, cakes, fried foods, and bread.[5–8]

Chocolate, a common confectionery derived from cacao beans, is a mixture of many ingredients including cocoa butter, cocoa liquor, and sweeteners. Cocoa butter, which is the continuous phase in chocolates, is responsible for providing chocolate with such important qualities as unique smooth feeling, glossy appearance, and snap. However, relatively high cost and vulnerability to climatic and political changes have necessitated replacing parts of cocoa butter in chocolates. There is also a need to

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[†] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to exclusion of others that may also be suitable.

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reduce the amount of cocoa butter in order to produce low-calorie chocolates. In the past, a mixture of vegetable oils, such as palm and palm kernel oils, have been used to replace cocoa butter.[9] In addition, there have been reports of a few other ingredients such as shea butter, lauric fat, and kokum fat that have also been used as cocoa butter replacement.[10,11]

This paper discusses the results of an investigation into the use of C-trim30 as a replacement for cocoa butter in chocolates. The effects of C-trim30 containing β-glucan (32 g kg^{-1}) on the rheological, tribological, and textural properties of chocolates are discussed.

EXPERIMENTAL

Materials

All ingredients, except C-trim30, used in the preparation of the chocolate formulations were obtained from commercial sources and used as supplied. These were: cocoa liquor (ADM, Milwaukee, WI, USA), liquid sucrose (Chicago Sweeteners, IL, USA), flaked cocoa butter (M&M Mars, Hackettstown, NJ, USA), lecithin (Thermolec-57, ADM, Decatur, IL, USA), and vanillin (DryVan 42–150, CK Products, Ft Wayne, IN, USA).

C-trim30 was produced by steam jet-cooking and fractionating oat bran concentrates as follows.[4,5] Oat bran concentrate (100 g) obtained from Quaker Oats Co. (Chicago, IL, USA) was suspended in water (1900 mL) by using a colloid mill (4000 rpm, 60 min, Polythron PT6000 with Aggregat PT-DA-6060/2WEC, Brinkmann Instruments Inc., Westbury, NY) and then passed through a 400 mesh sieve. After the sieve filtrate was centrifuged at 1590 × *g*, the supernatant was mixed with the fragments retained on the sieve. This reconstituted slurry was steam jet-cooked (65 psi, 140 °C, 1.2 L min^{-1} flow rate) and passed through a 200 mesh sieve. The separated liquid was centrifuged at 1590 × *g* for 15 min and the supernatant was drum-dried, yielding a composition of β-glucan, 32.0%; protein, 14.4%; starch, 45.3%; total lipid, 2.3%; and ash, 4.8%, on a dry basis.

Cocoa butter was replaced with the C-trim30 at 5, 10, and 15%, by weight.

Preparation of chocolate formula

Batches of the chocolate formulations, 100 g each, were prepared as follows: 15.0 g flaked cocoa butter, 45.0 g liquid sucrose, 39.6 g cocoa liquor, 0.4 g lecithin, and 0.003 g vanillin were mixed until a smooth consistency was obtained. The mixture was placed in a laboratory digital tempering pot (American Chocolate Mould Company, Bohemia, NY, USA) that consisted of a heating jacket with a rotating impeller. The chocolates were heated to 45 °C until they had a smooth glossy finish, cooled to 28 °C for 1 h, reheated to 33 °C and held for plating. Chocolates prepared without C-trim30 were used as control.

Rheological measurements

Flow properties of chocolates were investigated on a AR2000 rheometer (TA Instruments, New Castle, DE, USA). Tests were conducted at 40 °C using parallel plate geometry, with 40 mm diameter. Samples were pre-sheared at 5 s^{-1} for 5 min and their steady shear viscosities measured as a function of shear rates (1–100 s^{-1}). The rheological data was analyzed using the Casson model, which is given as follows:

$$\sqrt{\sigma} = \sqrt{a} + \sqrt{b}\sqrt{\dot{\gamma}} \quad (1)$$

where σ is shear stress, $\dot{\gamma}$ is shear rate, *a* is Casson yield stress, and *b* is Casson viscosity.

Tribological measurements

Tribological tests were conducted on a ball-on-flat tribometer constructed by combining the SP-2000 slip/peel tester (Imass, Inc., Accord, MA, USA), with Model 9793A test weight sled (Altek Co., Torrington, CT, USA). The schematics of the ball-on-flat tribometer are shown in Fig. 1. Stainless steel sheets with thin-film of chocolate were prepared for tribological measurements according to the method of Biresaw.[12] After tempering, the molten chocolates were applied to a stainless steel flat sheet (McMaster Carr Supply Co., Elmhurst, IL, USA) by using a doctor blade (JR Paul N. Gardner Co. Inc., FL, USA), and then allowed to dry at 25 °C for 2 h. Four flat sheets per chocolate sample were prepared. The flat stainless steel coated with the dry thin-film of chocolate was fastened on to the platen of the tribometer. Then, a weight sled with three clean balls on its bottom was placed on the flat sheet and connected to a 2.0 kg load cell with a steel wire. The platen was then moved away from the load cell at a speed of 2.54 mm s^{-1} for 24 s while the weight sled was stationary, consequently producing the friction between the weight sled balls and the chocolate-coated flat stainless steel. The friction force was automatically recorded by the microprocessor on the instrument at a maximum rate of 3906 samples s^{-1}.

Textural measurements

Penetration probing tests were conducted to investigate the hardness of chocolates using a texture analyzer (Texture Technologies Co., Scarsdale, NY, USA). Molded chocolates (4 cm × 0.5 cm × 5 cm) were penetrated by a flat stainless steel probe, 5 mm diameter, at a speed of 1 mm s^{-1}. Maximum peak force was obtained from the force *vs* time data. Five measurements were conducted on each sample, and three samples were tested from each chocolate formulation.

Statistical analysis

The SAS system (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis of experimental data. The significance of

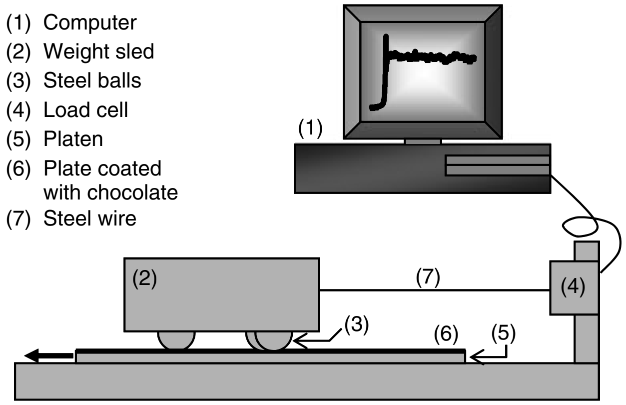

Figure 1. Schematic diagram of a ball-on-flat tribometer.

difference among samples was examined from analysis of variance (ANOVA), followed by Duncan's multiple range test for mean comparisons.

RESULTS AND DISCUSSION

Rheological characterization

The effect of C-trim30 on the flow behaviors of chocolates was investigated using steady shear measurements. For all samples, the slopes of the shear stress versus shear rate curves were not constant (Fig. 2a), indicating that the chocolates behaved as non-Newtonian fluids. The ratio of shear stress to shear rate (that is, viscosity) decreased with increasing shear rate for all the samples (Fig. 2b). This indicated that the chocolates became shear-thinning because of the presence of solids, as has been observed by others.[10]

The flow properties of the molten chocolate samples were characterized using the Casson model. The model has often been successfully applied to analyze the rheological properties of chocolates.[13,14] According to the Casson model, plots of the square root of shear rate *vs* square root of shear stress will result in a straight line. From the slope and intercept of such a plot, the Casson viscosity, *a*, and Casson yield stress, *b*, respectively, are obtained. The Casson yield stress is the stress required to make the chocolate begin to flow. It represents the low shear-rate properties of chocolate and is affected by particle–particle interaction, the amount and specific surface area of the particles, emulsifiers, and moisture.[15] A major contribution to the Casson yield stress is the absolute distance between solid particles in the chocolate.[16] The Casson yield stress increased with increasing concentrations of C-trim30 in the chocolates (Table 1). The increased Casson yield stress can be attributed to increased interactions between solid particles due to replacement of cocoa butter by C-trim30. The Cassen yield numbers from this work were within the range reported for dark chocolate, i.e. 4–32 Pa.[17]

Table 1. Effect of replacement of cocoa butter with C-trim30 on the Casson parameters of chocolates (values with the same letter in the same column are not significantly different at $P < 0.05$)

	Casson yield stress (Pa)	Casson viscosity (Pa s)	R^2
Control	5.742b	0.537c	1.00
5% C-trim30	6.787ab	0.678bc	0.99
10% C-trim30	6.795ab	0.970b	0.99
15% C-trim30	8.168a	2.046a	1.00

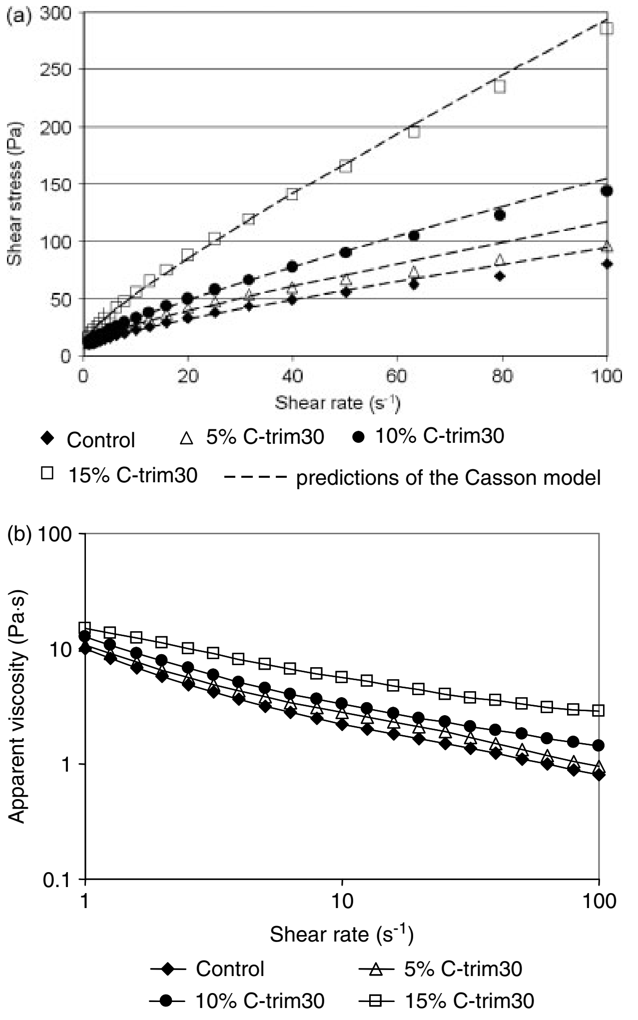

Figure 2. Effect of cocoa butter replacement with C-trim30 on the flow behaviors of chocolates at 40 °C: (a) shear stress *vs* shear rate; (b) viscosity *vs* shear rate.

The Casson viscosity is a direct measure of high shear-rate properties. When C-trim30 was used to make chocolates, the Casson viscosity increased exponentially, ranging from 0.54 to 2.05 (Pa s). Since chocolate viscosity depends on several factors, including the fat content and the particle size distribution,[18] replacement of cocoa butter with C-trim30 appeared to increase the chocolate viscosity. Increases in the Casson yield stress and viscosity of chocolate due to reduction of fat content has also been reported by others.[19,20]

Tribological properties

Plots of friction force *vs* time measured on a flat sheet metal coated with chocolate samples using a ball-on-flat tribometer are shown in Fig. 3a. This thin-film tribological method was selected to mimic the motion of the tongue for the mouth-feel of chocolates. The friction force profiles for all samples were similar, exhibiting a sharp initial rise followed by a rapid decrease to a steady-state value (Fig. 3a). This sharp initial rise of the friction force corresponds to the static friction force. The force is necessary to initiate the motion of the platen, i.e. to overcome the friction force holding it in place. Once the platen is in motion, the friction force corresponds to the kinetic friction force, which in general is slightly lower than the static friction and independent of measurement time.[12] Incorporation of C-trim30 into the chocolate formulation resulted in changes in the steady-state friction force. The kinetic friction force decreased with increasing concentrations of C-trim30 up to 10% (Fig. 3b). Unfortunately, chocolate with 15% C-trim30 was too viscous to apply uniformly on the flat sheet metal, and its tribological properties were not investigated.

From the friction force data in Fig. 3, the coefficient of friction (COF) of the chocolate formulations were calculated as follows:

$$\mathrm{COF} = \mathrm{F}/\mathrm{N} \qquad (2)$$

where F is the average steady-state kinetic friction from Fig. 3; and N is the normal load or the weight of the sled, which in this work is 1.5 kg.

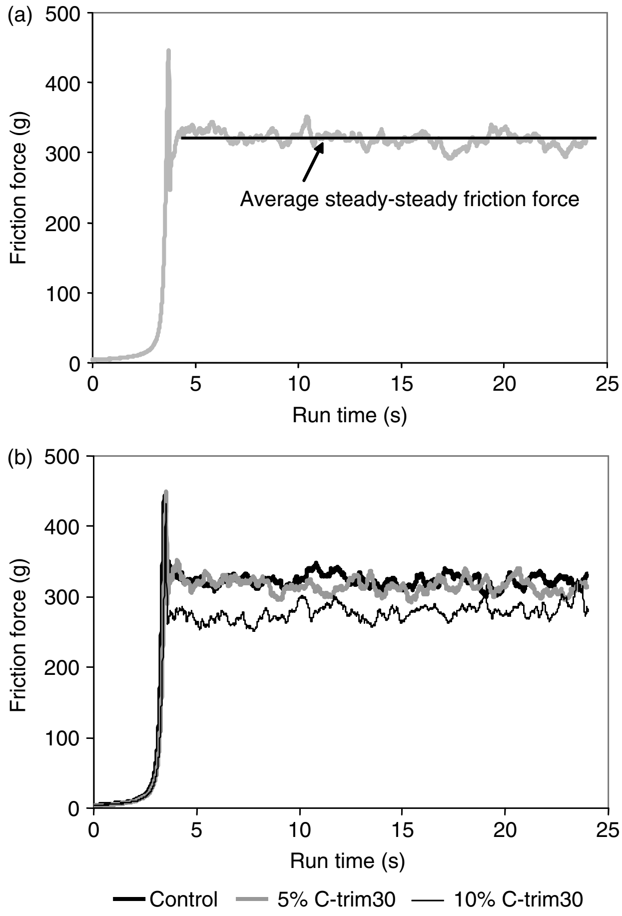

Figure 3. (a) Friction force *vs* run time of chocolates on a ball-on-flat tester; (b) Effect of cocoa butter replacement with C-trim30 on the friction force of chocolates on a ball-on-flat tester.

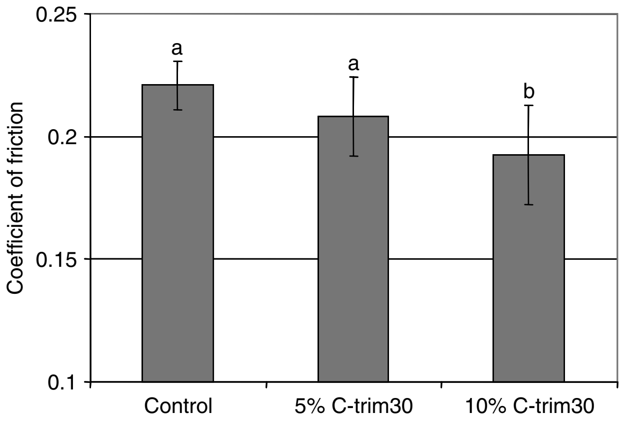

Figure 4. Coefficient of friction of chocolates containing different concentrations of C-trim30 (0, 5, 10%) (Different letters on the bars indicate a significant difference at $P < 0.05$).

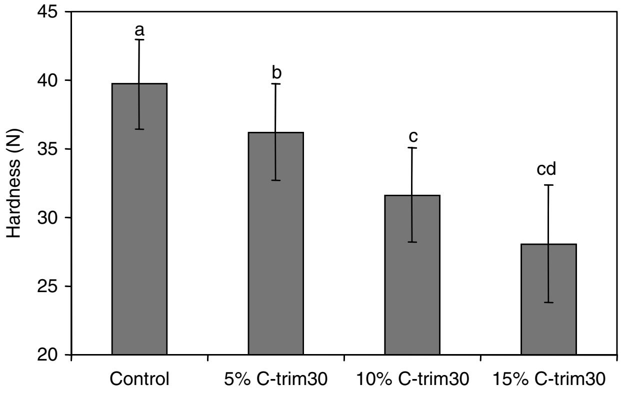

Figure 5. Changes in the hardness of the chocolates prepared with different concentrations of C-trim30 (0–15%) (The same letters on the bars indicate no significant difference at $P < 0.05$).

The effect of C-trim30 concentration on the COF of chocolate formulations is summarized in Fig. 4. When 5% of cocoa butter was replaced with C-trim30, the COF decreased slightly relative to the control. Further decrease of COF was observed by the chocolate with 10% of C-trim30. These observations indicate that the use of C-trim30 up to 10% lowers COF and improves the boundary lubrication properties of chocolates. The lower COF might imply a smoother mouth feel of the chocolates with added C-trim30.

Textural properties

The textural properties of chocolates containing C-trim30 were investigated using a penetration probing test. The maximum peak force that the chocolate samples withstood before fracture is shown in Fig. 5. This maximum peak force is a measure of the hardness of the chocolates.[19,21] It has been reported that chocolate hardness depends on the concentration of crystallized lipid phase (cocoa butter, milk fat) as well as the solid dispersed phase (sugar crystals, milk solids, cocoa solids).[19] The control had a hardness of around 40 N, which decreased with increasing concentration of C-trim30 (Fig. 5). It is well known that well-tempered chocolates have good snap, gloss, and stability against temperature and physical damage.[16] This is attributed to the β-form of cocoa butter, which has six polymorphic forms. Therefore, the replacement of cocoa butter with C-trim30 might have influenced the tempering process, which could have resulted in softening of the texture of the chocolates. The softer texture of the chocolates containing C-trim30 also correlated well with the lower COF obtained in the tribological studies (Fig. 4).

CONCLUSIONS

Cocoa butter in chocolates was replaced by a β-glucan-rich hydrocolloid (C-trim30) and its effects on the rheological, tribological, and textural properties were studied. Replacement of cocoa butter with C-trim30 increased the viscosity of molten chocolate. Also, the use of C-trim30 up to 10% produced softer chocolates with lower coefficient of friction. Since the viscosity of chocolate dramatically increased with the addition of C-trim30, only a limited quantity could be used to replace the cocoa butter.

The use of C-trim30 as a replacement for cocoa butter presents the opportunity to formulate ‘healthy’ chocolates with reduced calories from fat and also with soluble dietary fibers. Sensory evaluation would, however, be necessary to investigate the consumer preferences on these low-calorie chocolates containing C-trim30.

REFERENCES

1 Goldie MP, The new food pyramid. *Int J Dent Hyg* **3**:155–158 (2005).
2 Sloan AE, Top 10 global food trends. *Food Technol* **59**:20–32 (2005).

3 Wright JD, Kennedy-Stephenson J, Wang CY, McDowell MA and Johnson CL, Trends in intake of energy and macronutrients – United States, 1971–2000. *Jama-J Am Med Assoc* **291**:1193–1194 (2004).

4 Inglett GE, Low-carbohydrate digestible hydrocolloidal fiber compositions. USA Patent 20060134308 (2006).

5 Lee S, Warner K and Inglett GE, Rheological properties and baking performance of new oat beta-glucan-rich hydrocolloids. *J Agric Food Chem* **53**:9805–9809 (2005).

6 Lee S, Kinney MP and Inglett GE, Rheological characterization of a new oat hydrocolloid and its application in cake baking. *Cereal Chem* **82**:717–720 (2005).

7 Lee S and Inglett GE, Effect of an oat beta-glucan-rich hydrocolloid (C-trim30) on the rheology and oil uptake of frying batters. *J Food Sci* **72**:E222–E226 (2007).

8 Mohamed A, Rayas-Duarte P and Xu J, Hard Red Spring wheat/C-TRIM 20 bread: Formulation, processing and texture analysis. *Food Chem* **107**:516–524 (2008).

9 Lipp M and Anklam E, Review of cocoa butter and alternative fats for use in chocolate – Part A. Compositional data. *Food Chem* **62**:73–97 (1998).

10 Maheshwari B and Reddy SY, Application of kokum (*Garcinia indica*) fat as cocoa butter improver in chocolate. *J Sci Food Agr* **85**:135–140 (2005).

11 Quevedo R, Brown C, Bouchon P and Aguilera JM, Surface roughness during storage of chocolate: Fractal analysis and possible mechanisms. *J Am Oil Chem Soc* **82**:457–462 (2005).

12 Biresaw G, Biobased dry-film metalworking lubricants. *J Syn Lubr* **21**:43–57 (2004).

13 Briggs JL and Wang T, Influence of shearing and time on the rheological properties of milk chocolate during tempering. *J Am Oil Chem Soc* **81**:117–121 (2004).

14 Keogh MK, Murray CA and O'Kennedy BT, Effects of selected properties of ultrafiltered spray-dried milk powders on some properties of chocolate. *Int Dairy J* **13**:719–726 (2003).

15 Servais C, Ranc H and Roberts ID, Determination of chocolate viscosity. *J Texture Stud* **34**:467–497 (2004).

16 Afoakwa EO, Paterson A and Fowler M, Factors influencing rheological and textural qualities in chocolate – a review. *Trends Food Sci Tech* **18**:290–298 (2007).

17 Aeschlimann JM and Beckett ST, International inter-laboratory trials to determine the factors affecting the measurement of chocolate viscosity. *J Texture Stud* **31**:541–576 (2000).

18 Servais C, Jones R and Roberts I, The influence of particle size distribution on the processing of food. *J Food Eng* **51**:201–208 (2002).

19 Liang B and Hartel RW, Effects of milk powders in milk chocolate. *J Dairy Sci* **87**:20–31 (2004).

20 Nebesny E, Zyzelewicz D, Motyl I and Libudzisz Z, Properties of sucrose-free chocolates enriched with viable lactic acid bacteria. *Eur Food Res Technol* **220**:358–362 (2005).

21 Ali A, Selamat J, Man YBC and Suria AM, Effect of storage temperature on texture, polymorphic structure, bloom formation and sensory attributes of filled dark chocolate. *Food Chem* **72**:491–497 (2001).