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Effects of Replacing Skim Milk Powder with Soy Flour and Ball Mill Refining Time on Particle Size and Rheological Properties of Compound Chocolate

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ABSTRACT

Rheological properties of chocolate are important in manufacturing process for obtaining high-quality products with well-defined texture and are directly influenced by composition and their refining time. Soy protein benefits from nutritional and functional properties to be used in different foods. Effects of different replacement levels of skim milk powder by soy flour, (from 0 to 100%) and ball mill refining time (105 and 135 minutes) on particle size and rheological properties of compound chocolate were investigated. Considering four rheological models, it was found that compound chocolate behaved as a Casson fluid .Overall, the results indicated that Casson plastic viscosity values ranged between 1.36 and 5.47 (Pa s) and replacing skim milk powder with soy flour led to a significant (P< 0.05) increase in Casson plastic viscosity in either of the refining time treatments. Casson plastic viscosity and apparent viscosity also increased for all the replacement levels with increase in refining time from 105 to 135 minutes. Values of Casson yield ranged from 11.23 to 38.88 (Pa). By replacing soy flour, Casson yield value increased significantly (P<0.05). Casson yield value also increased with increase in refining time in samples containing only skim milk powder, but it decreased in samples containing soy flour.

Keywords: Ball mill refining time, Compound chocolate, Particle size, Rheological properties, Soy flour.

INTRODUCTION

Compound chocolate is formulated, combining cocoa and sugar with vegetable fat, usually tropical fats or hydrogenated fats, as a replacement for cocoa butter. In many countries this may not legally be called chocolate. Cacao Butter Substitute (CBS) is a fat that provides some of the desired physical characteristics to a confection, independent of its non-similar chemical composition to that of cocoa butter (Lawler and Dimick 1998). The use of Cocoa Butter Substitutes (CBS) has recently become more common as the cost of cacao butter has been on the increase (Lipp and Anklam, 1998).

A determination of rheological properties of chocolate is important in manufacturing process for obtaining high-quality products of well-defined textures (Servais *et al.,* 2004). Such factors as fat content, Particle Size Distribution (PSD), moisture content, emulsifiers, conching time, and temperature affect rheological properties and the production cost (Tscheuschner and Wunsche,

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1979). Chevalley, (1975) reported that, viscosity of suspensions can be greatly modified by changing PSD while maintaining the same solid content.

Flow of molten chocolate can be described by a number of mathematical models including Bingham, Herschel–Bulkley, Power law and Casson models (Chevalley, 1999; Servais *et al.*, 2004; Abbasi and Farzanmehr, 2009).

The most traditional methods of chocolate-making are based on the mixing of ingredients, grinding by roll refiners (refining phase), conching, and tempering. Many minor chocolate manufacturers, in particular, require a compact chocolate-making plant that is smaller than the traditional roll refiner/conching system. Many kinds of these plants have been developed. Perhaps the most common ones are based on re-circulation through a ball mill, which employs the relative motion of loose elements (balls) to generate a grinding action (Beckett, 2008). Alamprese *et al.* (2007) studied the optimization of processing parameters of a ball mill refiner for chocolate.

Soy protein benefits from nutritional and as well from functional properties to be used in different foods. Functionality of soy proteins is related to their surface-active properties, gelling capacity, and to fat and water absorption property (Orthoefer, 1978). Soy flour bears a great potential in being replaced for milk powder in chocolate due to its high protein and isoflavones content (Akinwale, 2000). Riedel (1990) reported that refined soy flour, as a natural antioxidant, is added to confectionery to prevent spoilage.Until the development of textured soybean proteins in the early 1970s, the major reason for adding soy proteins to foods in the U.S. was for their functional properties rather than as a source of dietary protein (Wolf and Cowan, 1975).

Soy flour contains 40% protein on a dry basis and contains a relatively high level of lysine, being able to provide all the essential amino acids required for growing children. Functional foods have become a means of delivering beneficial components in the human diet. As the functional food market continues to grow, surveys indicate consumers wish soy to be incorporated into food (Ohr, 2000). Pandey and Singh (2011) developed reduced sugar soy containing compound chocolate and studied its storage possibility. Zaric *et al.* (2011) investigated the effects of soya milk on nutritive, antioxidative, as well as rheological properties of chocolate produced in a ball mill.

Studies have been carried out to investigate the effects of composition and PSD on the rheological properties of different chocolates, such as the effects of particle size distribution as well as composition on the rheological properties of dark chocolate (Afoakwa *et al.,* 2008), impact of particle size distribution on rheological and textural properties of chocolate models of reduced fat content (Do *et al.,* 2007), effects of some bulk sweeteners on rheological properties of chocolate (Sokman and Gunes, 2006), rheology of different formulations of milk chocolates (Karnjanolarn and Mccarthy, 2006) and, too, the rheological properties of milk chocolates containing fibers as fillers (Bolenz *et al.,* 2006). Peymanpour *et al.* (2012) studied changes in rheology and as well on the sensory properties of wheat bread when oat flour added to the dough.

The objective followed in this study was to investigate the effect of replacing skim milk powder in compound chocolate with soy flour as well as ball mill refining duration on particle size and on the rheological properties of compound chocolate.

MATERIALS AND METHODS

The materials including cocoa powder containing 11% cacao butter (Delfi Cocoa, Johor Darul Takzim, Malaysia), lauric Cacao Butter Substitute (composed of hydrogenated palm kernel oil, Mettler Dropping Point : 36-42ºC/97-108ºF, Free Fatty Acid [% as oleic]: 0.1 max, Iodine Value: 1.5 max , SFC at 20ºC : 90-98, SFC at 35ºC: 6 max) supplied from Indonesia, Fuji oil Inc.. Lecithin (ADM, IL, USA), skim milk powder (Golshad, Mashhad, Iran), sugar (Iran sugar Co., Tehran, Iran), whole soybean flour containing 22.08% oil and 39.28% protein (Toos Soyan, Mashhad, Iran) constituted the ingredients for the production of compound chocolates.

Experimental Design

The two experimental variables used in the study were ball mill refining duration time and the level of skim milk powder replacement by soy flour. Ball mill temperature and pressure, as well as the level of lecithin were held constant.

A 2×4 factorial experimental design was employed, the two factors being comprised of:

1. Ball mill refining time: 105 and 135 minutes
2. Replacement level of skim milk powder by soy flour (solid non fat): 0, 33.33, 66.66 and 100% (w/w)

Skim milk powder was reduced, while soy flour being replaced instead. Total fat was kept constant (31.5%). For this purpose, oil content of soy flour was calculated and the amount reduced from the total fat in the mixture. Formulations of produced samples are presented in Table 1.

Preparation of Compound Chocolate Samples

Previously optimized formulation of compound chocolate was made use of (Table 1). All the experimental tests were performed on 5 kg batches of compound chocolate with a ball mill refiner made by Iranian company, Sepehr Machine Inc., (Tehran, Iran) containing 9.5 mm diameter stainless steel balls. Refining was carried out at 60°C at an agitator shaft speed of 100 rpm, recycling the mass through the ball bed at a medium flow of 2–3 kg min^{-1} of the recycling pump, for 105 and 135 minutes. All the ingredients were added to the ball mill at the beginning of the test while soy flour was added during the process. Refined compound chocolate was molded using special chocolate moulds and cooled at 4 °C for 30 minutes. Compound chocolates were demolded and stored in plastic containers to be later analytically tested in ambient temperature.

Statistical Analysis

Statistical analysis of data for investigating the effects of factors on particle size and rheological properties was performed employing SPSS 16.0 software (SPSS Inc., Chicago, IL). General linear model univariate ANOVA was made use of. All experiments were conducted in triplicates and the mean values reported. The mean differences were analyzed using Dunkan's test at $P< 0.05$.

Analytical Methods

Determination of Particle Size Distribution

Size distributions of compound chocolate

Table 1. Formulation of produced samples.

Sample ID	Refining time (minutes)	Replacement level of soy flour (%)	Skim milk powder (%)	Soy flour (solid non fa) (%)	Soy flour (oil) (%)	CBS (%)	Total fat (%)	Lecithin (%)	Sugar (%)	Cacao powder (%)
Ch1	105	0	15	0	0	31.5	31.5	0.5	47	6
Ch2	105	33.33	10	5	1.41	30.9	31.5	0.5	47	6
Ch3	105	66.66	5	10	2.82	28.68	31.5	0.5	47	6
Ch4	105	100	0	15	4.23	27.27	31.5	0.5	47	6
Ch5	135	0	15	0	0	31.5	31.5	0.5	47	6
Ch6	135	33.33	10	5	1.41	30.9	31.5	0.5	47	6
Ch7	135	66.66	5	10	2.82	28.68	31.5	0.5	47	6
Ch8	135	100	0	15	4.23	27.27	31.5	0.5	47	6

CH1-CH8: produced chocolates codes, from 1 to 8.

particles were determined by the laser light-scattering method (McFarlane, 1999), using particle size analyser Shimadzu 2600 (Shimadzu, Sald 2101, Japan). Before the analysis, samples were diluted with acetone and treated in a Branson 2200 ultrasonic system (Branson Ultrasonic Corporation, Danbury, CT, USA) for 5 minutes. PSD were parameters expressed in micrometers as the largest particle size (D_{90}), mean particle volume (D_{50}), smallest particle size (D_{10}) (Alamprese 2007).

Rheological Properties

To compare the rheological properties of produced compound chocolates with the traditional ones rheological measurements were carried out through an MCR 300 Physica rheometer (Anton Paar, Benelux). It was equppied with a CTD 600 thermo chamber operating in the controlled shear rate rotation mode. Samples were prepared and tested according to the Intl. Confectionery Association (ICA, previously IOCCC) guidelines as follows: to melt the compound chocolate samples the were incubated at 50°C for 75 minutes, then transferred to a cup (concentric cylinder geometry, Cup= 28.92mm, Bob= 26.66mm), after a pre-shear period of 15 min at 5/s, the shear rate was increased from 2 to 50/s in 3 min(ramp up) then maintained for 1 minute at 50 s^{-1}, before finally being decrease from 50 to 2 s^{-1} in 3 minutes (ramp down). The temperature was kept at 40°C with an accuracy of ±0.1°C during the measurements. Data were collected using Rheoplus/32 Service V3.10 Software.

Collected data were fitted with mathematical models including Bingham, Casson, Power law and Herschel-Bulkley (Abbasi and Farzanmehr, 2009).To select the best model describing the rehological properties of samples, two statistical parameters, including Root Mean Square Error (RMSE Equation (1)) and coefficient of determination (R^2) were estimated using Microsoft Excel (Microsoft Office, Package 2007) and Slidewrite Software (Computer package version 2.0, Advanced Graphics Software, Inc., Encinitas, CA) for the four rheological models.

$$RMSE = \left[\frac{1}{n} \sum_{1}^{n} (x_{\exp} - x_{pred.})^2 \right]^{0.5} \quad (1$$

Where, n is the number of experimental data, $x_{exp.}$, is the value obtained from experiment, $x_{pred.}$ is the predicted value by the corresponding model.

Rheological models are read as:

Casson: $\sqrt{\tau} = \sqrt{\tau_0} + \sqrt{\eta_{p1}} . \sqrt{\gamma^{\bullet}}$ (2

Herschel-bulkley: $\tau = \tau_0 + k\,(\gamma^{\circ})^n$ (3

Bingham: $\tau = \tau_0 + \eta_p \gamma^{\circ}$ (4

Powerlaw: $\tau = k\,\gamma^{\circ n}$ (5

Where, τ is shear stress (Pa), γ^0 is shear rate (s^{-1}), τ_0 the Casson yield or yield stress (Pa), η_{p1} standing for Casson plastic viscosity (Pa·s). η_p is plastic viscosity (Pa s), k the consistency coefficient (Pa s)^n and n representing flow behaviour index (dimensionless).

The Casson plastic viscosity and Casson yield values are calculated using $\tau^{0.5}$ *vs.* $\gamma^{0\ 0.5}$ curves

All the rheological parameters were calculated employing the most suitable model. Apparent viscosity was also calculated at a shear of 40 s^{-1}.

RESULTS AND DISCUSSION

Particle Size Distribution

Results indicating the D_{90}, D_{50} D_{10} values of compound chocolates are presented in Table 2. As shown in the table, the evaluated D_{90} values ranged between 12.11 and 21.44 µm, D_{50} values between 4.31 and 6.6 µm and while D_{10} values between 1.1 and 1.61 µm. D_{90} values are usually considered acceptable if lower than 23 µm (Beckett, 2008). It is in fact believed that, particles exceeding this dimension can cause an unpleasant sand effect in the mouth (Beckett, 1994). Beckett (2008) concluded that the largest prevalent

Table 2. Particle size distribution of compound chocolates.

Sample ID	Refining time (minutes)	D_{10}^{a} (μm)	D_{50}^{a} (μm)	D_{90}^{a} (μm)
Ch1	105	1.31±0.02	5.1±0.12	14.77±0.39
Ch2	105	1.32±0.03	5.2±0.15	14.95±0.39
Ch3	105	1.45±0.04	5.9±0.11	17.55±0.37
Ch4	105	1.6±0.04	6.6±0.11	21.44±0.41
Ch5	135	1.1±0.011	4.31±0.15	12.11±0.37
Ch6	135	1.22±0.02	4.62±0.18	13.5±0.39
Ch7	135	1.3±0.03	4.83±0.15	14±0.38
Ch8	135	1.45±0.04	5.3±0.15	14.96±0.39

Mean values±Standard deviations taken from triplicate analyses.
[a] D_{10}, D_{50} and D_{90}, respectively, represent 10%, 50% and 90% of all particles finer than these sizes.
CH1-CH8: produced chocolates code, from 1 to 8.

particle size is the key parameter for chocolate manufacture. The largest particle dimension determines the chocolate coarseness and textural character. Meanwhile, 6 μm is believed to be the minimum particle size if optimum rheological properties are to be achieved in the chocolate mass (Kruger, 1999). ANOVA showed that both the refining time and replacement level affected PSD significantly (P< 0.05) (Table 3). Replacing skim milk powder by soy flour led to significantly an increase in all PSD parameters (P< 0.05). This means that samples containing the highest quantity of soy flour carried the largest D_{90}, D_{50} and D_{10} values. This is because of less free fat (CBS) content of samples containing soy flour and its direct influence on PSD parameters. It should be noted that soy flour oil is released during refining. Similarly, Bolenz *et al*. (2003) concluded that refining samples with a high initial content of free milk fat resulted in significantly smaller particles than those with bound milk fat. All PSD parameters decreased significantly (P< 0.05) with increase in refining time. Despite the involvement of particle size distribution in determining suspension flow properties, Awua (2002) and Whitefield (2005) explained that it is not the only factor influencing rheological characteristics in chocolates.

Rheological Properties

Table 4 shows the two statistical parameters determined for validation of four rheological models used in this study. Based on statistical calculations, Herschel–Bulkley model, despite providing the highest R^2 values, was not chosen as the appropriate model since a further evaluation of RMSE revealed that the Casson model presents the most suitable fitting for all the compound chocolate formulations due to provision the highest R^2 *vs.* the lowest RMSE figures. Mohammadi Moghaddam *et al.* (2009) and also Abbasi and Farzanmehr (2009) used R^2,

Table 3. ANOVA Summary of F-ratios from particle size distribution.

Process variables	D_{10}^{a} (μm)	D_{50}^{a} (μm)	D_{90}^{a} (μm)
Refining time	1331.000*	69938.000*	201356.100*
Replacement level	1148.455*	24390.000*	69756.633*
Refining time×Replacement level	26.758*	1990.000*	18641.433*

* Significant *F*-ratios at *P*< 0.05.
[a] D_{10}, D_{50} and D_{90}, respectively, represent 10%, 50% and 90% of all the particles finer than these sizes.

Table 4. Effects of replacement level and refining time on fitting of experimental data with mathematical as models, based on R^2 and RMSE.

Sample ID	Model	R^2	RMSE	Sample number	model	R^2	RMSE
Ch1	Power law	0.983	3.91	Ch5	Power law	0.98	4.517
	Bingham	0.998	1.07		Bingham	0.987	3.515
	Herschel–Bulkley	0.998	1.024		Herschel–Bulkley	0.989	3.209
	Casson	0.992	0.152		Casson	0.987	0.205
Ch2	Power law	0.986	2.687	Ch6	Power law	0.983	5.584
	Bingham	0.998	1.025		Bingham	0.996	2.3
	Herschel–Bulkley	0.999	0.391		Herschel–Bulkley	0.997	1.996
	Casson	0.983	0.121		Casson	0.989	0.214
Ch3	Power law	0.995	2.7	Ch7	Power law	0.995	2.785
	Bingham	0.992	3.42		Bingham	0.992	3.44
	Herschel–Bulkley	0.999	0.3		Herschel–Bulkley	0.999	0.317
	Casson	0.999	0.021		Casson	0.999	0.027
Ch4	Power law	0.98	8.576	Ch8	Power law	0.992	5.46
	Bingham	0.993	4.695		Bingham	0.995	4.08
	Herschel–Bulkley	0.996	3.597		Herschel–Bulkley	0.999	1.3
	Casson	0.992	0.205		Casson	0.999	0.066

CH1-CH8: produced chocolates code, from 1 to 8.
RMSE: Root Mean Square Error.

RMSE and SE for validation of their studied models concluding that R^2 is not always a suitable statistical parameter for estimation of the models' validity. As a result, it can be said that replacing skim milk powder with soy flour, in spite of influencing the rheological parameters, had no effect on the mathematical model fitting and the same model being able to be used for the prediction of rheological behaviour of all compound chocolate samples. Casson model is widely used and recommended by ICA to describe flow behavior of chocolate (Bouzas and Brown, 1995). The Casson plastic viscosity and Casson yield values are calculated using $\tau^{0.5}$ vs. $\gamma^{0\,0.5}$ curves, where square of the slope and the intercept belong to the Casson plastic viscosity and Casson yield, respectively. Figure 1 shows the agreement between the experimental data and the Casson model in a sample containing 100% soy flour (refining time 130 minutes).

Casson Plastic Viscosity

The plastic viscosity relates to the energy required to keep the chocolate moving, once it has started to flow. This is also important

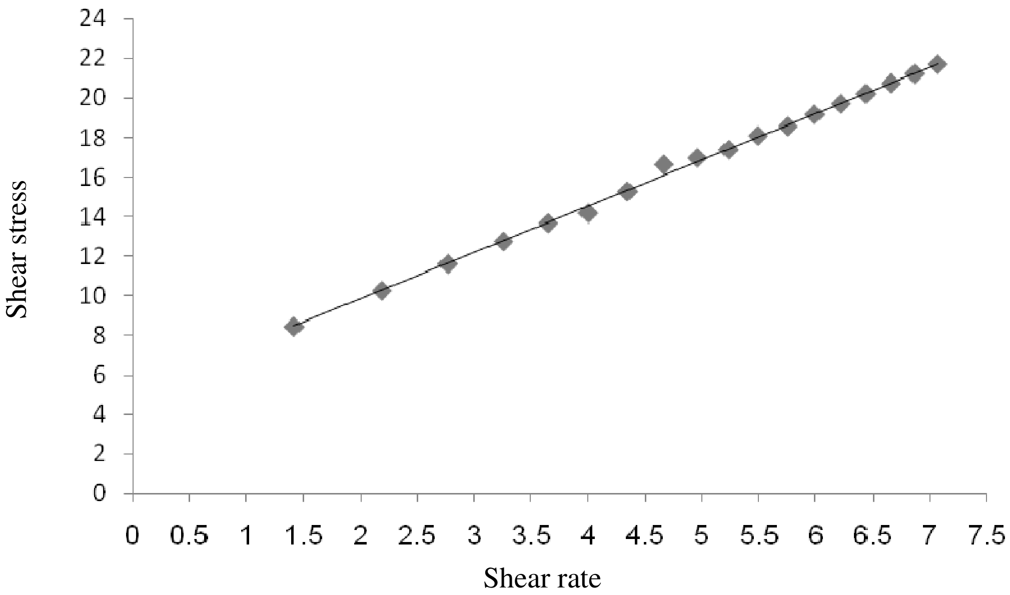

Figure 1. Shear rate vs. shear stress in samples containg 100% soy flour (refining time 130 minutes), Casson model being applied.

in determining the coating thickness of chocolate on pastry and also in determining the size of pumps needed to pump the liquid chocolate (Beckett, 2008). Casson plastic viscosity values are indicated in table 5. Casson plastic viscosity values ranged between 1.36 and 5.47 (Pa s), which is in a very good agreement with that reported by Aeschlimann and Beckett (2000) for milk chocolate (2.2–5.5 (Pa s)). This means these formulations can be easily employed for enrobing or coating. Results indicated that replacing skim milk powder by soy flour in compound chocolates led to a significant ($P< 0.05$) increase in viscosity in either one to increase in the refining time durations. This may be attributed to emulsifying and gel-forming properties of soy flour proteins (Zaric *et al.,* 2011).

Casson plastic viscosity also increased for all the replacement levels along with increase in refining time ranging from 105 to 135 minutes and particle size decrease. This was less pronounced in samples containing only milk powder. As particles become finer, more fat is required to coat the particles, if the fat content is kept constant, it will result in increase in viscosity. Afoakwa

Table 5. Effects of replacement level and refining time on Casson plastic visosity, Casson yield value and apparent viscosity

Sample ID	Refining time (Min)	Replacement level (%)	Casson plastic viscosity (Pa s)	Casson yield (Pa)	Apparent viscosity
Ch1	105	0	1.36±0.07	11.23±0.31	2.87±0.12
Ch2	105	33.33	1.90±0.05	32.71±0.33	5.21±0.11
Ch3	105	66.66	2.22±0.05	35±0.38	5.88±0.11
Ch4	105	100	4.12±0.10	38.88±0.39	9.09±0.2
Ch5	135	0	5.47±0.12	12.95±0.16	3.27±0.09
Ch6	135	33.33	2.52±0.09	18.14±0.13	4.81±0.11
Ch7	135	66.66	2.31±0.09	18.55±0.12	5.15±0.15
Ch8	135	100	1.53±0.08	26.68±0.14	9.96±0.15

Table 6. ANOVA Summary of F-ratios from Casson plastic viscosity, Casson yield and apparent viscosity.

Process variables	Casson plastic viscosity	Casson yield	Apparent viscosity
Refining time	5512.500*	26142.129*	434001.088*
Replacement level	17097.833*	178120.252*	679.198*
Refining time×replacement level	385.833*	6187.624*	28582.507*

* Significant *F*-ratios at *P*< 0.05.

(2008) reported, as the particles become finer, their number increases with a parallel increase in points of contact among particles, leading to increase in plastic viscosities. Servais *et al.* (2002) reported viscosity could double with solid content increases of even a few percent for high solid content suspensions.

The highest free fat content existed in samples containing only milk powder; therefore, increase in viscosity as a result of particle size reduction was less pronounced (Beckett, 2008). ANOVA revealed that both of the refining time durations as well as the replacement levels, affected Casson plastic viscosity significantly (P< 0.05) (Table 6).

Casson Yield Value

The yield value is an expression of the energy required to start the chocolate moving, shape retention, pattern holding, feet and tails, inclined surface coating and as well the presence of air bubbles (Seguine, 1988). ANOVA showed that both refining time and replacement level significantly affected Casson yield value (P< 0.05) (Table 6). Regarding the Casson yield values, Aeschlimann and Beckett (2000) reported a wide range (2–18 Pa) of yield values for the case of milk chocolates.

The values of Casson yield obtained in different samples ranged from 11.23 to 38.88 (Pa). Samples containing only milk powder for both refining time treatments fell in the appropriate range for milk chocolate as mentioned above, but samples containing soy flour stood out of range, for which the deviation was much less for the 33.33 and 66.66% replacement levels of the 135 minute refining time. By replacing soy flour, gel-forming and emulsifying properties of soy proteins and their causing intermolecular connections, resulted in significant increase in Casson yield value (P< 0.05). Casson yield value increased with particle size decrease in samples containing only milk powder. Yield value is largely affected by inter-particle contacts, showing a linear dependency on mean particle size. As the chocolate is ground finer and finer, there are more particles to interact, so the yield is increased. According to Prentice (1984), when particle size decreases, the number of bonds and consequently the degree of frictional contact between the particles increases, causing higher values of Casson yield. Beckett (2008) and Afoakwa *et al.* (2008) also reported that the Casson yield values increase dramatically as the chocolate becomes finer, meanwhile in samples containing soy flour, increasing ball mill refining time and a decrease in particle size reduced yield, which it may be due to breakage of some of intermolecular connections made before by soy flour.

In refining time of 105 minutes, Casson yield value increased from 11.23 to 38.88 representing 346% increase with soy flour increase. Similarly 206% increase was observed in the refining time of 135 minutes. This explains that combined effects of soy flour content and refining to exert the greatest influence on the yields of compound chocolates. This effect is however more pronounced at larger particle sizes (105 minutes refining time).

Regarding samples of high yields, it should be considered that higher yield values would make moulding and enrobing processes more difficult for producers. For industrial application, PGPR could further reduce the yield values of chocolates. Addition of 0.5% PGPR has been reported to affect up to 12-fold and 24% reductions in yield and in plastic viscosity respectively (Haedelt *et al.,* 2005). PGPR achieves steric stabilization of sugar particles, thereby reducing interactions on yield values and plastic viscosities in chocolates (Vernier, 1998).

Apparent Viscosity

Apparent viscosity of compound chocolates containing different levels of soy flour were determined at 40 s^{-1} shear rate as shown in table 5. Servais *et al.* (2002) noted that apparent viscosity could be represented by value of the viscosity at 30, 40, or 50 s^{-1} depending on product, but recommended viscosity value at 40 s^{-1} to represent apparent viscosity through relative reproducibility. Afoakwa *et al.* (2008) and Sokman (2006) reported apparent viscosity at 30 s^{-1}. Apparent viscosity ranged from 2.87 to 9.09 in 105 minute refining time and 3.27 to 9.96 for 135 refining time treatment. By replacing soy flour, apparent viscosity increased in both refining time durations. As particle size decreased the apparent viscosity increased substantially. This means that samples containing higher amounts of soy flour with longer refining times resulted in higher apparent plastic viscosities. Results obtained for apparent viscosity are in agreement with Casson plastic viscosity results, as reported previously. ANOVA indicated that both refining time and replacement levels significantly ($P< 0.05$) affected compound chocolate apparent viscosity with significant interactions among the interfering factors (Table 6).

CONCLUSIONS

Results indicated that ball mill refining time and soy flour directly influence the compound chocolate particle size and rheology. In general, Casson plastic viscosity increased as skim milk powder was replaced by soy flour in either one of the refining times. Similarly, Casson plastic viscosity and apparent viscosity increased at all replacement levels and with increase in refining time. By replacing soy flour, Casson yield value increased. Casson yield value also increased with increase in refining time in samples containing only milk powder, but decreased in the case of samples containing soy flour. Refining time and soy flour content could be manipulated to control compound chocolate rheology, influencing quality whilst reducing production costs. Considering the price, nutritional and functional properties of soy flour, its use seems to be very beneficial to the related industries.

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تاثیر جایگزینی شیر خشک بدون چربی با آرد سویا و زمان آسیاب کردن بر اندازه ذرات و ویژگی های رئولوژیکی فرآورده شکلاتی

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چکیده

خواص رئولوژیکی شکلات در فرآیند تولید برای دستیابی به محصولی با کیفیت بالا و بافت مناسب حائز اهمیت است. خواص رئولوژیکی مستقیما" تحت تاثیر ترکیبات و زمان آسیاب کردن است. پروتئین های سویا دارای خواص تغذیه ای و عملکردی هستند که می توانند در محصولات غذایی مورد استفاده قرار گیرند. تاثیر سطوح مختلف جایگزینی شیر خشک بدون چربی با آرد کامل سویا (از صفر تا ۱۰۰ درصد) و زمان آسیاب کردن (۱۰۵ و ۱۳۵ دقیقه) بر اندازه ذرات و خواص رئولوژیکی فرآورده شکلاتی مورد بررسی قرار گرفت. با توجه به چهار مدل رئولوژیکی بررسی شده، مدل کاسون بهترین مدل برای تعیین خواص رئولوژیکی نمونه ها انتخاب شد. نتایج نشان داد که ویسکوزیته کاسون در محدوده ۱/۳۶ تا ۵/۴۷ (پاسکال. ثانیه) قرار گرفت و جایگزینی شیرخشک بدون چربی با آرد کامل سویا باعث افزایش قابل ملاحظه ای در ویسکوزیته پلاستیک نمونه ها در هر دو زمان آسیاب کردن شد($P<0.05$). با افزایش زمان آسیاب کردن از ۱۰۵ به ۱۳۵ دقیقه در تمام سطوح جایگزینی، ویسکوزیته پلاستیک و ویسکوزیته ظاهری افزایش پیدا کرد. ($P<0.05$). مقادیر تنش تسلیم کاسون در محدوده۱۱/۲۳ تا ۳۸/۸۸(پاسکال) قرار گرفت. با جایگزینی آرد کامل سویا، تنش تسلیم کاسون به طور قابل ملاحظه ای افزایش یافت($P<0.05$). تنش تسلیم کاسون با افزایش زمان آسیاب کردن در نمونه های حاوی فقط شیر خشک افزایش و اما در نمونه های دارای آرد سویا کاهش یافت.