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Rheological Properties of Sugar-Free Milk Chocolate: Comparative Study and Optimisation

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Abstract

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The effects of sugar substitutes on rheological characteristics of compound milk chocolate using a simplex-lattice mixture design were evaluated. For this purpose, two bulking agents (maltitol and xylitol) at different levels (0–100%) were used and ten formulations were examined in order to find the optimum levels. All chocolate samples showed shear thinning behaviour. It was found that compound milk chocolate behaved as a Casson fluid. Chocolate formulations containing the highest maltitol substitution resulted in similar flow properties compared to those of the control and hence can be a good alternative. The results demonstrated that chocolate combinations containing 87.8% maltitol and 12.2% xylitol were found as the optimum concentrations producing the most acceptable rheological properties.

Keywords: chocolate; maltitol; flow properties; simplex-lattice mixture design; xylitol

In recent years sugar alcohols have become fundamental ingredients in the manufacture of many sugar-free products. Yet, we have not encountered any study about the suitability and applicability of maltitol and xylitol mixtures as sucrose substitutes during the manufacture of low-calorie milk chocolate. In this article, we have reported the influences of maltitol and xylitol as bulking agents on rheological properties of compound milk chocolate using a simplex-lattice mixture design. The results showed that the use of the above-mentioned components instead of sucrose could lead to the production of low-calorie compound milk chocolate without having the undesirable rheological effects on the chocolate samples. In addition, the simplex-lattice mixture design was found a very useful tool for finding optimum ratios of sugar substitutes in formulation.

Low-calorie chocolates are favourite foodstuffs among consumers and manufacturers. Reduced calorie products were found to be suitable for people with particular medical problems such as diabetes, obesity and heart diseases (Sandrou & Arvanitoyannis 2000). Replacing sucrose with bulking agents like polyols can reduce calories, glycaemic index, and also prevents dental cavities. Sugar alcohols have been used most frequently for manufacturing functional chocolates (Kruger 1999).

Maltitol (4-*O*-α-D-glucopyranosyl-D-sorbitol), as a commercially available preparation, is produced by the catalytic hydrogenation of maltose, which is composed of glucosyl-sorbitol units connected by α-1,4-glycosidic biding. It is a bulk sweetener and has a sweetness of almost 85–95% of that of sucrose. Maltitol has low hygroscopicity, excellent flow properties and crystalline structure, resulting in the final products with very good mouth feel and taste. Maltitol has been successfully incorporated into a wide range of foods including chewing gum, tabletted mints, and related products, hard candy, chocolate, and chewy candy (Fabry 1987). In addi-

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tion, xylitol or (2R,3r,4S)-pentane-1,2,3,4,5-pentol is a five-carbon polyol and it is produced by chemical conversion of xylan on a commercial scale. It has 95% of the sweetness of sucrose and therefore no additional intense sweetener is needed (Kato & Moskowitz 2001). Xylitol is slowly absorbed from the digestive tract system. After ingestion of large amounts, only some proportion of the ingested xylitol is absorbed and gets to the hepatic metabolic system. It is used as a sweetener basically in non-cariogenic confectionery including chewing gum, candies, chocolates and gumdrops.

Researches have scarcely been focused on maltitol and xylitol for use as bulking agents in the production of sugar-free chocolates (Rapaille *et al.* 1995; Sokmen & Gunes 2006). Sokmen and Gunes (2006) evaluated the influence of bulk sweeteners on rheological properties of dark chocolate and concluded that maltitol, xylitol, and isomalt can be used in the manufacturing of sucrose-free chocolates. Konar (2013) replaced sucrose with maltitol and inulin as bulking agents in the development of sugar-free milk chocolates and stated that the rheological properties of maltitol-containing samples undergo a series of changes with varying conching temperature. Rapaille and Gonza (1991) recommended that both dark and milk chocolate with desirable flavour can be produced with an anhydrous crystalline maltitol powder using normal manufacturing processes. Results from the previous studies demonstrate that replacing sucrose with these polymers as bulking agents could lead to the production of low-calorie chocolate, but the influences of maltitol and xylitol on the rheology and functionality in compound milk chocolate manufacture have not been fully clarified.

Rheological properties of chocolate are important in the manufacturing process for obtaining a high-quality product with well-defined texture depending on fat content, particle size distribution, moisture content, emulsifiers, conching time, and temperature (Tscheuschner & Wunsche 1979). These properties can be characterized by several mathematical models including Bingham, Herschel-Bulkley, and Casson models (Chevalley 1994; Servais *et al.* 2004). Replacement of sucrose with sugar alcohols would affect rheological properties and therefore the processing conditions and quality of chocolates. In addition, the simplex-lattice mixture design is a useful technique for recognizsing optimum amounts of components in product formulations and it can minimise the number of trials. Thus, the present study was aimed at investigating the effects of replacing the sugar in compound milk chocolates with different combinations of maltitol and xylitol on steady rheological properties, also finding the optimum levels of these compounds, using a simplex-lattice mixture design.

MATERIAL AND METHODS

Material. The current research ingredients include different materials such as: cocoa powder (Altinmarka, Turkey), lauric cocoa butter substitute CBS (MOI, Malaysia; composed of hydrogenated palm kernel oil, Mettler dropping point 36–42°C, free fatty acid as oleic – max. 0.1%, iodine value – max. 1.5, SFC at 35°C – max. 6), whole milk powder (Zarrinshad, Iran), maltitol (Roquette Frères, France), xylitol (Roquette Frères, France), sucrose (Iran sugar Co., Iran), soy lecithin (Cargill, Netherlands), and vanillin (Polar Bear, China).

Preparation of compound milk chocolate samples. Chocolate samples (Table 1) were produced in a laboratory ball mill (5 kg batches) and formulated from the mixture design (Table 2). The diameter of balls in the ball mill was 8 mm, and the mixer speed 40 rpm. The mill was outfitted with a recirculation system, with a speed of 10 kg/hour. All the components and as much as half of the whole lecithin were added to the ball mill at the beginning of mixing. Milk chocolate samples were homogenised at 55°C. The temperature of the chocolate masses was decreased to 45°C prior to the addition of lecithin, applied half an hour before completion of mixing. Particle size was determined with a digital micrometer (Mitutoyo Co., Japan) to control the particle size of chocolate paste during processing and achieve a mean particle size of < 35 μm. The resulting compound milk chocolate

Table 1. Formulations used in compound milk chocolate production

Material	Composition (%)
Cocoa powder	6
Maltitol	0–33 (Table 2)
Xylitol	0–33 (Table 2)
Whole milk powder	26
CBS	34.5
Lecithin	0.5
Vanillin	0.01

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Table 2. Experimental design and mass fraction of two components in compound chocolate formulation

Formulation	Level (%)		w_{x_1}/g	w_{x_2}/g
	x_1	x_2		
1	100	0	33	0
2	0	100	0	33
3	50	50	16.5	16.5
4	75	25	24.75	8.25
5	25	75	8.25	24.75
6	100	0	33	0
7	0	100	0	33
8	50	50	16.5	16.5
9	75	25	24.75	8.25
10	25	75	8.25	24.75
11	0	0	0	0
12	0	0	0	0

x_1 – maltitol; x_2 – xylitol

obtained was moulded and cooled at 4°C for 30 min, removed from the moulds, wrapped in aluminium foil and stored at 18°C. The samples were stored away from light and heat prior to analysis. Also, it is necessary to be mentioned that the control samples contained sucrose instead of sugar replacers.

Rheological measurements. Steady shear rheological properties of the chocolate samples were measured using a shear stress controlled rheometer (MCR301; Anton Paar, Austria) with a coaxial cylinder system (cup and bob). The chocolate samples were melted prior to measurement by incubation at 50°C for 75 min, and pre-sheared for 15 min at shear rate 5 Pa/s and temperature 40°C, before measurement cycles started. Afterwards, shear stress was measured as a function of the shear rate over a wide range of 5 to 50 Pa/second. Each measurement took 180 s at 40°C and 50 measurements were taken (Afoakwa *et al.* 2009). Collected data were fitted with mathematical models including power law, Bingham, Herschel-Bulkley, and Casson models (Farzanmehr & Abbasi 2009). The two statistical indexes of root mean square error (RMSE) and coefficient of determination (r^2) were calculated to select the best model describing the steady rheological properties of the samples (Yeganehzad *et al.* 2013). Moreover, the rheological parameters including plastic viscosity and yield stress values of the selected models were determined. The moisture was determined according to 931.04 method of AOAC (1990).

Statistical analysis. The effects of ingredient proportions on chocolate rheological properties were studied with the simplex-lattice design using Minitab 16 for the two component mixture systems with constraints which comprised maltitol (x_1) and xylitol (x_2). All of which were restricted at the total of 33% of total chocolate blend. The dependent variables, Casson plastic viscosity, Casson yield stress, flow index and moisture content were analysed and the fitted models were subjected to analysis of variance (ANOVA) to determine significance (P < 0.05), determination coefficient (r^2) and lack of fit. Minitab's response optimiser tool was conducted to recognise the combination of experimental factors which simultaneously optimise the responses. The mentioned function was used to obtain the individual desirability (d) for each response, maximising the composite desirability and identifying the optimal input variable settings. Mathematical model fittings were evaluated with the Curve Fitting Toolbox (cftool) of rheological data using MATLAB v. R2012a software.

RESULTS AND DISCUSSION

Mean values for the responses (Casson plastic viscosity, Casson yield stress, flow index, and moisture content) were analysed (Table 3). The experimental consequences received for the studied parameters were statistically evaluated by fitting the data to different models and the calculated regression coefficients are shown in Table 5. As predetermined in Table 2, the following experiments are equivalent: experiment 1 = 6; 2 = 7; 3 = 8; 4 = 9; 5 = 10. The best fitted model which maximises the r-squared with P-value less than 0.05 at the 95% confidence level was selected. For comparison aims, experiment 11 and 12 represent the control formulation made with sucrose.

All selected models were statistically significant (P < 0.05) which indicated a significant relationship between the variables and the ingredients at the 95% confidence level. The equations of the fitted models are presented in Table 6.

Rheological properties. Apparent viscosity of the samples decreased with increasing shear rate. Addition of xylitol as a bulking agent increased the apparent viscosity of chocolate mix (data not shown). In addition, all of the chocolate samples showed shear thinning behaviour, which is in agreement with previous studies (Do *et al.* 2007; Afoakwa *et al.* 2008; Fernandes *et al.* 2013). Structural decomposition

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Table 3. Mean and standard deviation of quality parameters

Runs	Casson		Flow index	Moisture (%)
	viscosity (Pa/s)	yield (Pa)		
1	1.630 ± 0.021	4.134 ± 0.003	0.72 ± 0.007	0.89 ± 0.014
2	2.644 ± 0.003	1.838 ± 0.002	0.84 ± 0.007	1.18 ± 0.021
3	2.324 ± 0.002	2.726 ± 0.003	0.81 ± 0.007	1.05 ± 0.007
4	2.013 ± 0.001	3.365 ± 0.002	0.76 ± 0.007	0.98 ± 0.007
5	2.535 ± 0.002	2.217 ± 0.047	0.81 ± 0.007	1.09 ± 0.004
6	1.6 ± 0.021	4.138 ± 0.003	0.71 ± 0.007	0.87 ± 0.014
7	2.648 ± 0.003	1.835 ± 0.002	0.83 ± 0.007	1.15 ± 0.021
8	2.327 ± 0.002	2.722 ± 0.003	0.80 ± 0.007	1.04 ± 0.007
9	2.015 ± 0.001	3.368 ± 0.002	0.75 ± 0.007	0.97 ± 0.007
10	2.538 ± 0.002	2.215 ± 0.047	0.82 ± 0.007	1.09 ± 0.004
11	1.709 ± 0.012	3.847 ± 0.035	0.74 ± 0.007	0.91 ± 0.007
12	1.726 ± 0.012	3.798 ± 0.035	0.75 ± 0.007	0.92 ± 0.007

and also alignment of the constituent molecules might be the reasons for shear thinning behaviour of the molten chocolate samples (Izidoro *et al.* 2008; Fernandez *et al.* 2013). Thus, for maintaining the structural quality of chocolate samples, a shear rate level applied during the production process should be elected intently.

Consequently, in order to clarify the influences of various formulations of sugar substitutes on the rheological behaviour of compound milk chocolates, their shear stress vs. shear rate data was fitted with some reported mathematical models including power law (1), Bingham (2), Herschel-Bulkley (3), and Casson (4) equation.

$$\sigma = \kappa\gamma^n \quad (1)$$

$$\sigma = \mu_{pl} (\gamma) + \sigma_0 \quad (2)$$

$$\sigma = \kappa\gamma^n + \sigma_0 \quad (3)$$

$$(\sigma)^{0.5} = (\kappa_1)^{0.5}(\gamma)^{0.5} + (\sigma_0)^{0.5} \quad (4)$$

where: σ – shear stress (Pa); κ – consistency coefficient (Pa.s^n); γ – shear rate (s^{-1}); μ_{pl} – plastic viscosity (Pa.s); σ_0 – yield stress (Pa); κ_1 – Casson plastic viscosity (Pa.s); n – flow behaviour index (dimensionless)

The fitting of experimental data with models was evaluated on the basis of the r^2 and RMSE. Based on statistical calculations, the Bingham, Herschel-Bulkley and Casson models provided the highest r^2 values, but were not chosen as the best model. Because further evaluation of RMSE revealed that the Casson model presents the most suitable fitting for all the chocolate combinations due to providing the highest r^2 as well as the lowest RMSE values (data are not shown). Thus, the appropriate model were chosen based on the highest r^2 value and the lowest RMSE value (Yeganehzad *et al.* 2013).

Moghaddam *et al.* (2009) and Abbasi and Farzanmehr (2009) concluded that r^2 is not always a proper statistical parameter for evaluation of the model's reliability. As a result, it can be suggested that replacing sucrose with maltitol and xylitol, in spite of influencing the rheological characteristics, had no effect on the mathematical model fitting and the same model being able to be used for the determining of rheological behaviour of all the chocolate samples. The Casson model is broadly used and offered by IOCCC (International Office of Cocoa, Chocolate and Confectionary 1973) to describe flow behaviour and rheological analysis of chocolate (Bouzas & Brown 1995). The Casson viscosity and Casson yield stress were assessed using $\sigma^{0.5}$ and $\gamma^{0.5}$ curves, where the square of the slope and the intercept belong to Casson viscosity and Casson yield value, respectively.

Casson plastic viscosity. The effects of various combinations of sucrose substitutes on the mean Casson plastic viscosity, yield stress, flow index and moisture content are shown in Table 3. ANOVA re-

Table 4. ANOVA summary of $P < 0.05$ responses

Process variables	Casson		Flow index	Moisture content
	viscosity	yield		
Maltitol	0	0	0	0
Xylitol	0	0	0	0
Maltitol × xylitol	0	0	0	0.131

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vealed that both of the sugar alcohols affected Casson plastic viscosity significantly ($P < 0.05$). The term associated with the interaction between the effects of both components was significant ($P < 0.05$) (Table 4). Generally, increasing in xylitol concentrations with a simultaneous reduction in maltitol concentration resulted in an increase in the Casson plastic viscosity (Table 3). The highest Casson viscosity was achieved by substituting sucrose entirely with xylitol. In opposite, milk chocolate formulations with high amounts of maltitol (100%) resulted in the lowest Casson viscosity. Chocolate containing the highest maltitol was found to be very similar to the control in the tested Casson viscosity (Table 3).

Casson plastic viscosity values range between 1.6 and 2.648 Pa/s, which is in very good agreement with the data reported by Toker *et al.* (2016) for compound milk chocolate (1.83–2.31 Pa/s). This means these formulations can be easily employed for compound milk chocolate manufacture.

Higher plastic viscosity caused by xylitol may be associated with its physical characteristics such as hygroscopicity, crystallinity and specific surface area. Different hygroscopicity of sugar alcohols is one reason for different Casson viscosity values among the samples. Abbasi and Farzanmehr (2009) reported that chocolate formulations containing high levels of sugar substitutes (100% maltodextrin) had higher moisture content and Casson viscosity. Ziegler *et al.* (2004) noted that increasing the moisture content of the chocolate leads to an increase in chocolate viscosity. Moreover, higher plastic viscosity with xylitol may be related with its higher solid volume fraction in chocolate because the density of xylitol (1.52 g/cm^3) was somewhat lower than that of maltitol (1.63 g/cm^3). Because the bulk sweeteners were added to a chocolate blend on weight basis, chocolate formulation with xylitol had more solids.

Fluctuations in conching temperature and time can change the viscosity and final texture of the chocolate samples (Bolenz *et al.* 2003). The milk powder used in the formulation had a moisture content of nearly 4%; during conching, the water of crystallisation inherently present in this ingredient is released and some moisture can be absorbed by xylitol because of its hygroscopic nature, which increases the viscosity.

Sokmen and Gunes (2006) noted that chocolate samples containing isomalt had higher plastic viscosity due to isomalt's higher solid volume fraction, lower conching temperature and different hygroscopicity, crystallinity and specific surface area. Konar (2013) investigated the conching temperature and bulk sweeteners on rheological properties of prebiotic milk chocolate containing inulin. It was concluded that maltitol is a more suitable sucrose substitute in milk chocolates containing inulin and has a potential to produce the sugar-free and 'tooth-friendly' prebiotic chocolates.

Casson yield stress. Casson yield values for milk chocolate have been reported to be between 2 and 18 Pa (Aeschlimann & Beckett 2000). The yield values obtained in our study almost fell in this range. Almost 80% of the chocolate formulations were within the range reported (Table 3).

A usual trend demonstrated that an increase in maltitol concentration with simultaneous decrease in xylitol concentration led to an increase in Casson yield stress (Table 3). The results stated that the interaction between the effects of both components was significant ($P < 0.05$) (Table 4). The highest value of 4.138 Pa and the lowest value of 1.835 Pa for Casson yield stress belonged to samples containing 100% maltitol and 100% xylitol, respectively. Control samples and formulations containing high concentrations of maltitol had higher yield values than the xylitol formulations as it is indicated by Table 3.

In terms of maltitol, a significant increase in Casson yield values was detected at higher proportions. This behaviour can be associated mostly with the high molecular mass of the ingredient (Abbasi & Farzanmehr 2009). It can be pointed out that the high Casson yield value of maltitol formulations is due to an agglomeration mechanism in suspension systems. High molecular weight of maltitol increases the intermolecular (non-polar) interactions in chocolate mass. As a result the mass becomes firmer and agglomerates and thus more energy is required to start flowing.

In addition, sugar alcohols have different numbers of hydrophilic active sites. By increasing the conching temperature these groups become more active and bond with neighbouring amino acid side chains. Since the fat phase is hydrophobic, therefore agglomeration occurs and yield value enhances.

Hence, the higher yield value of chocolate with maltitol could be associated with the high molecular mass of maltitol (344) vs. xylitol (152). Sokmen and Gunes (2006) stated that maltitol resulted in higher yield stress in comparison with isomalt and xylitol due to maltitol's PSD, which contained higher amounts of smaller particles. Low yield stress in the samples with high percent of xylitol indicates that interac-

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Table 5. Regression models for quality parameters of compound milk chocolates

Fitted model[a]	Casson viscosity quadratic model ($P = 0$)	Casson yield dtress quadratic model ($P = 0$)	Flow index quadratic model ($P = 0.011$)	Moisture content linear model ($P = 0$)
Lack of fit	$P = 0.802$	$P = 0.622$	$P = 0.149$	$P = 0.195$
R squared	99.96%	99.99%	97.25%	98.50%
R squared (adjusted)	99.95%	99.99%	96.46%	98.07%
Durbin-Watson statistics	1.63858	1.55115	2	1.12604

[a]linear model consists of first-order terms for each of the components, the quadratic model adds cross products between pairs of components

tion forces between xylitol particles were weak and thus less force is needed for the flow of chocolates.

Flow behaviour index (n). The index is very important in determining the stability of the product. Flow index (n) of all chocolate samples was in the range from 0.71 to 0.84 (Table 3). These n values lower than 1 indicate shear thinning behaviour above the yield stresses. The trend of variations is similar to the trends noted with Casson viscosity. Generally, chocolate with a high level of maltitol (75%) had a very similar flow index in comparison with that of the control. On the other hand, the 100% xylitol combinations caused higher flow index than others ($P < 0.05$). This consequence may be a result of the higher crystallinity of xylitol in comparison with maltitol. This increase in flow index may be due to the presence of more crystals in the chocolate with xylitol which can cause difficultly in crystal alignment during the production of chocolate (Briggs & Wang 2004).

Flow index could be related to the strength of the aggregated particle to the particle network system of chocolate blend during manufacture (Beckett 2000; Servais *et al*. 2004) with the distribution and arrangement of particle sizes, fat and emulsifier contents as the effective factors dictating the rheological flow behaviour of chocolate (Afoakwa *et al*. 2007). The rate index of prebiotic milk chocolates produced by Konar (2013) comprised similar values for samples with isomalt and maltitol. The results illustrated that almost all the formulations containing isomalt and maltitol were pseudoplastic ($0 < n < 1$).

Moisture content. The effect of various combinations of sugar alcohols on the mean values of moisture content is shown in Table 3. As it can be seen, the lowest values belong to formulations containing 100% maltitol. In contrast, the highest moisture content was observed in samples containing high mass fractions of xylitol. Due to the high hygroscopicity level of xylitol, the formulations with high proportions of xylitol showed high moisture content. Samples containing high ratios of maltitol were not different from the control in terms of moisture content (Table 3). The relationship between the moisture content and the ingredients (maltitol and xylitol) was linear (Table 6).

Moisture content of the formulations ranged between 0.87 and 1.18, which is within the acceptable limit (< 1.5%). This explains why some sugar alcohols are popular for replacing sucrose in chocolate formulations. Farzanmehr and Abbasi (2009) stated higher moisture content for chocolate formulations possessing high proportions of maltodextrin, inulin and polydextrose. The optimisation technique predicted an optimum value of 0.9260% with 87.8421% maltitol and 12.1578% xylitol, indicating a higher hygroscopicity for xylitol than maltitol (Figure 1).

Predicted models. According to the above-mentioned explanations and in order to find the optimized conditions, the moisture content and rheological parameters were developed for each parameter (Casson viscosity, Casson yield stress, flow index, and moisture content) as it is indicated by Table 6. Analysis of variance (ANOVA) in Table 5

Table 6. Predicted equations for the experimental data of compound milk chocolate formulations

Variable	Predicted model
Casson viscosity (Pa/s)	$y = 0.049x_1 + 0.08x_2 + 0.0007x_1x_2$
Casson yield (Pa)	$y = 0.125x_1 + 0.056x_2 - 0.0009x_1x_2$
Flow index	$y = 0.022x_1 + 0.025x_2 + 0.00008x_1x_2$
Moisture content (%)	$y = 0.027x_1 + 0.035x_2$

x_1 – maltitol; x_2 – xylitol

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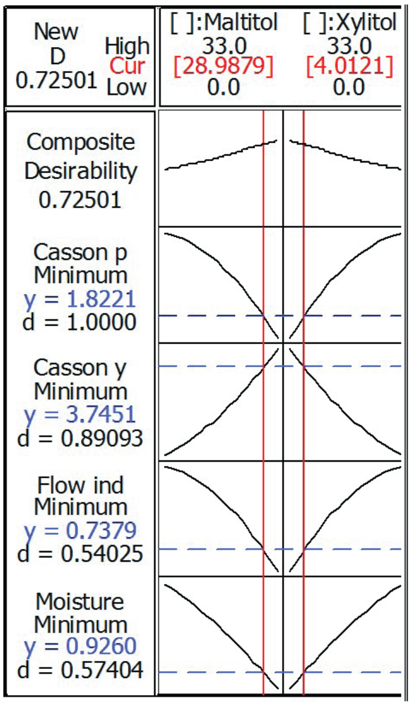

Figure 1. Optimisation of effective parameters on flow properties and moisture content of chocolate

Vertical red lines – factor settings; red numbers – factor (maltitol and xylitol) level settings; horizontal blue lines and numbers – responses for the factor level; d – the individual desirability for each response

indicated that quadratic polynomial models were adequate for the prediction of only Casson viscosity, Casson yield stress and flow index of samples. The quadratic model comprises the effects of each variable (maltitol, xylitol) and their interactive effects. A linear model for moisture content shows a steady rate of increase or decrease in the data. The models showed no lack of fit for moisture content, Casson viscosity, Casson yield value and flow index because P values were higher than $P > 0.05$ (0.195, 0.802, 0.622, and 0.149) and coefficients of multiple determinations, R^2, being 0.985, 0.999, 0.999, and 0.972 all indicate that models fit the experimental data points. The model equations for the responses can be written as Table 6 where x_1 and x_2 is maltitol and xylitol concentration (g/33 g), respectively, and y is the response.

Optimisation of chocolate formulation. This stage recognizes the combination of experimental variables which simultaneously optimise several responses. The optimisation plot shows the effect of each factor (columns) on the responses or composite desirability (rows). Composite desirability is the weighted geometric mean of the individual desirabilities for the responses. The vertical red lines in the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level settings (in red). The horizontal blue lines and numbers represent the responses for the current factor level. d is the individual desirability for each response. Taking into account all quality properties, and using the optimisation tool where quality responses were minimised (Casson viscosity, Casson yield, flow index, and moisture content), formulation one consisting of 87.8421% maltitol and 12.1578% xylitol was selected as having the maximum desirability. On the basis of our findings on optimisation process, the best acceptance limits for Casson viscosity, Casson yield stress, flow index, and moisture content, which show the highest similarity to the control, were 1.8221, 3.7451, 0.7379, and 0.9260, respectively (Table 8). These findings indicate that the formulations containing high concentrations of xylitol did not demonstrate desirable rheological properties due to their high moisture content, Casson viscosity and flow index. Therefore, it can be finalised that maltitol and xylitol can be used in the ranges commended in Table 8 for improving the flow properties. However, xylitol can only be used up to 12.1578% and above this proportion it cannot improve rheological properties. The combination of variables which achieved the overall optimum desirability (composite desirability) and optimisation of effective parameters on flow properties and moisture content of chocolate are illustrated in Table 7 and Figure 1, respectively. The combination of variable levels which maximized the desirability function over the indicated region is shown in Table 8.

Table 7. Combination of variables which achieved the overall optimum desirability

Variable	Low	High	Optimum
Maltitol (g)	0.0	33.0	28.9879
Xylitol (g)	0.0	33.0	4.0121

Table 8. Combination of factor levels which maximises the desirability function

Response	Optimum
Casson plastic viscosity (Pa/s)	1.8221
Casson yield stress (Pa)	3.7451
Flow index	0.7379
Moisture content (%)	0.9260

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CONCLUSION

Low-calorie compound milk chocolate can be produced using a low-calorie sweetener. Such a chocolate can compete with ordinary milk chocolate. On the other hand, the sweetness of maltitol and xylitol is close to that of sucrose and no additional intense sweeteners may be needed. Replacement of sucrose by maltitol and xylitol blends in sugar-free compound milk chocolate has different effects on the rheological characteristics. The influence is dependent not only on the type of sugar substitute but also on the levels present. Various concentrations of maltitol and xylitol were used to improve the rheological properties (Casson plastic viscosity and yield value) during the production of low-calorie chocolates. The optimum concentrations of 28.9879/33 g maltitol and 4.0121/33 g xylitol were found based on all studied parameters. Multiple response optimizations using a simplex-lattice mixture design were found to be a useful tool for identifying the effects of sugar replacement by maltitol and xylitol on rheological properties. The current study showed that chocolate with high levels of maltitol resulted in similar rheological properties to sucrose and thus it can be recommended as a suitable alternative to sucrose in chocolate formulations. Future work will focus on the hardness measurements and sensory characterisation of the optimized bulking agents in sugar-free milk chocolate. Further experiments with other combinations of sugar alcohols should be conducted to determine the effects of bulk sweeteners on physicochemical and sensory properties of chocolates.

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