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The effects of the reduced sugar on macaron quality

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Abstract Higher levels of sugars affected both firmness and cohesiveness in macaron batter which the latter was more affected. For macaron shell quality, higher levels of granulated and confectioner's sugars caused more fracturability, hardness and cohesiveness of macaron shells. Both sugars showed significantly pronounced effects on textural attributes of macaron shells, especially on its brittleness, hardness, and cohesiveness. The study showed that the amount of granulated sugar could be reduced from 150 g to 130 g and confectioner's sugar from 150 g to 126 g without affecting their acceptability in a professional panel sensory evaluation. The impact of reduced sugar on macaron shells was reduce feet height and increased chewiness. The macarons made from either reduced or non-reduced sugar levels which had similar overall liking scores that were not significantly different (p>0.05).

Keywords: Macaron, Sugar reduction, Meringue, Confectioner's sugar, Sugar syrup, Healthy

Introduction

Macaron are confections made with egg white, icing sugar, granulated sugar, almond meal and often food coloring. They were originally from Italy, but were introduced to France during the Renaissance and has since been adopted world-wide in various flavours and forms (Cindy, 2009). In some countries, including the U.S.A. and UK "macaroons" are produced tthat are similar, but are flavoured with desiccated coconut and often called coconut macaroons. The perfect macaron shells should be crunchy outside and chewey inside and also have a little foot underneath the shell. Some famous chefs around the world have secret methods and recipes for their macarons and the idea of revealling chefs' secret techniques of making perfect macaron has been the subject of scientific research (Annie, 2012; Gabriel, 2014). In the process of making macarons, sugar is separated into two portions. The first is granulated sugar that is added in the process of preparing meringue. The second is confectioner's sugar mixed with almond powder. Sugar is a key component in macaron shells as it contributes both to flavor and structure of the finished

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product. It is commonly assumed that granulated sugar functions to strengthen the meringue while confectioner's sugar contributes to lightness of texture (Annie, 2012). Gabriel (2014) reported that the separation of egg white from egg yolk and leaving the white at room temperature for 24 h could contribute to better quality of macarons than using just-seperated egg whites.

Increasingly, consumption of healthy food is the focus and desire for many consumers globally. Many bakery products are high in fat and sugar and may be considered unhealthy. Therefore, improvement of bakery products could be achieved by reduction in fat and sugar, as well as fortification with fiber, using gluten-free and dairy-free constituents and developing low glycemic index products. The four main ingredients of macarons are ground almond, granulated sugar, confectioner's sugar and egg white. In order to develop a healthy macaron, the reduction of sugar has to be considered because their levels are high, but besides giving sweetness, sugar is a functional ingredient affecting the structure, texture and flavor of macarons (Annie, 2012). Annie (2012) also reported that different sugars (granulated and confectioner's sugars) used in the recipe can impact on appearance, especially the height of the foot, the shiny surface and the texture of macaron shells. Therefore, the effects of reducing the granulated and confectioner's sugars levels on the quality of macarons using Response Surface Methodology (RSM) was the aim of this study.

Materials and methods

Materials

Chicken eggs (Sanchai Farm brand), were bought from Tesco Lotus, supermarket. The eggs were separated into yolks and whites and the whites were aged by keeping them in air tight containers at 5^oC for 7 days. The other ingredients used were granulated sugar, confectioner's sugar and ground almonds, all purchased from a local bakery shop.

Preparation of macaron shell

The prepared aged egg whites were used to make macaron shells by adapting the recipe and method from Chef Pierre Herme (Pierre, 2015). Normally marcaron making is usually divided into two parts; almond paste and meringue parts. Almond paste consisted of 150g of almond powder and 150g confectioners' sugar sifted together that was then added to 50g of aged egg white, almond powder and confectioner's sugar and mixed well untill it became a paste. For meringue part, 150g granulated sugar and 40g water were heated to 118 ℃ then 50g of aged egg white was whisked into the mixture using a standing mixer (Artisan Kitchen Aid) at a speed 6 for 2 min. The syrup was then slowly poured into the whisked egg white and continuously whisked untill the temperature had reduced to 40 ℃. The whisking attachment was changed to paddle and the almond paste was added and mixed at a speed 1 for 2 min. The macaron batter was then deposited in a round shape (3cm in diameter) on a Teflon sheet and allowed to stand for 15 min after which time the deposited macaron pan was taken to the convection oven for baking at 130 ℃ for 12 min. The macaron shell was analyzed and its properties were measured.

Experimental design

Response surface methodology (RSM) was applied to optimize reduced amountss of granulated and confectioner's sugars (X_1, granulated sugar; X_2, confectioner's sugar) for producing the reduced sugar macaron containing minimum firmness and cohesiveness of macaron batter and fracturability, hardness and cohesiveness of macaron shells using Design Expert software version 7.0.0 (Stat-Ease Inc., Minneapolis, MN, USA). Central composite design was employed to establish the model. The minimum and maximum of both sugars used in this optimization were 120 g and 150 g. Each independent variable was at three levels: -1 (low level), +1 (high level) and 0 (center point) (Table 1). The design scheme consisted of 13 treatments with five replicates of center point and all the designs were done in duplicate. Independent variables, their process levels and the experimental results concerning firmness of macaron batter (Y1), cohesiveness of macaron batter (Y2), fractubility of macaron shells (Y3), hardness of macaron shells (Y4) and cohesiveness of macaron shells (Y5) are shown in Table 1. The experimental data were fitted to the second-order polynomial model given below (1):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X^2{}_1 + \beta_{22} X^2{}_2 + \beta_{12} X_1 X_2 \quad (1)$$

where Y was the dependent variable (response), β is the regression coefficient where β_0 was intercept term, β_1 and β_2 were linear terms, β_{11} and β_{22} were quadratic terms and β_{12} was interaction term. X_1 and X_2 were independent variables.

The effects of the amount of both sugars on the textural properties of macaron batter amd macaron shells were also determined. The prediction model of the reduced granulated and confectioner's sugars together with all responses was conducted to obtain the minimum amounts of each sugar that is needed to be used but still resulting in the good properties of macaron shells.

Texture measurement of macaron batter

Firmness (maximum force) and cohesiveness of 150 g of macaron batter was measured using a Texture Analyzer (TX-TA PLUS) with a backward extrusion probe (40 mm diameter disc, P40). The pre-test, test and post-test speeds used were 3.0, 3.0 and 1.0 mm/s, respectively. The compression distance was 3 cm. Three replications were used in the test.

Texture measurement of Macaron shells

The textural properties of macaron shell was evaluated using a Texture Profile Analysis (TPA) programme using a Texture Analyzer (TA-XT Plus) with compression platen diameter probe of 75mm (P75). The fracturability (the first broken force), hardness (maximum force) and cohesiveness were determined on 10 macaron shells. The pre-test, test and post-test speeds were used 0.5, 0.5 and 1.0 mm/s, respectively. Fifty percent of strains were set for the test.

Sensory evaluation

The macaron shells made from the control (no reduced sugar) and the reduced sugar recipe were tested by 10 professional chef panalists who had experience in the bakery industry of at least 5 years and had made macarons previously. Using a 9-point hedonic scale, roundness of shape, height of feet, porosity, hardness, chewiness and overall likeing of macaron shell were assessed.

Statistical analysis

Data was subjected to statistical analysis using one-way analysis of variance (ANOVA). Sensory analysis used a randomized complete block design (RCBD). A t-test was used for analyzing significant differences between two samples of macaron shells at $p \leq 0.05$ level by using SPSS version 16.0. The experiment was carried out in triplicate.

Results

Optimiztion of the reduced amount of granulated and confectioner's sugars

The experimental results, including firmness of batter (Y1), cohesiveness of batter (Y2), fracturability of macaron shells (Y3), hardness of macaron shells (Y4) and cohesiveness of macaron shells (Y5) of each run of the experiment are shown in Table 1. The analysis of the data shows the effects of the amount of granulated sugar (X1) and the amount of confectioner's sugar (X2) on firmness and cohesiveness of batter and fracturability, hardness and cohesiveness of macaron shells that were described by fitted second-order polynomial models (Table 2 and 3). The *p*-values showed fracturbility and hardness of shells was highly significantly related to the the two variables for the amount of granulated and confectioner's sugars (Table 2). The regression models showed statistically significant ($p \leq 0.05$) correlations, with a high coefficient of determination (R^2) and no significant lack-of-fit (Table 2).

Effects of granulated sugar and confectioner's sugar on each response

The effects of granulated sugar and confectioner's sugar on the firmness and cohesiveness of macaron batter are shown in Figure 1, which indicated that granulated sugar increased that in turn resulted in the firmness and cohesiveness of macaron batter decreasing. Conversely, the increased level of confectioner' sugar increased the firmness and cohesiveness of macaron batter.

The effect of granulated sugar and confectioner's sugar on the fracturability, hardness and cohesiveness of macaron shells are shown in Figure 2. Increasing granulated sugar and confectioner's sugar resulted in increased fracturability and hardness of macaron shells. The maximum amount of granulated sugar plus the maximum amount of confectioner's sugar could lead the highest levels of hardness of macaron shells. The cohesiveness of macaron shells increased with decreasing granulaled sugar until a certain level affected the cohesiveness of macaron shells that then increased. Increased levels of confectioner's sugar resulted in increased in the cohesiveness of macaron shells. In addition, the maximum amout of confectioner's sugar, no matter amount of the granulated sugar, resulted in the highest cohesiveness of macaron shells.

The values of the minimum amounts of the granulated and confectioner's sugar and its response predicted from the model

The optimum values of all the variable factors for obtaining the minimum amounts of both sugars in making macaron shells are shown in Table 4. From preliminary results (data not shown) the firmness and cohesiveness of macaron batter should be a minimum to obtain even porosity and crumb and for their fracturabilty, hardness and cohesiveness they should be brittle outside and be soft, and easy to chew. Therefore, all factors were set as minimum values. To obtain the minimum amount of both sugars, the prediction model was manipulated and the result showed in Table 4. From this it appears that the minimum amount of granulated sugar was 130.46g and confectioner'sugar was 125.66g. These resulted in levels of firmness of batter of 0.098 kg force, the cohesiveness of batter was 162.32 and the fracturability, hardness and cohesiveness was 0.26 kg force, 4.21 kg force and 0.25, respectively (Table 4).

Table 1. Central composite design of two variables with their observed responses

Experiment	Independent variables: X_1: Amount of granulated sugar — Coded	X_1: Actual (g)	X_2: Amount of confectioner's sugar — Coded	X_2: Actual (g)	Responses: Y_1: Firmness of batter (kg.force)	Y_2: Cohesiveness of batter	Y_3: Fracturability of shell (kg.force)	Y_4: Hardness of shell (kg.force)	Y_5: Cohesiveness of shell
1	-1	120	-1	120	0.166	231.16	0.141	3.965	0.27
2	-1	120	-1	135	0.110	178.63	0.216	4.259	0.30
3	-1	120	-1	150	0.138	199.44	0.340	4.350	0.33
4	0	135	0	120	0.109	176.28	0.324	4.241	0.28
5	0	135	0	135	0.087	142.78	0.314	4.350	0.27
6	0	135	0	135	0.079	148.03	0.334	4.369	0.27
7	0	135	0	135	0.056	104.45	0.346	4.360	0.25
8	0	135	0	135	0.098	166.27	0.347	4.385	0.26
9	0	135	0	135	0.096	174.63	0.360	4.363	0.24
10	0	135	0	135	0.090	162.74	0.456	4.488	0.31
11	+1	150	+1	120	0.069	127.57	0.442	4.474	0.36
12	+1	150	+1	135	0.100	170.86	0.509	5.007	0.37
13	+1	150	+1	150	0.154	236.35	0.580	5.733	0.38

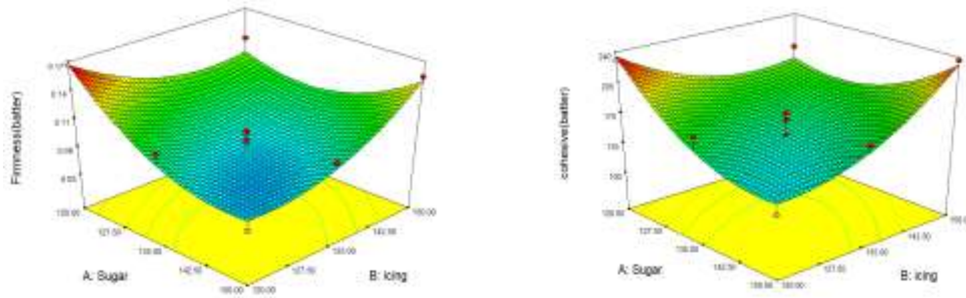
Table 2. The *p*-value of the second-order polynomial models of the amount of granulated sugar (X_1) and the amount of confectioner's sugar (X_2) and the responses (firmness of batter, cohesiveness of batter, fracturability of shells hardness of shells and cohesiveness of shells) and the coefficients of determination (R^2)

Coefficient	**Firmness of batter (Y_1)**	**Cohesiveness of batter (Y_2)**	**Fracturability of shell (Y_3)**	**Hardness of shell (Y_4)**	**Cohesiveness of shell (Y_5)**
Model	0.0171*	0.0424*	<0.0001*	<0.0001*	0.0004*
X_1	0.0792	0.2487	<0.0001	<0.0001	0.0008
X_2	0.4197	0.3187	<0.0001	<0.0001	0.0224
X_1X_2	0.0168	0.0227	0.1665	<0.0001	0.2349
X_1^2	0.0431	0.0928	0.7069	<0.0001	0.0004
X_2^2	0.0908	0.1569	0.0304	0.8199	0.0776
$X_1^2X_2$	-	-	-	<0.0001	-
$X_1X_2^2$	-	-	-	0.0002	-
Lack of fit	0.3863^{ns}	0.6992^{ns}	0.3022^{ns}	0.9231^{ns}	0.2684^{ns}
R^2	0.81	0.75	0.98	0.99	0.89

* Significantly difference ($p \leq 0.05$), ^{ns} no significant difference (p>0.05)

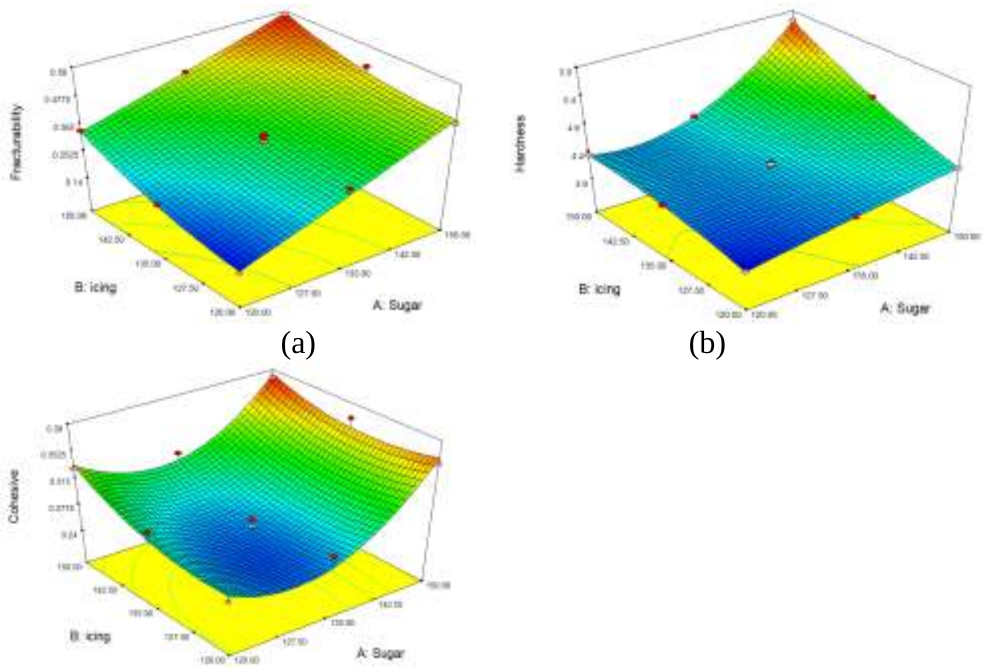
Table 3. The prediction model of each responses and two variables of the amount of granulated sugar (X_1) and the amount of confectioner's sugar (X_2)

Responses		**Prediction model**	**R^2**
Firmness of batter (kg.Force)	=	$0.082-0.015X_1+0.0063X_2+0.028X_1X_2+0.027X_1^2+0.021X^2$	0.81
Cohesiveness of batter	=	$147.01-12.41X_1+10.59X_2+35.13X_1X_2+28.29X_1^2+23.05X_2^2$	0.75
Fracturability of macaron shell (kg. Force)	=	$0.36+0.14X_1+0.078X_2-0.015X_1X_2+0.0046X_1^2+0.032X_2^2$	0.98
Hardness of macaron shell (kg. Force)	=	$4.37+0.37X_1+0.12X_2+0.22X_1X_2+0.27X_1^2-0.0017X_2^2+0.29X_1^2X_2+0.099X_1X_2^2$	0.99
Cohesiveness of macaron shell	=	$0.26+0.035X_1+0.018X_2+0.01X_1X_2+0.059X_1^2+0.019X_2^2$	0.89



(a) (b)

Figure 1. Effects of the amount of granulated sugar, sugar (A) and confectioner's sugar, icing (B) on firmness of batter (a), cohesiveness of batter (b)



(a) (b)

(c)

Figure 2. Effects of the amount of granulated sugar, sugar (A) and confectioner's sugar, icing (B) on fracturability of macaron shell (a), hardness of macaron shells (b) and cohesiveness of macaron shells (c)

Table 4. The values of the minimum amount of the granulated and confectioner's sugar and its response (firmness and cohesiveness of batter, fracturability, hardness and cohesiveness of macaron shell) predicted from the model

Variables and responses	Values			
	Goal	Lower Limit	Upper Limit	Prediction
Amount of granulated sugar	Minimize	120	150	130.46
Amount of confectioner's sugar	Minimize	120	150	125.66
Firmness of batter	Minimize	0.056	0.166	0.098
Cohesiveness of batter	Minimize	104.45	236.35	162.32
Fracturability of shell	Minimize	0.14	0.58	0.26
Hardness of shell	Minimize	3.96	5.73	4.21
Cohesiveness of shell	Minimize	0.24	0.38	0.25

Sensory evaluation of the macaron shell from the control and reduced sugar recipe

The 10 panelists, who were the professional macaron chefs, were chosen for the sensory evaluation. Using a 9-point hedonuc scale they assesses the how much they liked the shape, height of macaron feet, shell porosity, hardness, chewiness and overall liking for macaron were tested. The result showed that no significant differences (p>0.05) in their score for how much they liked the shape, shell posity, hardness and overall liking between the macarons made from the control (no reduced sugar) and the macarons made from the reduced sugar recipe, but the feet height was significantly lower ($p \leq 0.05$) and chewiness was significantly higher ($p \leq 0.05$) for the reduced sugar recipe compared to the control (Table 5). The panelists liked the chewiness properties of macaron shell made from reduced sugar rather than the control, but the control had higher liking scores for the height of feet compared to the reduced sugar recipe.

Table 5. Sensory evaluation (9-point hedonic scale) of macaron shell from control recipe (A) and macaron shell from reduced sugar (B) (n=10)

Attributes	samples	N	Sensory score	t	Sig.
Round shape	A	10	7.00 ±0.94	0.768	0.45
	B	10	7.40 ±1.35	0.768	
Height of macaron foot	A	10	6.90 ±1.52	-2.829	0.01*
	B	10	5.20 ±1.14		
Shell porosity	A	10	6.00 ±2.31	0.550	0.59
	B	10	6.50 ±1.71		
Hardness	A	10	6.70 ±0.67	-0.166	0.87
	B	10	6.50 ±1.77		
Chewiness	A	10	5.90 ±1.79	2.041	0.05*
	B	10	7.20 ±0.92		
Overall Liking	A	10	7.10 ±0.88	0.268	0.79
	B	10	7.20 ±0.79		

* Significantly different ($p \leq 0.05$)

Discussion

Optimization the amount of the reduced sugar, the predicted model and the effects of granulated sugar and confectioner'sugar on each response

The effects of granulated sugar on firmness and cohesiveness of macaron batter might be explained by the higher sugar content entrapping air and stabilizing air pockets longer so resulting in the firmness and cohesiveness of the batter increasing its fluffiness. Conversely, the increase in confectioner's sugar increased the firmness and cohesiveness of macaron batter, could be explained by the confectioner's sugar, to which the almond paste was added make before mixng giving more viscosity to the macaron batter. Likewise, the firmness and cohesiveness of macaron batter increased with the increase in confectioner's sugar. Similar results were shown by Annie (2012) who found that when the amount of sugar were increased, the macaron porosity was smaller and the texture were harder and well combined.

Increasing of both granulated sugar and confectioner's sugar resulted in increases in both fracturability and hardness of macaron shells because granulated sugar helped to build their structure making them harder, which improves the cohesiveness of macaron shells (Maache-Rezzoug *et al.*, 1998; Gallagher *et al.*, 2003; Pareyt *et al.*, 2009; Kawai *et al.*, 2014; Biguzzi *et al.*, 2015). Edward (2000) stated that sugar syrup added into egg-whites can coagulate protein, and make egg foam became more stable. Also, Arwa (2013) reported that the main effect of sucrose on foam stability was to increase the liquid viscosity around the bubbles that stabilizes the foam structure making macaron batter stable, unified, smooth and shiny. Using the maximum recommended amount both granulated sugar confectioner's sugar together (150g of each) can improve the hardness in macaron shells indicating that both types of sugar positively affected the fracturablity and hardness of macaron shells. Therefore, the amounts of both sugars are important for the firmness and cohesiveness of batter and ensuring that macaron shells are stronger and nicer appearance after baking. The suitable propotion of granualated and confectioner's sugars was major key for the fracturability and hardness of the macaron shells.

Comparative sensory evaluation of macaron shells from the control and reduced sugar recipe

The sensory evaluation the panel could detect no significant differences in most of the chacteristics that they were asked to assess (shape, shell porosity, hardness and overall liking) between macarons that were made from no reduced sugar and the reduced sugar recipes, but the feet height was lower and chewiness higher in the reduced sugar recipe compared to the no reduced sugar recipe. The Macaron Master (not dated) gave the top quality criteria for macarons as shell texture, filling texture, flavour (not overly sweet) and aesthetics, therefore it can be concluded that reducing the sugar would probably not affect the acceptability of the macarons. Also, when Kim *et al*. (2017) tested the sensory characteristics (color, flavor, taste, texture and overall acceptance) of macarons they found that it could be affected by additives for example Barbary fig flavoring. Also, Weenuttranon *et al*. (2019) showed that the type of almond powder used in macarons could affect their appearance as assessed by sensory panel. From this lack of effect on most of the factors tested it can therefore be concluded that the reduction of sugars in the recipes for macarons did not affect the most important sensory characteristic and could be used commercially because it would be a more healthy product.

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