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Development of reduced calorie chocolate cake with jackfruit seed (*Artocarpus heterophyllus* Lam.) flour and polydextrose using response surface methodology (RSM)

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Abstract: Response Surface Methodology (RSM) with Central Composite Rotatable Design (CCRD) was performed in this study to develop an acceptable reduced calorie chocolate cake. The range of the independent variables, namely Jackfruit Seed (JFS) flour (20-25% replacement of wheat flour) and polydextrose (10-15% replacement of sucrose) were identified which affect the volume, specific volume, symmetry and uniformity of the chocolate cake. The coefficient of determination, R^2 values for volume, specific volume, symmetry and uniformity were greater than 0.900. The optimum level for replacement of sugar with polydextrose was at 11% and wheat flour with JFS flour was at 16% with calorie reduction approximately 34% from the control cake formulation.

Keywords: Responses surface methodology, polydextrose, jackfruit seed flour

Introduction

High ratio cakes contain more sugar than flour and widely used in the baking industry (Rosenthal, 1995). However, due to its high caloric content, over consumption of cake may contribute to obesity. With the current trend in food industry, foods that contain low-calorie sugar- and fat-replacers are popular due to increase in nutritional and health awareness in the calorie reduction in the diet (Dilek *et al*., 2007). However, altering the ingredients and their levels, so as to reduce the calorie and increase the fiber content of the product, causes readily detectable losses in appearance, mouthfeel and texture (Amanda and Carole, 1991).

JFS flour has been successfully incorporated into bread at 25% level and was accepted by sensory panel (Hasidah and Noor Aziah, 2003). Thus, JFS flour can be substituted at a certain level for wheat flour to satisfy consumer demands for increased fibre content in cakes. The seed of jackfruit which is a waste from the fruit industry has commercial potential for application as a cheap source of fiber replacing wholemeal.

Sucrose acts as a tenderizer by retarding and restricting gluten formation, increase the temperature of eggs protein denaturation and starch gelatinization (Osman, 1975). Polydextrose (Litesse® from Danisco Sweeteners Ltd.) can be used as a sugar- and fat-replacer. Polydextrose is low in calorie (1 kcal/g) because it is poor gastrointestinal absorption and high resistance to microbial degradation in the colon (Figdor and Bianchine, 1983). The lack of sweetness of polydextrose would be an advantage in sucrose based food (Anibal and Raul, 1981). Polydextrose has similar technological properties to sugar and functions in food as humectants, bulking agent, stabilizer and texturiser. Polydextrose (Litesse®) is non-glycemic; hence it does not create insulin demand. Previous Study has shown that Litesse® promotes the growth of intestinal Lactobacillus and bifidus and their fermentation in the large intestine yields short-chain fatty acids (Danisco, 2003).

In recent years, the response surface methodology (RSM) has become the most popular optimization methods for optimizing a process when the independent variables have an interaction effects on the response (Tang *et al*., 2010). It had been used in many food researches and product developments such as in bread formulation (McCarthy *et al*., 2005), cookies (Lee *et al*., 2011) and cake (Neville and Setser, 1986). The purpose of this study are 1) to optimize the levels of polydextrose and JFS flour to partially replace sucrose in and wheat flour in producing reduced calorie chocolate cake and 2) to compare the physical chemical characteristics of optimized formulation with the control cake.

Materials and Methods

Materials

Polydextrose (Litesse® Ultra) was supplied by Danisco Sweeteners (M) Co., Ltd. The emulsifier, sucrose ester F-160 was obtained from Dai-Ichi

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Kogyo Seiyaku Co., Ltd. (Kyoto, Japan). The dry ingredients were purchased from Sunshine Trading Company, Penang. The jackfruit seed were supplied from Tropical Farm, Penang and processed into flour.

Jackfruit seed (JFS) flour preparation

The seeds were cleaned under running water and then boiled for 15 min. The seeds were cooled before the outer skin (hilum) was peeled off manually. The seeds were sliced and dried in air drying oven (model Afos Dryer). The dried seeds were then grounded into flour with 60 mesh of particle size.

Cake preparation

Formulation for chocolate cakes was prepared by a single bowl mixing method according to modified formulation from Neville and Setsar (1986) as shown in Table 1. The eggs, sugars, sucrose ester were mixed up for 2 and 5 min at the speed of 4 and 6 (Kitchen Aid Mixer, model 5-C, Hobart, IN), respectively. The mixture was then mixed at speed 8 for 2 min to form lighter, creamier and 'floppy' batter. After mixing, the sifted self-raising flour, JFS flour and cocoa powder were then added into a mixing bowl and mix at speed 2 for 2 min. Milk, margarine and polydextrose were heated together in saucepan until melted. The mixture was poured into bowl and mix at speed 2 for 1 minute. The batter (250 g) was then transferred to 12 cm x 5 cm x 4 cm greased tin cake pan and baked in an electric oven (model Salva Modular) at 180^0C for 35 min. The cakes were then removed from the oven and allowed to cool for 2 hours and were later packed in a 25 cm x 15 cm low-density polyethylene packages at room temperature for 24 hours prior to physical quality analysis. Data reported were based on the mean of three replications.

Table 1. Formulation of control and reduced calorie (RC) chocolate cake

Ingredients	Control cake (g)	RC cake (g)
Sugar	130	115.84
Margarine	45	35
Sucrose ester	8	12
Non fat milk	125	140
Egg	100	100
Cocoa powder	25	25
Self-raising flour	115	96.7
Polydextrose[a]	-	14.15
JFS flour[b]	-	18.32

[a] % replacement of sucrose
[b] % replacement of wheat flour

Experimental design

RSM was employed to determine the optimal combination of polydextrose and JFS flour replacement in development of reduced calorie cake using Stat-Ease software (Design Expert version 5.0.7, Corp., MN). Two independent variables namely polydextrose ($ß_1$) and JFS flour ($ß_2$) were chosen. At 5 levels and a total of 13 different combinations including five replicates of the centre point were chosen in random order according to a central composite rotatable design configuration for two factors (Cochran and Cox, 1957). The experimental design in the coded (x) and actual (X) levels of independent variables were related to the coded variables (xi, i = 1 and 2) by a second degree polynomial using the equation below.

$$\text{Responses}, Y = ß_0 + ß_1 (X_1) + ß_2 (X_2) + ß_{12} (X_1)(X_2) + ß_1^2 (X_1) + ß_2^2 (X_2)$$

The coefficients of the polynomial were represented by:

Responses, Y = scores of each physical properties evaluated
$ß_0$ = intercept
$ß_1$ = coefficient for polydextrose (poly) level at the first order term
$ß_2$ = coefficient for JFS flour level at the first order
$ß_{12}$ = coefficient for interaction among poly and JSF level
$ß_1^2$ = coefficient for poly level at the second order term
$ß_2^2$ = coefficient for JFS flour level at the second order level
(X_1) = % poly replacement of sucrose
(X_2) = % JFS replacement of wheat flour

The analysis of variance (ANOVA) tables were generated and the effect and regression coefficients of individual linear, quadratic and interaction terms were determined. The significances of all terms in the polynomial were judged statistically by computing the F-value at a probability (p) of 0.001, 0.01 or 0.05. The regression coefficients were then used to make statistical calculation to generate contour maps from the regression models.

Physical measurement of cakes

The volume of cake was determined by rapeseed displacement method according to Lin and Lin (2001). Proximate analyses of fat, ash, protein (N x 6.25), crude fibre, moisture and carbohydrate were conducted according to AOAC (1990) methods. The calorie value was determined according to Basil and Sandra (1983) method. Cake uniformity and symmetry was determined from the cross-sectioned cake tracing by AACC method 10-91 (2000). Specific volume (ml/g) was computed by dividing the cake volume by weight.

Statistical analysis

Data were analyzed by using SPSS version 11.0 (Illinois, US) using analyses of variance (ANOVA). Significant differences were tested using Duncan Multiple Range test.

Results and Discussion

Statistical analysis

Effect of replacement level of polydextrose and JFS flour on four dependent variables (volume, specific volume, symmetry and uniformity) of the cake are shown in Table 2. The estimated regression coefficients, R^2 and probability values for all dependent variables are tabulated in Table 3. The *P*-values were used as a tool for checking the significance of each coefficient, which indicated the interaction patterns between the variables (Chun *et al*., 2007). The smaller the *P*-value, the more significant was the corresponding coefficient (Karthikeyan *et al*., 1996). Table 3 showed that both the linear and quadratic term of all parameters (polydextrose, $ß_1$ and JFS flour, $ß_2$) had significant (at least at $p<0.05$) effect on all dependent variables. The R^2 values obtained were 0.9498, 0.9092, 0.9788 and 0.9678 for volume, specific volume, symmetry and uniformity, respectively. The closer the R^2 value to unity the better the empirical model fits the actual data, which supported by the lack of fit test. This meant that R^2 of more than 0.75 were satisfactory and considered accurate enough for prediction purposes (Irwandi *et al*., 2000).

Table 2. Effect of replacement level of polydextrose and JFS flour on four dependent variables

Run	Independent variables		Dependent variables			
	$X_1(x_1)$ Polydextrose[a] (%)	X_2 (x_2) JFS flour[b] (%)	Y_1 Volume[c] (ml)	Y_2 Specific volume (ml/g)	Y_3 Symmetry[c] (cm)	Y_4 Uniformity[c] (cm)
1	15.00 (+1)	25.00 (+1)	550	2.5	1.0	0
2	8.96 (-α)	20.00 (0)	560	2.5	1.5	0.15
3	12.50 (0)	20.00 (0)	560	2.6	1.7	0
4	10.00 (-1)	25.00 (+1)	560	2.52	0.7	0.15
5	16.04 (+α)	20.00 (0)	550	2.55	0.6	0.1
6	12.50 (0)	20.00 (0)	560	2.65	1.7	0
7	12.50 (0)	12.93 (-α)	565	2.59	1.65	0.1
8	12.50 (0)	20.00 (0)	560	2.6	1.7	0
9	12.50 (0)	20.00 (0)	560	2.6	1.7	0
10	15.00 (+1)	15.00 (-1)	555	2.65	1.0	0.15
11	12.50 (0)	27.07 (+α)	555	2.5	0.5	0.1
12	10.00 (-1)	15.00 (-1)	570	2.55	2.2	0.1
13	12.50 (0)	20.00 (0)	560	2.6	1.7	0

[a] % replacement of sucrose
[b] % replacement of wheat flour
[c] Mean of triplicate measurements

Effect on the volume

Figure 1 shows the response surface for the effect of independent variables on the volume of RC cake. As shown in Table 3, volume was negatively related to the linear effect of polydextrose ($p<0.001$) and JFS flour ($p<0.001$). The volume was significantly decreased with the increase level of polydextrose and JFS flour (Figure 1). Sugar delayed the starch gelatinization during cake baking and its allowed the air bubbles to expand by carbon dioxide and water vapour before the cake sets (Kim and Walker, 1992). As a result the cake structure was highly aerated and higher in volume. Delayed gelatinization of starch in sugar solution was attributed to the abilities of sugar to limit availability of water to starch granule, lowered the water activity, formation of sugar bridges between starch chains and formation of an anti plasticizing effect, relative to water (Kim and Walker, 1992). Therefore, lowering sugar by substituting polydextrose resulted in early gelatinization of starch during baking process and restricted the volume of cake. It was shown that substitution of JFS flour into the formulation resulted in a progressive decreased in loaf volume. To overcome the problem, prolong beating was carried out to incorporate air, and make the resultant batter was thicker than traditional batter.

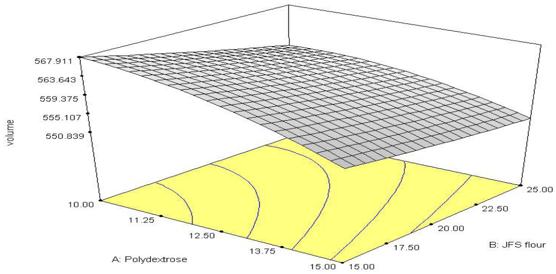

Figure 1. Response surface plot of the effects of polydextrose (% replacement of sucrose) and JFS flour (% replacement of wheat flour) on volume of reduced calorie (RC) cake

Effect on the specific volume

Figure 2 shows the response surface plot at different replacement level of polydextrose and JFS flour on specific volume. Table 3 indicated that specific volume was affected by polydextrose, with positive linear ($p<0.05$) and negative quadratic effects at $p<0.01$. However, the linear and quadratic effects of JFS flour were negative at $p<0.01$ and $p<0.05$, respectively (Table 3). As the JFS flour replacement level increased the specific volume decreased. Hence, an increased in polydextrose and decreased in JFS flour might increased the specific volume of the RC cake (Figure 2).

Table 3. Estimated regression coefficient, R^2 and P or probability values, P for volume, specific volume, symmetry and uniformity

Coefficient	Volume (ml)	Specific volume (ml/g)	Symmetry (cm)	Uniformity (cm)
$ß_0$	560	2.61	1.70	0
$ß_1$	-4.89***	0.019*	-0.27***	-0.021**
$ß_2$	-3.64***	-0.038**	-0.39***	-0.012
$ß_1ß_2$	1.25	-0.038*	0.38***	-0.05
$ß_1^2$	-2.19**	-0.028**	-0.28***	0.059***
$ß_2^2$	0.31	-0.03*	-0.27***	0.047***
P-value	0.0002	0.0016	0.0001	0.0001
R^2	0.9498	0.9092	0.9788	0.9678

$ß_1$ = Polydextrose
$ß_2$ = JFS flour
* Significant at 0.05 level
** Significant at 0.01 level
*** Significant at 0.001 level

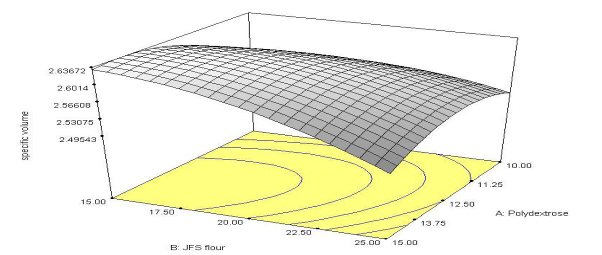

Figure 2. Response surface plot of the effects of polydextrose (% replacement of sucrose) and JFS flour (% replacement of wheat flour) on specific volume of reduced calorie (RC) cake

Effect on the symmetry

Replacement of polydextrose had a negative effect on the symmetry indices at linear and quadratic terms, showing significant levels at p<0.001 and p<0.001, respectively (Table 3). The same pattern also can be observed on the negative effect of JFS flour on the symmetry at linear (p<0.001) and quadratic (p<0.001) term (Table 3). Positive symmetry indices are desirable because they indicated peaked cake, whereas negative values indicate collapsed cakes (Shelke *et al*., 1992). Thus decreasing the replacement level of polydxtrose and JFS flour would increase the symmetry indices to positive values.

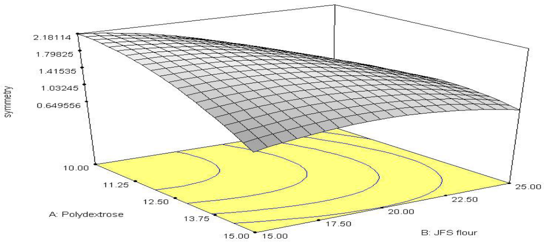

Figure 3. Response surface plot of the effects of polydextrose (% replacement of sucrose) and JFS flour (% replacement of wheat flour) on symmetry of reduced calorie (RC) cake

Effect on the uniformity

Table 3 shows that polydextrose have a negative linear and positive quadratic terms on the uniformity of RC cake which were significant at p<0.01 and p<0.001, respectively. To develop an 'optimum' cake should have uniformity indices of zero. Positive or negative values indicated that one side of the cake is higher than the other (Shelke *et al*., 1992).

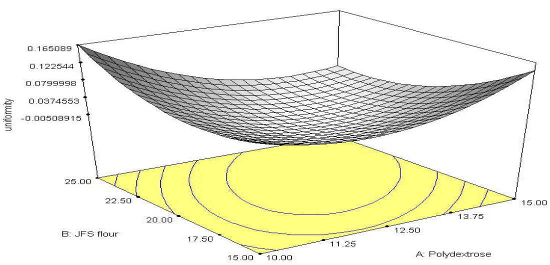

Figure 4. Response surface plot of the effects of polydextrose (% replacement of sucrose) and JFS flour (% replacement of wheat flour) on uniformity of reduced calorie (RC) cake

Proximate and physical measurement

Result of proximate analysis, physical analysis and calorie value of control and reduced calorie (RC) chocolate cake are shown in Table 4. RC cake was found to have significantly (p<0.05) higher moisture content compared to control cake (Table 4). The hygroscopic nature of polydextrose (Freeman, 1982) resulted moistness in RC cake than control cakes. It was also due to the high water absorption capacity of JFS flour which was 205% (dwb) higher than wheat flour, which was only 66.6% (dwb) (Vanna *et al*., 2002). This indicated that JFS flour has good ability in binding water.

Table 4. Proximate analysis (db), physical analysis and calorie value of control and reduced calorie (RC) chocolate cake**

Attribute	Control cake (%)	RC cake (%)
Moisture	$22.38^a \pm 0.007$	$31.17^b \pm 0.76$
Fat	$15.73^a \pm 0.28$	$3.52^b \pm 0.01$
Protein	$5.68^a \pm 5.68$	$9.89^b \pm 9.88$
Ash	$1.58^a \pm 0.01$	$5.02^b \pm 0.03$
Crude fiber	$0.91^a \pm 0.75$	$5.36^b \pm 0.17$
Carbohydrate[1]	53.72^a	45.04^b
Volume	$580^a \pm 0.70$	$570^b \pm 0.70$
Specific volume	$2.64^a \pm 0.28$	$2.63^a \pm 0.30$
Symmetry	$1.40^a \pm 0.28$	$2.20^a \pm 0.57$
Uniformity	0.00^a	0.00^a
Caloric value (kcal/100g)	$379^a \pm 0.70$	$251^b \pm 0.70$

db = dry basis
Mean values ± SD of triplicate analysis in the same row with different superscript letter are significantly different at p < 0.05 using Duncan's multiple range test.

As shown in Table 4, RC cake contained significantly (p<0.0.5) lower fat (3.52%) than the control cake (15.73%) due to effect of polydextrose as a fat replacer (Danisco, 2003). RC cake also indicated significantly (p<0.05) high content of crude fibre about 2.74% (dwb) as compared to control cake (0.84%) (dwb). This showed that partial replacement of JFS flour increase the fibre content in RC cake. As shown in Table 4, RC cake contained 255.29 kcal/100 g calorie values as compared to control cake (379 kcal/100 g) with calorie reduction approximately 34% from the control cake. The results was in compliance with the FDA regulation (Title 21, CFR Section 101.60 (b)(4)) that reduced calorie food may be used in the labeling of food if the food contain at least 25 percent fewer calories than the reference food (Code of Federal Regulations, 2010).

Optimization

In order to verify the optimum level of polydextrose and JFS flour in producing reduced calorie cake, Design Expert version 5.0.7 software was used with desired goals for each variables and responses as summarized in Table 5. The goals for polydextrose were set to follow Standard 1.2.3 - Mandatory Advisory Statements and Declarations Table 2 to clause 5 which stated not to exceed 25 g/100 g of food because it was potential for laxative effect (Allergen Bureau, 2010). Numerical optimization was carried out for this study. Table 6 presented the optimum level of polydextrose and JFS flour and its predicted and experimental values. The experimental values from the optimized formulation (11% polydextrose replacement for sucrose, 16% JFS flour replacement for wheat flour) for RC cake were as follow: volume (570 ml), specific volume (2.63 ml/g), symmetry (2.20 cm) and uniformity (0.00 cm). From Table 6, indicated that the different between the predicted and experimental results were less than

10%. Thus, showed the response model was adequate in prediction.

Table 5. Criteria and outputs for numerical optimization of reduced calorie (RC) chocolate cake

Criteria	Goal	Limit	output
Polydextrose[a] (%)	In the range	10-15	11.10
JFS flour[b] (%)	In the range	15-25	16.00
Volume (ml)	maximum	550-570	566.73
Specific volume (ml/g)	In the range	2.5-2.65	2.59
Symmetry (cm)	maximum	0.5-2.2	2.07
Uniformity (cm)	minimum	0-0.15	0.05
Desirability	-	-	0.78

[a] % replacement of sucrose
[b] % replacement of wheat flour

Table 6. Predicted and experimental values of the response variables at optimum formulation

Response variables	Optimum product		Difference (%)
	Predicted values	Experimental values[a]	
Volume (ml)	566.73	570 ± 0.70	0.57
Specific volume (ml/g)	2.59	2.63 ± 0.30	1.52
Symmetry (cm)	2.07	2.20 ± 0.57	5.9
Uniformity (cm)	0.05	0.00	1.00

[a] Mean ± SD of triplicate analysis

Conclusion

The optimization for the development of reduced calorie chocolate cake was successful in partially replacing sucrose with polydextrose at 11% and JFS flour at 16% by using Responses Surface Methodology (RSM). Final optimized cake formulations resulted in approximately 34% calorie reduction as compared to the control cake.

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