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Quality improvement of gluten-free doughnuts by using hydrocolloids

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ABSTRACT

Gluten-free foods are alternative products for consumers who have wheat gluten allergies, a symptom of celiac disease. However, replacing wheat with gluten-free flour usually results in the loss of some quality attributes of products. Hydrocolloids are widely used to improve the characteristics of gluten-free products. In this study, response surface methodology was applied to analyze the effect of hydrocolloids, including xanthan gum, carboxymethyl cellulose (CMC), and hydroxypropylmethyl cellulose (HPMC), on the physical and sensory properties of gluten-free yeast doughnuts. The flour base of gluten-free doughnuts contained jasmine rice flour, buckwheat flour, and corn flour at a weight ratio of 50:30:20, respectively. A face-centered central composite design with three hydrocolloids treated as independent variables was utilized to investigate their effects on the doughnuts' physical and sensory characteristics. Each of the hydrocolloids was set at a concentration range of 0-1 g/100 g. Results revealed that adding xanthan gum improved the mass change, moisture content cohesiveness, and chewiness of gluten-free doughnuts. HPMC helped improve the volume change and moisture content, and CMC enhanced the texture of gluten-free doughnuts. The combination of the three hydrocolloids at weight ratios of 0.5:0.5:0.5 and 1:1:1 significantly improved gluten-free doughnuts compared with the control and commercial products as indicated by their sensory scores and microstructure ($p<0.05$).

Keywords: gluten-free; doughnut; xanthan gum; hydroxypropylmethyl cellulose; carboxymethyl cellulose

1. INTRODUCTION

Gluten is found in the endosperm of some cereal grains, such as wheat, rye, and barley. It is composed of glutenin and gliadin that provide the structure necessary to form a dough. Gluten is a known allergen causing celiac disease symptoms, such as diarrhea, bloating, fatigue, and other health problems (Catassi and Fasano, 2008). As such, gluten-free products have a high demand (Hager et al., 2012; Hischenhuber et al., 2006, Puerta et al., 2020). Currently, some gluten-free bakery products, such as bread, cookies, and cakes, are commercially available. Mixed gluten-free flours, such as rice flours, corn starch, potato starch, soy flour, and buckwheat flour, have been successfully used. However, some properties of gluten-free products, especially their water holding capacity, are lost compared with those of conventional wheat products (Hager et al., 2012), leading to poor organoleptic characteristics (Puerta et al., 2020). Many studies have reported that the addition of some hydrocolloids, such as xanthan gum, carboxymethyl cellulose (CMC), and hydroxypropylmethyl cellulose (HPMC), can help improve the properties of gluten-free bakery products because of their gas retention promoting capability (McCarthy et al., 2005; Catassi and Fasano, 2008; Rosell and Marco, 2008; Hager and Arendt, 2013; Mohammadi et al., 2014).

Doughnuts are well-known wheat flour-based bakery products. Their important physical properties include texture and specific volume (Shih et al., 2001). Wheat gluten plays an important role in trapping air in doughnuts to create such desired properties. Therefore, such properties may be lost in gluten-free doughnuts. Previous studies showed that gluten-free doughnuts are formulated from rice flour combined with commercially available gluten-free flour containing garbanzo bean flour, potato starch, tapioca flour, sorghum flour, and fava flour with added xanthan gum (Melito and Farkas, 2013). Other studies have demonstrated that HPMC improves the properties of gluten-free soy doughnuts by acting as an oil barrier film on the surface of doughnuts and preventing oil migration (Kim et al., 2015). However, the final products developed in previous studies are not as satisfactory as control wheat samples. Although many alternative gluten-free flours have been explored in many other bakery products, few studies have focused on flour formulations combined with mixed hydrocolloids, especially in gluten-free doughnuts. Therefore, this study was conducted to investigate the effect of mixed hydrocolloids on the physical and sensory properties of gluten-free doughnuts based on mixed flours.

2. MATERIALS AND METHODS

2.1 Doughnut ingredients

Jasmine rice flour was purchased from a local community enterprise (Roi Et, Thailand). Buckwheat flour (Imported from Australia by BBI, Bangkok, Thailand) and corn flour (McGarrett, imported and repacked from the USA by Intercontinental Good, Bangkok, Thailand) were obtained from Foodland Supermarket (Bangkok, Thailand). CMC and HPMC were procured from Dow Chemical Co., Ltd. (Bangkok, Thailand). Xanthan gum was bought from Chemipan Co., Ltd. (Bangkok, Thailand). Instant dry yeast for bakery (Fermipan, AB MAURI Vietnam Ltd.) and other ingredients were purchased from a local market.

2.2 Doughnut preparation

Our doughnut recipe (Table 1) was modified from the one used by Melito and Farkas (2012). Wheat flour was replaced with a combination of gluten-free flours, including jasmine rice flour, buckwheat flour, and corn flour, at a ratio of 50:30:20 based on a preliminary experiment to prepare gluten-free doughnuts.

Wheat flour, milk powder, baking powder, and xanthan gum were mixed in a mixing bowl (KitchenAid, model 5k5ss, USA) and sieved to prepare the dough. Sugar and yeast were subsequently combined with the dry ingredients. Then, egg, vanilla extract, salt, and water were added. The mixture was mixed at speed level six of the mixing bowl for 5 min. Trans-fat free shortening with 100% fat (melting point of 47-48°C; Crisco, USA) and butter with 80% fat (melting point of 32-35°C; Allowrie, Thailand) were added and stirred at speed level six of the mixing bowl for 1 min to form the dough. The dough was proofed for 30 min at room temperature (35-37°C), cut into a circle with a diameter size of approximately 8 cm, and drilled into the middle cross-sectional area with a diameter pore size of approximately 1.5 cm to obtain a ring shape. The formed dough was proofed for 30 min at atmospheric temperature and deep-fried in 2 L of trans-fat free shortening (Crisco, USA) at 180°C. Each side of the control wheat doughnut and the gluten-free doughnut was fried for 60 and 50 s, respectively. The fried doughnuts were allowed to cool on paper towels.

Table 1. Doughnut formulations

Ingredients	Wheat doughnut*		Gluten-free doughnut	
	Weight (g)	% (flour basis)	Weight (g)	% (flour basis)
Wheat Flour	350.0	100.0	-	-
Jasmine rice flour	-	-	175.0	50.0
Buckwheat flour	-	-	105.0	30.0
Corn flour	-	-	70.0	20.0
Water	191.4	54.7	191.4	54.7
Shortening	28.4	8.1	28.4	8.1
Egg	37.8	10.8	37.8	10.8
Sugar	18.9	5.4	18.9	5.4
Milk powder	18.9	5.4	18.9	5.4
Yeast	9.0	2.6	9.0	2.6
Butter	28.4	8.1	28.4	8.1
Salt	4.7	1.4	4.7	1.4
Baking powder	4.7	1.4	4.7	1.4
Xanthan gum	3.5	1.0	0-3.5	0-1
CMC	-	-	0-3.5	0-1
HPMC	-	-	0-3.5	0-1
Vanilla extract	1.6	0.5	1.6	0.5

Note: *modified from Melito and Farkas (2013)

2.3 Experimental design

Response surface methodology with Design Expert version 6.0.8 (Stat-Ease Inc., MI, USA) was used to design the experiments. A non-rotatable face-centered central composite design (CCF) was chosen to generate the combination of the three independent variables, namely, xanthan gum, CMC, and HPMC. According to published literatures (Lazaridou et al., 2007; Turabi et al., 2010; Sabanis and Tzia, 2011) and preliminary experiments, each hydrocolloid was set at a concentration range of 0%-1% (w/w) based on the weight of flours. Twenty trials were conducted, and they comprised eight factorial points, six axial points, and six center points (Table 2). The suitable model was evaluated with least square regression to identify the significant effect of hydrocolloid concentration on the attributes of doughnuts, including mass change, volume change, density change, moisture, textural properties, and sensory score. The selected results were illustrated in three-dimensional graphs and scanning electron micrographs as determined by significant model fitting (F-test, $p<0.05$) with a nonsignificant lack of fit ($p>0.05$).

Table 2. Experimental design

Trials	Ingredient variables (g/100g flour)			Point type
	Xanthan gum (Coded unit)	CMC (Coded unit)	HPMC (Coded unit)	
GF1	0.5(0)	0.5(0)	0.5(0)	Center
GF2	0(-1)	1(1)	0(-1)	Axial
GF3	1(1)	0(-1)	0(-1)	Axial
GF4	0(-1)	1(1)	1(1)	Axial
GF5	0.5(0)	0.5(0)	0.5(0)	Center
GF6	0.5(0)	1(1)	0.5	Factorial
GF7	0.5(0)	0.5(0)	0.5(0)	Center
GF8	0(-1)	0(-1)	1(1)	Axial
GF9	0.5(0)	0(-1)	0.5(0)	Factorial
GF10	0.5(0)	0.5(0)	0(-1)	Factorial
GF11	0.5(0)	0.5(0)	1(1)	Factorial
GF12	0.5(0)	0.5(0)	0.5(0)	Center
GF13	1(1)	0.5(0)	0.5(0)	Factorial
GF14	1(1)	0(-1)	1(1)	Axial
GF15	0.5(0)	0.5(0)	0.5(0)	Center
GF16	0(-1)	0(-1)	0(-1)	Factorial
GF17	0(-1)	0.5(0)	0.5(0)	Factorial
GF18	0.5(0)	0.5(0)	0.5(0)	Center
GF19	1(1)	1(1)	0(-1)	Axial
GF20	1(1)	1(1)	1(1)	Factorial

Note: GF = gluten-free doughnut

2.4 Physical property evaluation

The doughnut samples before (fresh unproofed dough) and after frying were evaluated in terms of the percentages of changes in mass, volume, and density. The percentages of the changes in mass (%Δm), volume (%Δv), and density (%$\Delta\rho$) were calculated using Equations 1, 2, and 3. The bulk volume of the doughnut sample was measured through sesame displacement (AACC Approved method 10.05, 2000).

$$\%\Delta m = \left[\frac{mf - mi}{mi}\right] \times 100 \quad (1)$$

$$\%\Delta v = \left[\frac{vf - vi}{vi}\right] \times 100 \quad (2)$$

$$\%\Delta \rho = \left[\frac{\frac{mf}{vf} - \frac{mi}{vi}}{\frac{mi}{vi}}\right] \times 100 \quad (3)$$

where m_i and v_i are the initial mass (g) and bulk volume (mL), respectively, and m_f and v_f are the final mass (g) and bulk volume (mL) of the doughnut, respectively.

Texture profile analysis was performed using a texture analyzer TA-XT 2i (Stable Micro Systems, Surrey, UK). The crumb of the fried doughnut was cut into squares with dimensions of 2 cm × 2 cm × 2 cm. The test was conducted with a 50 mm-diameter cylinder probe at a speed of 2 mm/s and with 75% trigger-type strain. Hardness, springiness, cohesiveness, and chewiness were the recorded data.

For moisture content determination, the fried doughnut samples were placed in an aluminum bag and kept in a freezer (−18°C) for 24 h. The doughnut samples were removed from the freezer and allowed to equilibrate at room temperature (25±5°C). Each doughnut (approximately 2 g) was ground and subsequently dried in a hot air oven at 105°C to a constant weight (±0.005 g) taken for approximately 8 h (AOAC, 1995) to determine the moisture content.

2.5 Scanning electron microscopy

The microstructure of the selected experimental gluten-free doughnut was observed using a scanning electron microscope (JSM-IT300LV, JEOL, Japan) and compared with those of the control wheat doughnut and the gluten-free doughnut commercially available in a local market. The doughnut samples were cut into pieces with a size of 5 mm × 5 mm × 5 mm, freeze dried for 48 h, and kept in a vacuum-sealed aluminum-laminated bag until measurement. Each doughnut was placed in a sample holder, coated with gold, transferred to a SEM, and observed at 10 kV × 27 magnification.

2.6 Sensory evaluation

Sensory evaluation was carried out using 50 untrained panelists (20-40 years old), which included students and staff of Silpakorn University. All the doughnuts were coated with glaze (Sampaotong Food and Supply Ltd., Part., Thailand) before they were served. They were then scored using a 9-point hedonic scale with 1 being "dislike extremely," 5 being "neither like nor dislike," and 9 being "like extremely." The doughnut samples selected on the basis of their characteristics and physical properties were used for sensory evaluation and compared with the control wheat and commercially available gluten-free doughnuts. The doughnut samples blinded with three-digit codes were simultaneously but randomly served to each panelist who was asked to taste each sample and evaluate their liking in terms of product attributes, including appearance flavor, taste, texture, and overall perception.

2.7 Statistical analysis

Design Expert version 6.0.8 (Stat-Ease Inc., MI, USA) was applied to generate response surface plots and statistically analyze data using a regression model to describe the effect of hydrocolloids on the physical properties of gluten-free doughnuts. The significance of the regression model was determined via ANOVA, coefficient of determination (R^2), and coefficient of variation (% C.V.). Sensory data were analyzed using SPSS version 16.0 (SPSS Inc., Chicago) following a randomized complete block design treated as blocks by the panelists. Means were compared via Duncan's new multiple range test, and statistical significance was determined at 95% confidence ($p<0.05$).

3. RESULTS AND DISCUSSION

The characteristics of the control wheat doughnut and the commercially available gluten-free doughnut were measured in terms of moisture content, hardness, springiness, cohesiveness, and chewiness (Table 3). Only the changes in mass, volume, and density of the experimental control wheat doughnut were evaluated. The moisture content, hardness, and chewiness of the commercially available gluten-free doughnut, purchased from a local market in Thailand, were higher than those of the control wheat doughnuts. The springiness and cohesiveness of the control wheat doughnuts were higher than those of the commercially available gluten-free doughnuts. The physical properties of the experimental gluten-free doughnut samples are shown in Table 4.

Table 3. Physical properties of the control wheat and commercially available gluten-free doughnuts

Trials	Mass change (%)	Volume change (%)	Density change (%)	Moisture content (%)	Hardness (N)	Springi-ness	Cohesive-ness	Chewi-ness
Control Doughnut	3.75± 0.71	127.62± 14.60	-53.97± 3.10	26.72± 1.21	3.89± 0.23	0.49± 0.01	0.76± 0.02	1.45± 0.09
Commercial Gluten-free Doughnut	-	-	-	33.82± 0.57	36.76± 2.73	0.18± 0.06	0.42± 0.06	4.79± 0.65

Table 4. Treatment combinations with three variables for eight response variables in a non-rotatable (face centered) central composite design

Trials	Ingredient variables (g/100 g flour)			Responses							
	Xanthan gum (Coded unit)	CMC (Coded unit)	HPMC (Coded unit)	Mass change (%)	Volume change (%)	Density change (%)	Moisture content (%)	Hard-ness (N)	Springi-ness	Cohesive-ness	Chewi-ness
GF1	0.5(0)	0.5(0)	0.5(0)	-1.05	47.45	-32.89	24.14	12.93	0.26	0.59	2.37
GF2	0(-1)	1(1)	0(-1)	5.31	22.32	-13.89	21.12	12.06	0.32	0.45	1.74
GF3	1(1)	0(-1)	0(-1)	-0.07	16.82	-14.46	29.24	12.76	0.26	0.72	2.41
GF4	0(-1)	1(1)	1(1)	-1.28	31.27	-24.73	21.45	9.56	0.31	0.56	1.68
GF5	0.5(0)	0.5(0)	0.5(0)	2.66	48.07	-27.06	25.70	9.61	0.25	0.63	1.50
GF6	0.5(0)	1(1)	0.5	1.98	39.14	-26.68	25.47	9.87	0.29	0.60	1.69
GF7	0.5(0)	0.5(0)	0.5(0)	2.48	46.30	-29.93	28.56	11.79	0.25	0.61	2.42
GF8	0(-1)	0(-1)	1(1)	4.43	36.37	-16.70	25.02	10.29	0.29	0.43	1.26
GF9	0.5(0)	0(-1)	0.5(0)	-0.33	25.97	-20.86	28.26	10.82	0.21	0.66	1.48
GF10	0.5(0)	0.5(0)	0(-1)	2.62	30.24	-21.19	22.50	9.45	0.29	0.48	1.30
GF11	0.5(0)	0.5(0)	1(1)	-1.86	37.26	-28.49	28.20	15.27	0.23	0.50	1.78
GF12	0.5(0)	0.5(0)	0.5(0)	-0.08	45.31	-31.21	26.69	12.97	0.26	0.51	2.04
GF13	1(1)	0.5(0)	0.5(0)	-1.28	27.81	-22.73	28.87	16.92	0.29	0.66	3.21
GF14	1(1)	0(-1)	1(1)	-0.33	21.97	-18.28	27.88	12.69	0.29	0.77	2.84
GF15	0.5(0)	0.5(0)	0.5(0)	0.97	43.40	-29.57	25.32	11.21	0.25	0.65	1.78
GF16	0(-1)	0(-1)	0(-1)	2.73	20.04	-14.43	19.25	9.86	0.29	0.50	1.43
GF17	0(-1)	0.5(0)	0.5(0)	2.18	28.30	-20.36	27.85	8.61	0.31	0.45	1.17
GF18	0.5(0)	0.5(0)	0.5(0)	1.01	46.51	-28.84	28.83	11.61	0.31	0.69	2.45
GF19	1(1)	1(1)	0(-1)	-0.86	31.05	-24.35	29.74	9.94	0.25	0.72	1.82
GF20	1(1)	1(1)	1(1)	3.25	55.10	-33.42	31.67	8.15	0.23	0.59	3.28

Note: GF = gluten-free doughnut

3.1 Effect of hydrocolloids on the changes in mass, volume, and density

According to our response surface model evaluation via ANOVA (Table 5), the quadratic model was appropriate (p<0.05) for explaining the relationship between the change in mass and the concentrations of xanthan gum and CMC and had a nonsignificant lack of fit (p>0.05). An example of a three-dimensional graph illustrating the effect of the CMC and xanthan gum concentrations on the change in the mass of gluten-free doughnuts is shown in Figure 1. An increase in the xanthan gum and CMC concentrations negatively affected the mass change, whereas the effect of HPMC was not significant and thus excluded from the quadratic model. Kim et al. (2015) reported that mass change is related to oil uptake in doughnuts. Gluten-free doughnuts absorb a lower amount of oil than wheat doughnuts do because the added hydrocolloid acts as an oil barrier film. However, the varied amounts of the experimental hydrocolloids would be insufficient to elicit an obvious influence on the change in the mass of doughnuts.

The effects of xanthan gum, CMC, and HPMC levels on the change in the volume of doughnuts could be explained using the quadratic regression model (p<0.05; Table 5). However, the effect of the hydrocolloids on the change in the volume of doughnuts was not so obvious and the predictive model was weakly reliable because of the significant lack of fit (p<0.05) and the low adjusted R^2. Only CMC and HPMC significantly influenced the change in the volume of doughnuts (p<0.05). As demonstrated in Figure 2, xanthan gum and CMC concentrations were significantly associated with the change in the volume of doughnuts (p<0.05). This result was supported by the previous findings of Lazaridou et al. (2007), who reported that the addition of xanthan gum and CMC causes an increase in the specific volume of gluten-free bread. The doughnut volume increased as a result of hydrocolloid addition because of the ability of hydrocolloids to enhance the gas retention capacity of doughnut (Gujral et al., 2003).

The effect of hydrocolloid concentration on the change in the density of doughnuts followed the quadratic regression model ($p<0.05$) with a nonsignificant lack of fit ($p>0.05$) and a relatively high coefficient of determination (Table 5). All the hydrocolloids significantly affected the change in the density of doughnuts ($p<0.05$). Similar to the effect of hydrocolloids on the change in volume, a significant association of xanthan gum and CMC concentrations with the change in the density of doughnuts was observed ($p<0.05$; Figure 3). These results could be explained by the inverse relationship between volume and density.

Table 5. ANOVA and regression coefficients of the response variable (in terms of actual factors)

Variables	Estimated coefficient responses				F-values			
	Mass change	Volume change	Density change	Moisture content	Mass change	Volume change	Density change	Moisture content
Model	Quadratic	Quadratic	Quadratic	Linear	10.15*	4.89*	11.85*	8.11*
Constant	11.35	22.92	-8.39	21.79	-	-	-	-
X_1	-24.56	19.91	-32.33	6.54	18.14*	0.54	13.21*	21.29*
X_2	-8.49	8.67	-12.75	-0.04	2.51	8.65*	23.27*	0.004
X_3	-	16.18	-11.90	1.47	-	9.82*	18.12*	3.04
X_1^2	11.96	-30.54	26.59	-	7.56*	4.16	15.37*	-
X_2^2	-	-12.56	8.40	-	-	0.70	1.53	-
X_3^2	-	-7.75	4.12	-	-	0.27	0.37	-
X_1X_2	12.100	25.09	-5.16	-	12.39*	8.18*	1.69	-
X_1X_3	-	1.96	3.72	-	-	0.05	0.88	-
X_2X_3	-	5.76	-3.29	-	-	0.43	0.69	-
Lack of fit	-	-	-	-	3.80	10.67*	0.13	1.66
R^2	0.73	0.81	0.91	0.60	-	-	-	-
Adjusted R^2	0.65	0.65	0.84	0.53	-	-	-	-

Note: X1 = xanthan gum, X2 = CMC, X3 = HPMC; * significant at $p<0.05$

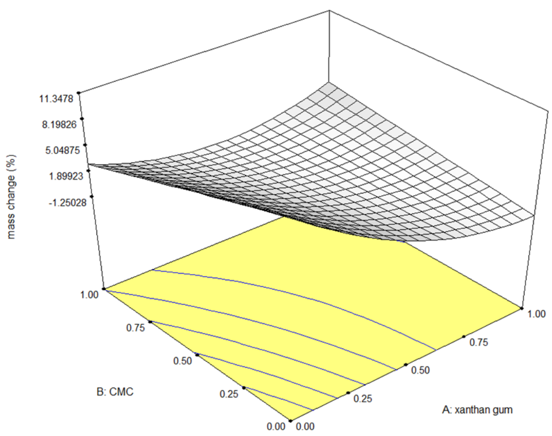

Figure 1. Effect of xanthan gum and CMC concentrations on the change in the mass of gluten-free doughnuts at an HPMC concentration of 0.50% flour basis

3.2 Effect of hydrocolloids on moisture content

Moisture content is one of the key factors contributing to the textural properties of doughnuts. The water binding capacity of hydrocolloids helps prevent bread crumb degradation during storage (Mohammadi et al., 2014). Our experimental results revealed that gluten-free doughnuts without the added hydrocolloids (GF16) had the lowest moisture content (19.25%). By contrast, doughnuts with high levels of the three hydrocolloids had the highest moisture content (31.67%). The moisture content of gluten-free doughnuts increased when the hydrocolloid concentration increased because of the water holding capacity of CMC, xanthan gum, and HPMC (Mariotti et al., 2013; Burešová et al., 2016). A linear regression model with xanthan gum concentration as a significant single variable ($p<0.05$) was used to describe the effect of hydrocolloids on the moisture content of gluten-free doughnuts (Table 5). Figure 4 shows the effect of xanthan gum and CMC on the moisture content of doughnut. The similar dominant effect of xanthan gum on moisture content of bread has also been reported by Mohammadi et al. (2014). However, the variations in the moisture contents of the replicated doughnut samples formulated at center points (GF1, GF5, GF7, GF12, GF15, and GF18) were possibly attributed to the unsteady relative humidity because the experiments were conducted under uncontrolled atmospheric conditions.

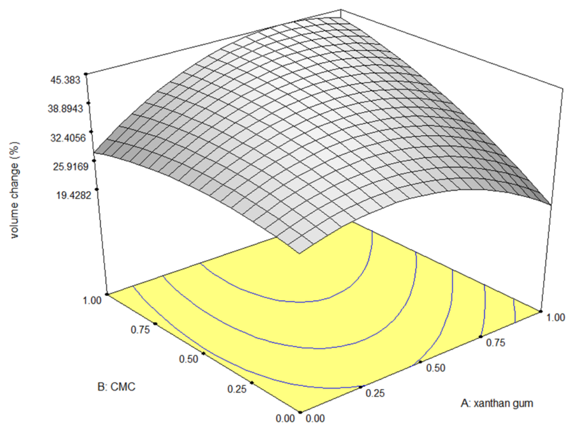

Figure 2. Effect of xanthan gum and CMC concentrations on the change in the volume of gluten-free doughnuts at an HPMC concentration of 0.50% flour basis

3.3 Effect of hydrocolloids on textural properties

The textural properties of doughnuts influence consumers' acceptance. For example, hardness and cohesiveness are associated with the softness and crumbling of doughnuts. Liu et al. (2018) showed that xanthan gum and HPMC have a softening effect on gluten-free steamed bread. Among the four textural parameters measured in this study (hardness, springiness, cohesiveness, and chewiness), only the effects of hydrocolloids on cohesiveness and chewiness were significantly observed and explained with the linear regression model (p<0.05; Table 6). However, the coefficient of determination of the predictive model was not very high, and xanthan gum was the only variable significantly associated with cohesiveness and chewiness in the linear regression model (p<0.05). However, the non-significant effect of xanthan gum on cohesiveness of gluten-free bread has been reported by Burešová et al. (2016). The effects of hydrocolloids on the textural properties of gluten free-products differed because their chemical structures and amounts used vary in terms of ingredients in different product formulations and processing methods (Mir et al., 2016). The effect of xanthan gum on the textural properties of gluten-free doughnuts in this study was not so obvious because of its low and narrow concentration range.

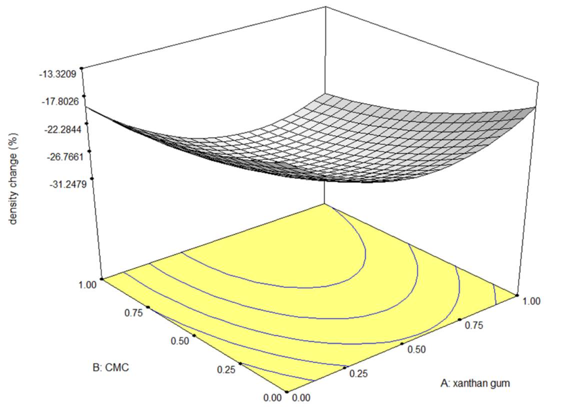

Figure 3. Effect of xanthan gum and CMC concentrations on the change in the density of gluten-free doughnuts at an HPMC concentration of 0.50% flour basis

3.4 Microstructure of doughnuts

The microstructures of the experimental gluten-free doughnut samples selected on the basis of their sensory property discretion (Ratios of xanthan gum, CMC, HPMC at 0:0:0, 0.5:0.5:0.5 and 1:1:1), control wheat doughnuts, and commercially available gluten-free doughnuts were observed under a scanning electron microscope (Figure 5). The porosity of the inner microstructure of the doughnuts was formed by ruptured cells because of water migration during frying. The air cells in the gluten-free doughnuts added with hydrocolloids were larger and more evenly distributed than those in the control sample without hydrocolloids and the commercially available doughnuts because of the crumb porosity of gluten-free doughnuts. However, the formation and distribution of air cells in the experimental gluten-free doughnuts were slightly poorer than those of the control wheat doughnut. The addition of hydrocolloids, such as HPMC, to gluten-free doughnuts results in the formation of denser inner structures and less porosity than those of control wheat samples (Kim et al., 2015). Nevertheless, with the addition of hydrocolloids to gluten-free doughnuts, air cells become stable (Figures 5C and 5D) by forming a thick layer on their surface, hence reducing the opportunity for coalescence of individual gases in cells to remain a separate discrete entity of gas bubbles. Consequently, their morphological characteristics become more stable than that of the control gluten-free sample (Figure 5B). Similarly, Ozkoc et al. (2009) explained the influence of hydrocolloid addition on the stability of gas cells in bread.

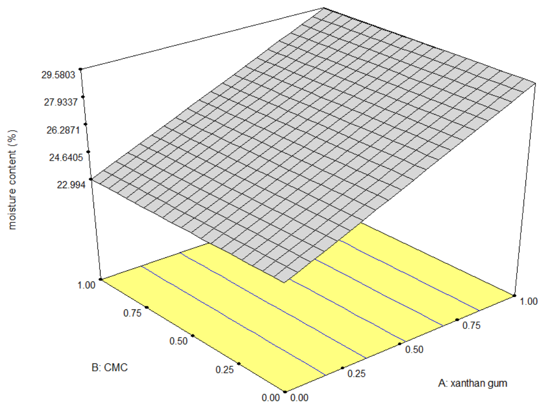

Figure 4. Effect of xanthan gum and CMC concentrations on the moisture content of gluten-free doughnuts at an HPMC concentration of 0.50% flour basis

Table 6. ANOVA and regression coefficients of the response variable (in terms of actual factors)

Variables	Estimated coefficient responses				F-values			
	Harness	Springiness	Cohesive-ness	Chewiness	Harness	Springiness	Cohesive-ness	Chewiness
Model	Linear	Quadratic	Linear	Linear	0.39	1.71	8.44*	7.98*
Constant	10.80	0.27	0.49	1.06	-	-	-	-
X_1	2.02	-0.14	0.22	1.26	2.13	4.96	24.86*	21.17*
X_2	-1.37	0.11	-0.03	0.16	0.98	0.53	0.45	0.33
X_3	0.38	0.02	-0.006	0.43	0.08	0.74	0.02	2.43
X_1^2	-	0.13	-	-	-	4.54	-	-
X_2^2	-	-0.05	-	-	-	0.70	-	-
X_3^2	-	-0.02	-	-	-	0.06	-	-
X_1X_2	-	-0.07	-	-	-	3.18	-	-
X_1X_3	-	0.006	-	-	-	0.03	-	-
X_2X_3	-	-0.04	-	-	-	0.87	-	-
Lack of fit	-	-	-	-	4.01	1.78	1.48	1.34
R^2	0.16	0.61	0.61	0.59	-	-	-	-
Adjusted R^2	0.01	0.25	0.54	0.52	-	-	-	-

Note: X1 = xanthan gum, X2 = CMC, X3 = HPMC; * significant at p<0.05

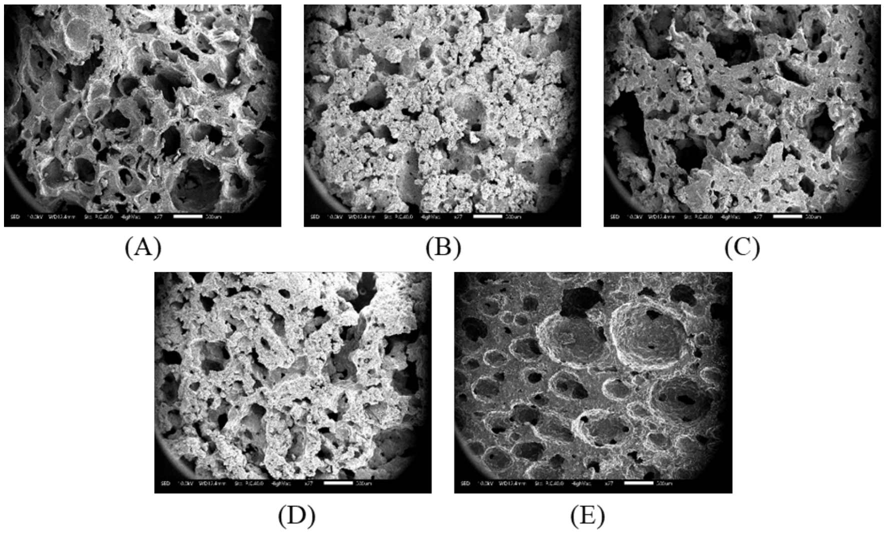

Figure 5. Scanning electron micrographs illustrating the microstructure of doughnuts: (A) control wheat doughnut, (B) GF (0:0:0), (C) GF (0.5:0.5:0.5), (D) GF (1:1:1), (E) commercially available gluten-free doughnut

3.5 Sensory Evaluation

The sensory hedonic scores of the selected gluten-free, wheat, and commercially available gluten-free doughnuts are presented in Table 7. The sensory scores of all attributes of the experimental gluten-free doughnuts were significantly lower than those of the control wheat doughnut (p<0.05). However, the hedonic scores (p<0.05), especially for taste, texture, and overall acceptance, of the gluten-free doughnuts with the added hydrocolloids at xanthan gum, CMC, and HPMC ratios of 0.5:0.5:0.5 and 1:1:1 significantly improved compared with those of the gluten-free doughnuts without the added hydrocolloids and the commercially available gluten-free doughnuts. Previous studies reported that the overall acceptance of gluten-free doughnuts is less than that of control wheat doughnuts (Melito and Farkas, 2013). In our study, the developed gluten-free doughnuts received acceptance scores higher than 5 in the 9-point hedonic scale, so they were considered acceptable (Lazaridou et al., 2007). Thus, the developed gluten-free doughnut formula with the suggested hydrocolloid addition could be used as a product prototype for further commercial production.

Table 7. Sensory hedonic scores of the selected gluten-free, wheat, and gluten-free doughnuts

Samples	Appearance	Flavor	Taste	Texture	Overall acceptance
CW	7.26±1.45^{a}	7.38±1.18^{a}	6.86±1.46^{a}	7.14±1.59^{a}	7.3±1.54^{a}
Commercial	5.71±1.56^{b}	4.40±1.63^{c}	4.24±1.67^{c}	3.8±1.97^{d}	4.18±1.74^{d}
GF(0.5:0.5:0.5)	6.02±1.38^{b}	6.05±1.37^{b}	6.15±1.45^{b}	6.04±1.57^{b}	6.25±1.31^{b}
GF(1:1:1)	6.04±1.30^{b}	6.24±1.15^{b}	6.33±1.28^{b}	6.27±1.31^{b}	6.44±1.07^{b}
GF(0:0:0)	5.65±1.55^{b}	5.89±1.36^{b}	5.84±1.66^{b}	4.85±1.83^{c}	5.67±1.50^{c}

Note: CW = control wheat doughnut, Commercial = commercially available gluten-free doughnut, GF = gluten-free doughnut with the ratio of hydrocolloids (xanthan gum:CMC:HPMC) shown in parentheses

Letters indicate significant differences among values within each column as determined by Duncan's multiple range test *(p≤0.05)*

4. CONCLUSION

The combination of xanthan gum, CMC, and HPMC improved the volume change, density change, moisture content, and cohesiveness of gluten-free doughnuts. Sensory evaluation revealed that the results of adding xanthan gum, CMC, and HPMC at ratios of 0.5:0.5:0.5 and 1:1:1 to the gluten-free doughnut formula were more satisfactory than those of the control gluten-free doughnuts and their commercially available counterparts. Although the quality attributes of the developed gluten-free doughnuts were still poorer than those of the control wheat doughnut, their acceptance scores were considerately satisfactory. This study could be used as a basis for developing gluten-free doughnuts and similar gluten-free bakery products by preparing the appropriate mixture of hydrocolloids.

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