Quality and estimated glycemic profile of baked protein-enriched corn chips

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Abstract This study aimed to develop gluten-free protein-enriched corn snack chips and evaluate their physical properties and in vitro estimated glycemic index. Flours containing yellow corn and soybean flours, and soy protein isolate (in a proportion of 2.5:1.0:1.0 by weight respectively), cellulose gum, salt, and baking powder were homogeneously mixed followed by the addition of water and kneaded to form a dough. Response surface methodology was used to optimize baking powder levels (0–2.0%), dough sheet thickness (0.7–1.7 mm), and baking time (6–12 min) of the chips baked at 160 °C. Dough sheet thickness and baking time had significant effect on all the examined physical properties (water activity ranged from 0.15 to 0.71, hardness ranged from 377 to 2105 g, and browning index ranged from 38.4 to 60.7) ($P < 0.05$) except fracturability. However, all the variables had a significant quadratic effect on the fracturability (ranged from 1 to 23 peaks) of the chips ($P < 0.01$). The chips prepared from 1.2% baking powder, 1.2 mm dough sheet thickness, and baked for 9.0 min were considered the best and were significantly lower in the estimated GI value (48.8) ($P < 0.05$) when compared to non-soy corn chips (75.0). These baked protein-enriched corn chips developed could be considered as protein-rich and low glycemic index healthy snacks.

Keywords Corn · Protein enrichment · Chips · Physical properties · Glycemic index

Introduction

Gluten-free cereal products are attracting more attention by consumers and researchers because prolamins in some cereal grains such as wheat, oats, and barley cause celiac disease to genetically sensitive people, which comprise approximately 1% of world population (Evans and Sanders 2012; Ferreira et al. 2016). However, unlike flours containing gluten, mostly gluten-free cereal flours have a poor elasticity and cohesion resulting in technical difficulties for snack production processes and affecting the texture of the produced snacks (Lara et al. 2011).

Corn, a gluten-free cereal suitable for people with celiac disease, is one of the highest agricultural crops in production as the third largest staple food worldwide after wheat and rice (Gwirtz and Garcia-Casal 2014). Traditional corn snack chips usually contain high carbohydrate and fat, but low protein content. One of these is fried corn tortilla chips account for 80% of corn-based snacks consumed worldwide, which is usually made of masa, a processed corn dough flour. To reduce fat content, the frying process of traditional tortilla chips has also been modified to baking process (Kayacier and Singh 2003). However, the texture of baked tortilla chips is less crispy than fried ones, and requires modifications with additives to meet a desirable texture and taste (Quintero-Fuentes et al. 1999). The baking process has been applied for the preparation of corn biscuits (Lara et al. 2011), wheat bread containing 50% corn flour (Daglioglu and Tasan 2003) and crunchy corn mixed snacks (Olapade and Ogunade 2014). However, more work still needs to be done on baked corn based chips

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for improvement of their texture properties that usually lack in baked gluten-free corn products.

Corn based products are usually low in protein and high in starch that contributes to high calorie and glycemic index. Glycemic index (GI) is an important parameter corresponding to the rise in a person's blood sugar level after consumption of foods within 2 h. This index is an indicator that can be used to classify foods into low- (≤ 55), moderate- (55–69), or high- (≥ 70) GI types (Atkinson et al. 2008). Data from clinical studies suggest that consumption of low GI foods in daily diet helps prevent insulin resistance and metabolic syndrome (Hasjim et al. 2010) and mostly corn based chips have moderate to high GI scores (60–103 with bread as reference) (Ai and Jane 2016). To compensate a low protein content problem, protein fortification is a common practice in food ingredients and food product preparation. Corn snacks fortified with various high protein sources such as legumes, soybeans, and shrimp have been developed for protein enrichment (Rababah et al. 2012; Shaviklo et al. 2015).

The objective of the present study was to develop baked protein-enriched corn chips for the snack industry. Response surface methodology was used to determine the optimum processing variables of baking powder level, dough sheet thickness and baking time to produce corn chips with desirable physical properties enriched soy flour and protein. The effect of protein fortification on glycemic index of the prepared corn chips was also estimated in vitro.

Materials and methods

Materials

Yellow corn flour containing 10.0% protein, 66.7% carbohydrates, 6.7% fiber and 3.3% fat was purchased from Palmetto Farm (Avon, MA, U.S.A.). Soybeans obtained from Natural Soybean and Grain Alliance (Fayetteville, AR, U.S.A.) were ground and sieved through 60 mesh to prepare soy flour (protein 46.0%, carbohydrates 4.3%, fat 20.9% and fiber 2.2%). Soy protein isolate (SPI) (90% protein) was obtained from Archer Daniels Midland Co. (Decatur, IL, U.S.A.). Baking powder (Clabber Girl Corp., Terre Haute, IN, U.S.A.) and salt (Morton Salt, Inc., Chicago, IL, U.S.A.) were purchased from a local store, while cellulose gum BAK130 was supplied by Danisco, Inc. (New Century, KS, U.S.A.).

Preparation of protein-enriched corn chips

Mixed dough flour containing corn and soybean flours, and SPI was prepared in a proportion of 56.0:22.0:22.0 to have

approximately 10 g protein (20% daily value) (calculated based on the protein contents of corn flour, soybean flour and SPI) per serving size of 28 g. Then, cellulose (1.0% by weight), salt (2.0% by weight), baking powder level (0–2.0% by weight) and water (67% by weight) were added and kneaded to form a dough. The dough was flattened using a stainless steel pasta maker into a thickness of 0.7–1.7 mm, and then cut into 2×2 cm pieces before baking. The dough sheet pieces were baked at 160 °C for 6–12 min. The baked chips were cooled to ambient temperature, placed in Ziploc bags and stored at ambient temperature until analysis.

Experimental design, regression analysis and optimization of preparing protein-enriched corn chips

Experimental design for preparing protein-enriched corn chips was performed by Box-Behnken design (BBD) of response surface methodology (RSM). The experimental data were generated from three variables (baking powder level of 0–2.0%, dough sheet thickness of 0.7–1.2 mm, and baking time of 6–12 min) (Table 1). Second-order polynomial model was used for each analyzed response in the

following equation: $Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 +$

$\sum_{i=1}^3 \sum_{j=1}^3 \beta_{ij} X_i X_j$, while Y was the predicted response, β represented the estimated regression coefficients, with β_0 was the constant term, β_i represented the linear effects, β_{ii} was the quadratic effects, β_{ij} was the interaction effects, and X_i and X_j were the independent coded variables mentioned above (Panghal et al. 2018). Water activity, browning index, fracturability and hardness values were selected as the dependent variables.

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Moisture content and water activity determinations

The moisture content of the chips was also analyzed using a hot air oven method (AACC 1990), while the water activity was determined by using a dew point water activity meter (model 4TE, AquaLab, Pullman, WA, U.S.A.).

Color determination

The color parameters of the protein-enriched corn chips, including lightness (L^*), redness (a^*) and yellowness (b^*) were determined by a CR-300 Chroma meter (Konica Minolta Inc., Tokyo, Japan) and based on these values, browning index (BI) was calculated according to the equations below (Maskan 2001; Panghal et al. 2019; Chhikara et al. 2019).

Table 1 Physical properties of protein-enriched corn chips prepared with different levels of baking powder, thickness of dough sheet, and baking times

Run	variable codes (X_1 , X_2 , X_3)	Moisture (g/100 g)	Water activity	Hardness (g)	Fracturability	L^*	a^*	b^*	Browning index
1	− 1, − 1, 0	1.9 ± 0.2	0.20 ± 0.01	754 ± 146	6 ± 0.6	70.1 ± 1.4	7.6 ± 0.2	27.6 ± 0.5	57.0 ± 1.1
2	1, − 1, 0	4.9 ± 0.7	0.38 ± 0.01	781 ± 129	9 ± 0.8	74.4 ± 0.5	5.5 ± 0.2	27.9 ± 0.5	51.5 ± 0.9
3	− 1, 1, 0	9.8 ± 1.4	0.54 ± 0.00	1224 ± 159	7 ± 0.9	77.6 ± 0.4	1.1 ± 0.1	26.7 ± 0.5	42.2 ± 0.8
4	1, 1, 0	8.9 ± 0.6	0.51 ± 0.04	1057 ± 256	5 ± 0.8	80.0 ± 0.8	0.5 ± 0.1	26.3 ± 0.2	39.4 ± 0.5
5	− 1, 0, − 1	10.0 ± 0.2	0.58 ± 0.01	946 ± 59	6 ± 0.6	76.1 ± 0.5	0.4 ± 0.1	25.5 ± 0.5	40.2 ± 1.0
6	1, 0, − 1	11.7 ± 0.6	0.64 ± 0.00	997 ± 92	1 ± 0.5	75.9 ± 0.6	1.7 ± 0.4	25.1 ± 0.7	40.9 ± 1.6
7	− 1, 0, 1	1.8 ± 0.3	0.24 ± 0.01	1531 ± 368	4 ± 0.6	72.7 ± 0.7	6.0 ± 0.4	28.6 ± 0.5	55.1 ± 0.6
8	1, 0, 1	3.5 ± 0.9	0.29 ± 0.00	1783 ± 222	14 ± 3.1	75.6 ± 1.0	4.7 ± 0.5	28.4 ± 0.7	50.6 ± 2.2
9	0, − 1, − 1	8.1 ± 0.7	0.42 ± 0.00	377 ± 38	3 ± 0.6	76.9 ± 0.6	1.0 ± 0.1	26.1 ± 0.2	41.4 ± 0.3
10	0, 1, 1	17.2 ± 0.7	0.71 ± 0.01	459 ± 92	2 ± 0.5	77.5 ± 0.8	0.5 ± 0.4	24.9 ± 0.5	38.4 ± 0.9
11	0, − 1, 1	1.1 ± 0.5	0.15 ± 0.01	766 ± 141	4 ± 1.0	69.9 ± 0.8	7.5 ± 0.2	29.2 ± 0.3	60.7 ± 1.0
12	0, 1, 1	2.6 ± 0.7	0.26 ± 0.05	2105 ± 225	5 ± 0.8	77.8 ± 0.4	1.9 ± 0.5	28.1 ± 0.8	45.5 ± 2.4
13	0, 0, 0	3.7 ± 0.5	0.32 ± 0.01	954 ± 85	21 ± 2.1	76.1 ± 2.7	2.1 ± 0.9	27.0 ± 0.5	44.8 ± 2.4
14	0, 0, 0	4.3 ± 0.8	0.32 ± 0.00	1154 ± 138	23 ± 4.8	76.4 ± 0.9	2.3 ± 0.3	27.1 ± 0.8	45.0 ± 2.5
15	0, 0, 0	4.7 ± 0.9	0.33 ± 0.06	1190 ± 138	20 ± 5.4	77.1 ± 0.6	1.3 ± 0.3	27.2 ± 0.8	43.6 ± 0.9

Variable codes (− 1, 0, 1) of baking powder level (0, 1.0, 2.0% respectively), dough sheet thickness (0.7, 1.2, 1.7 mm respectively), and baking time (6, 9, 12 min respectively) represent for X_1 , X_2 , and X_3 respectively. Values are means of three determinations ± standard deviation

$$BI = 100 \times (x - 0.31)/0.17$$

$$x = (a^* + 1.75 \times L^*) / (5.645 \times L^* + a^* - 3.012 \times b^*)$$

Fracturability and hardness determination

The fracturability and hardness of the protein-enriched corn chips were determined using a TA-XT2i texture analyzer (Scarsdale, NY, U.S.A.) equipped with a P/0.25S ball probe. The analysis was conducted at a pre-test speed of 1.0 mm/s, test speed of 1.0 mm/s, distance of 10.0 mm. The numbers of positive peaks obtained during compression were used to express the fracturability of chips (Nath and Chattopadhyay 2007). The hardness of chips was the maximum force of the peak load value required to break the samples according to the time-force curve (Yuksel and Kayacier 2016).

Estimated glycemic index (EGI) determination

The estimated glycemic index of protein-enriched corn chips were determined by the method of Goñi et al. (1997), with some modification. Briefly, corn chip samples were grounded and sequently hydrolyzed by pepsin for 1 h and then α -amylase for 3 h. During α -amylase enzymolysis, the hydrolyzed samples were withdrawn every 30 min up to 180 min and the enzyme was inactivated at 100 °C for

5 min. After cooling to ambient temperature, the hydrolyzed samples were further hydrolyzed by amyloglucosidase at 60 °C. The glucose concentration of hydrolyzed samples was measured with a glucose assay kit (GAGO-20, Sigma-Aldrich, Inc., St. Louis, MO, U.S.A.). Hydrolysis index (HI) was calculated from the ratio between the area under hydrolysis curve (0–180 min) of samples and that of white bread. Estimated glycemic index (eGI) was calculated by the following equation: $eGI = 39.71 + 0.549HI$. Non-fortified corn chips (made of 100% corn flour) and soybean flour-corn (SF-corn) chips (made of 78.0% corn flour and 22.0% soybean flour) were used as comparative samples.

Statistical analysis

The experiment was conducted in three replicates and the results were expressed as mean ± standard deviation. Response surface plot and analysis of variance (ANOVA) were performed using the Design-expert software V8.06 (Stat-Ease, Inc., Minneapolis, MN, U.S.A.). All generated models adequately explain the variation of responses with the coefficient of determination R^2 -value (> 0.90) and its statistical significance was determined using the F-test.

Results and discussion

Moisture content and water activity of protein-enriched corn chips

The moisture content and water activity of the protein-enriched corn chips under different baking process parameters according to BBD is shown in Table 1. The moisture content ranged from 1.1 to 17.2 g/100 g, while the water activity ranged from 0.15 to 0.71. Regression analysis (Table 2) showed that the thickness of dough sheet and baking time both significantly affected the moisture of the chips at linear ($P < 0.001$), interaction ($P < 0.01$) and quadratic level ($P < 0.05$), while all three parameters significantly affected the water activity at linear ($P < 0.01$) with interaction between baking powder content and thickness ($P < 0.001$) and thickness and baking time ($P < 0.01$) and quadratic level for baking powder content ($P < 0.001$) and baking time ($P < 0.01$). The negative coefficients of the first order term (Table 2) indicated that moisture content and water activity gradually decreased with the increase of baking time.

The moisture and the water activity of samples varied more broadly (1.1 g/100 g to 17.2 g/100 g and 0.15–0.71 respectively) with the same baking powder level (1.0%) and baking time (12 min), but different dough sheet thickness (0.7 mm and 1.7 mm) (Table 1). This result indicated that the thickness of dough sheet is an important parameter affected the moisture content and water activity of chips during baking. For water activity, although the thickness of dough sheet and baking time showed more significant linear effect ($P < 0.001$) than baking powder

level ($P < 0.05$), baking powder level had the most significant effect at quadratic level ($P < 0.001$) (Table 2). The result also showed that when the baking powder level increased from 0 to 2.0% at the thickness of 0.7 mm, the water activity of chips did not change much at the beginning and then increased gradually. Similar with the moisture content, the thickness of dough sheet was positively related with the water activity of the chips, while baking time had a negative correlation. The results also showed that moisture content and water activity had a very strong linearity with a R^2 -value of 0.9494. Baking is a complex process which involves simultaneous heat and mass transformation to affect the quality of baked food. Baking powder that contains mostly sodium bicarbonate can produce gas intensely to make products puffy with the heating time extended (Sakin-Yilmazer et al. 2012). Variation in water activity reflects the migration activities of water inside of the products during baking, which is related to crispness and softness textural attributes for consumer acceptability (Primo-Martin et al. 2009). However, superficial dry layer of baked products would reduce the flux of water vapor during heating (Lara et al. 2011). The phenomenon observed in the present study suggested that sodium bicarbonate in the baking powder might affect water evaporation and water transition due to the change in the microstructure of chips during baking (Feyissa et al. 2011).

The regression equations describing the effect of the process variables on the water activity of protein-enriched corn chips at actual level after deleting the non-significant terms is given as:

Table 2 Estimated regression coefficients and significant for second-order polynomial model responses on physical properties of protein-enriched corn chips

Parameters	Moisture (g/100 g)	Water activity	Hardness (g)	Fracturability	L^*	a^*	b^*	Browning index
Intercept	4.24	0.32	1099.95	21.09	76.55	1.89	27.04	44.43
X_1	0.68	0.033 ^b	20.12	0.90	1.17 ^a	− 0.34	− 0.099	− 1.52 ^a
X_2	2.80 ^c	0.11 ^c	270.86 ^b	− 0.21	2.70 ^b	− 2.20 ^b	− 0.59 ^c	− 5.64 ^c
X_3	− 4.75 ^c	− 0.18 ^c	425.65 ^b	1.56	− 1.29 ^a	2.08 ^b	1.58 ^c	6.39 ^c
X_1X_2	− 0.94	− 0.054 ^c	− 48.54	− 1.38	− 0.46	0.38	− 0.18 ^a	0.66
X_1X_3	0.001	− 0.003	50.30	3.23 ^a	0.75	− 0.65	0.037	− 1.27
X_2X_3	− 1.88 ^b	− 0.045 ^b	314.41 ^a	0.65	1.81 ^a	− 1.28	0.005	− 3.07 ^a
X_1^2	0.79	0.070 ^c	120.94	− 5.72 ^b	− 0.74	1.13	− 0.56	1.65
X_2^2	1.33 ^a	0.014	− 266.65 ^a	− 8.55 ^c	− 0.30	0.65	0.11	1.43
X_3^2	1.69 ^a	0.049 ^b	93.31	− 9.02 ^c	− 0.72	0.18	− 0.11	0.62
R^2	0.98	0.99	0.94	0.97	0.94	0.94	0.99	0.98
Lack of fit	4.84	16.14	2.81	1.04	7.51	4.54	1.37	7.27

X_1 : baking powder level (%), X_2 : dough sheet thickness (mm), and X_3 : baking time (min). Values with lower letters are affected significantly; a, b, and c mean $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively

$$\begin{aligned}\text{Water activity} = & 0.69 + 0.03X_1 + 0.45X_2 - 0.12X_3 \\ & - 0.11X_1X_2 - 0.02X_2X_3 + 0.07X_1^2 \\ & + 5.41X_3^2\end{aligned}$$

Textures of protein-enriched corn chips

Fracturability and hardness are important characters for crispy products, and used interchangeably to describe the crack and crumble of these products such as chips (Kayacier and Singh 2003). In this study, the fracturability value (the number of major positive peaks appeared during compression) of the chips increased with the increase of baking powder level, dough sheet thickness, and baking time and then decreased; all these parameters showed a similar pattern as shown in Table 1 and Fig. 1a. The maximum value (23 ± 4.8) was reached at the middle level of all three variables (1.0% baking powder, 1.2 mm dough sheet thickness and 9 min baking time). The quadratic effects of baking powder level ($P < 0.01$), dough sheet thickness ($P < 0.001$) and baking time were significant ($P < 0.001$) on fracturability of the chip samples, but all the variables showed no linear effect on this property (Table 2). The result also showed that there was a significant interaction effect between baking powder content and baking time ($P < 0.05$). The minimum fracturability (1 ± 0.5) was obtained from the chips containing 2.0% baking powder with a dough sheet thickness of 1.2 mm and baked for 6 min. Nath and Chattopadhyay (2007) reported that baking time was one of the most significant variables affecting the crispness of baked snacks made of potato and soy; the fracturability values of these snacks ranged from 29 to 45. Baking powder that mainly contains sodium bicarbonate is a common leavening agent used in the bakery industry to produce air gaps during heating, and the numbers of small air cells will increase with increasing sodium bicarbonate (Berrios et al. 2004). However, the fracturability of chips made in present study was not significantly affected by baking powder level ($P > 0.05$). The fracturability of these chips increased to maximum value when the baking powder level increased to 1.0% and then decreased when the baking powder level increased to 2.0% (Fig. 1a). It is due to that small air cells expanded and glued together by gelatinized starch paste during baking (Quintero-Fuentes et al. 1999), the decreased the number of air cells near the surface of the chips would decrease the number of fracture peaks obtained by the testing instrument during the compression process.

The minimum hardness of the chip samples was 377 ± 38 g (from the chip that contained 1% baking powder, from dough sheet thickness of 0.7 mm, and baked for 6 min) (Table 1). This was about six times less hard

Fig. 1 Interaction effects of baking powder level, dough sheet thickness, and baking time on **a** fracturability, **b** hardness, and **c** browning index of protein-enriched corn based chips

than the maximum value which was 2105 ± 225 g (from the chips containing 1.0% baking powder, the dough sheet thickness of 1.7 mm, and baked for 12 min). The dough sheet thickness and baking time showed more significantly effect on the hardness of chips at linear term ($P < 0.01$) than their interaction effect ($P < 0.05$) (Table 2), while the baking powder level showed no effect on the hardness of

the chips. Kayacier and Singh (2003) reported that the hardness of baked tortilla chips increased to 1328 g when baked for 4 min and then decreased to 945 g when baked for 5 min, which could be related to the quick vaporization and diffusion of moisture to form larger sponge-like air cells making the chips less hard. In the present study, the hardness of the chips made from thicker dough sheet (1.7 mm) increased rapidly from 459 ± 92 g to 2105 ± 225 g with the increase of baking time (6–12 min), but increased slowly from 377 ± 38 g (6 min) to 766 ± 141 g (12 min) for the chips made from thinner dough sheet (0.7 mm) (Table 1, Fig. 1b). The results this study also indicated that the effects of the studied variables on the hardness and fracturability of the chips had a very poor correlation (R^2 -value = 0.0437), which can be interpreted as a hard product may not necessarily mean crispy (Kayacier and Singh 2003).

The relationships between the response and independent variables in terms of actual value after deleting non-significant terms are given as:

$$\text{Fracturability} = 109.11 + 0.11X_1X_3 - 5.72X_1^2 - 34.21X_2^2 - 1.00X_3^2$$

$$\text{Hardness} = 881.13 + 1312.23X_2 - 314.22X_3 - 16.76X_2X_3 - 1066.61X_2^2$$

Color of protein-enriched corn chips

Color is considered as one of the most important parameters for the quality and acceptability of baked products. The L^* , a^* , and b^* values of the analyzed chip samples ranged from 69.9 ± 0.8 to 80.0 ± 0.8 (100 represents the brightest white), 0.4 ± 0.1 to 7.6 ± 0.2 (higher value represents a more intense redness), and 24.9 ± 0.8 to 29.2 ± 0.3 (higher value represents a more intense yellowness) respectively. The dough sheet thickness and baking time of protein-enriched corn chips significantly affected all color parameters measured in the present study at linear level ($P < 0.05$) (Table 2). Although the L^* value decreased slowly (from 76.9 to 69.9) for thinner dough sheet thickness (0.7 mm) with baking time extended, the reduction of L^* value was higher than that for thick dough sheet (1.7 mm, the L^* values changed just slightly, from 77.8 to 77.5). A study by Rababah et al. (2012) showed that when the amount of SPI added was higher than 3% would significantly decrease the L^* value of fortified corn chips ($P < 0.05$). A study by Singh et al. (2014) also showed that an increase in protein content would decrease the L^* value. In the present study, the SPI added into the chips (22%) was much higher. Probably due to this, the lightness was kept constant by the baking time when the baked chips was made from thicker dough sheet (1.7 mm).

Based on these three values the calculated browning index (BI) values of the prepared corn chips ranged from

38.4 ± 0.9 to 60.7 ± 1.0 . All the variables significantly affected the BI values measured in the present study at linear level ($P < 0.05$ and $P < 0.001$) (Table 2). The effect of baking time and dough sheet thickness on BI value was similar to that on L^* value, the BI values increased from 38.4 to 45.5 when the baking time increased for dough sheet thickness of 1.7 mm, while the increase of the BI values much higher (from 41.4 to 60.7) for thinner dough sheet (0.7 mm) (Table 1, Fig. 1c). There was a significant interaction effect of dough sheet thickness and baking time, but no quadratic effect was observed from all the evaluated variables on the BI value of the studied chips. The relationship between response and independent variables in terms of actual value after deleting non-significant terms is given as:

$$\begin{aligned} \text{Browning index} = & 31.44 - 2.59X_1 - 7.95X_2 \\ & + 1.32X_3 - 2.05X_2X_3 \end{aligned}$$

Optimization

Baking is a complex process resulted in a series of physical, chemical and biochemical changes in the product. Here, the optimization of baking procedure due to the differences in the baking powder level, dough sheet thickness, and baking time of protein-enriched corn chips were investigated and conducted by the following criteria: minimum water activity value [0.3 or less to ensure a bacterial growth prevention and minimize undesirable many chemical reactions (Berk 2018)], BI value (lower BI means less non-enzymatic browning reaction) and hardness (low hardness is responsible for a better biting property and crispness), and maximum fracturability (high fracturability is responsible for a better crispness of baked products). The ranges of the three predicted optimized baking conditions obtained from response surface model are as follows: baking powder levels of 1.15–1.19%, dough thickness of 0.7–1.7 mm and baking times of 7.94–10.14 min (Table 3). The results in this table also show that the experimental physical parameters of the chips were similar to the predicted values. This indicates that the corresponding model used was effective to be applied into processing baking conditions for preparation of these protein-enriched corn chips. The optimized baking procedures of corn chips all showed the water activity was 0.29–0.36, which are close to the range of low water activity bakery product such as crackers and chips for safety and shelf life concerns (Smith et al. 2004). The predicted hardness value of the chips made under these optimized conditions ranged from 549 to 1396 g, which are much lower than a regular corn chip (about 1800 g) reported by Rababah et al. (2012). Fracturability and hardness are important characters for crispy products. The optimized baking conditions resulted

Table 3 Optimum quality parameters of protein-enriched corn chips obtained according to experimental and predicted baking conditions

Baking condition			Moisture (g/ 100 g)	Water activity (a_w)	Fracturability	Hardness (g)	Browning index
Baking powder (%)	Thickness (mm)	Baking time (min)					
Predicted value							
1.15	0.7	7.9	4.2	0.29	11	549	48.3
1.19	1.2	9.0	4.4	0.33	21	1117	46.1
1.18	1.7	10.1	6.1	0.36	12	1396	41.8
Experimental value							
1.15	0.7	7.9	4.6 ± 0.3	0.32 ± 0.01	10 ± 1.2	632 ± 24	47.1 ± 2.3
1.19	1.2	9.0	4.3 ± 0.3	0.30 ± 0.01	23 ± 2.3	850 ± 101	44.0 ± 0.5
1.18	1.7	10.1	5.8 ± 0.1	0.39 ± 0.00	9 ± 2.2	1100 ± 137	40.5 ± 1.6

The experimental values of dependent variables are means of three determinations ± standard deviation

Table 4 Estimated glycemic index (eGI) of corn chips prepared according to the optimized baking conditions

Types of chips ^a	Starch hydrolysis rate curve area ^b	Hydrolysis index (HI)	Estimated glycemic index (eGI) ^c
Non-fortified corn	2099 ± 49	64.3 ± 1.5	75.0 ± 2.2
SF-corn	1753 ± 33	53.7 ± 1.0	69.2 ± 1.53
SF-SPI-corn	542 ± 124	16.6 ± 3.8	48.8 ± 5.7

The optimized process conditions used were baking powder level of 1.19%, dough sheet thickness of 1.2 mm and baking time of 9.0 min

^aNon-fortified corn: chips made of 100% corn flour; SF-corn: chips made of 78.0% corn flour and 22.0% soybean flour; SF-SPI-corn: protein-enriched chips made of 56.0% corn flour, 22.0% soybean flour and 22.0% soy protein isolate

^bStarch hydrolysis curve area of white bread (standard) was 3264 ± 72

^cThe values (means of three determinations ± standard deviation) were affected significantly at $P < 0.001$

into high fracturability and medium harness of the prepared chips and could be considered as the best combination of baking process. The optimized procedure process for protein-enriched corn chips selected were baking powder level of 1.19%, dough sheet thickness of 1.2 mm and baking time of 9.0 min. The estimated glycemic index of the protein-enriched corn chips produced under the optimum processing procedure was determined further. These resulted corn chips had the eGI value of 48.8 ± 5.7 and could be potentially classified as a low GI type snack chips (Atkinson et al. 2008). This eGI value was significantly lower ($P < 0.001$) than the eGI values of non-fortified corn (75.0 ± 2.2) and SF-corn chips (69.2 ± 1.53). High eGI value of non-fortified corn could be related to an increase in the rapid digestible starch of corn at high baking or extrusion temperature (150 °C and above) (Thakur et al. 2017). These results are similar with previously reported results of protein-enriched chips made of sorghum, another gluten-free cereal grain (Jiang et al. 2018). The lower eGI value of these protein-enriched chips could be caused by the ability of soy protein to significantly lower the starch digestion of the chips by entrapping the starch molecules in the food matrix (Table 4).

Conclusion

Response surface methodology was successfully applied to develop the manufacturing procedure of baked protein-enriched corn chips. Dough sheet thickness and baking time showed linear and interactive effects on moisture, water activity, hardness, and browning index of the chips. Fracturability, the most important textural property of the chips, was significantly affected by all three variables at the quadratic effect. The optimized condition of the chips was 1.19% baking powder, dough sheet thickness of 1.2 mm, and baked for 9.0 min resulting in high fracturability and low hardness, those could be responsible for a better crispness, the most important property of snack chips. The consumption of protein-enriched corn chips with soybean flour and SPI can also have positive implication for human health, due to their high protein content (about 10 g protein per serving size of 28 g) and lower eGI value compared to non-fortified corn chips.

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