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RESEARCH ARTICLE

The manufacturing of puffed corn flakes: Optimization, characterization and sensory attributes

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ABSTRACT

Corn snacks are growing worldwide in food market. Puffing is an alternative processing technology to improve the characteristics of food products with the benefit of low oil. However, the puffing process of corn flakes is rarely studied in recent research. Thus, the objective of this study is to optimize the conditions of puffing with the raw material of corn grit and compare with extrusion, frying and baking process in the aspect of microstructure and sensory evaluation of corn flakes. The results showed that the optimized conditions of puffing flakes were 6 min of pretreated time, 226 °C of puffing temperature, 9 s of puffing time. And the experimental responses of crispy, hardness and browning index at the optimized conditions are 0.73 ± 0.05 nm, 1317.52 ± 23.14 g, 56.91 ± 0.87, respectively. To compared with other traditional process that manufacture the corn flakes, the microstructure and sensory evaluation are applied. The microstructure of puffing method presented porous and spongy structure with numerous cavities in small sizes. For the sensory evaluation, the score of taste, texture, color and overall acceptability applied for puffing is the highest. In conclusion, the puffing would be a novel technology to manufacture tasty corn flakes in the snack food industry.

Keywords: Corn flakes; Optimization; Puffing; Response surface methodology; Sensory attributes

INTRODUCTION

Corn snacks are a kind of ready-to-eat snacks that attracts many young ages group all over the world. They presented the desirable appearance of yellow coarse flakes with strong flavor of corn and crunchy sensory (Ahn et al., 2020). The traditional food processing technology for corn snacks mainly contains baking, frying, extrusion. Among them, frying technique, such as fried corn chips, shared about 80 % corn snack products in the world. However, high fat content in fried corn snacks is not healthy for people who have the need of keeping fit (Asokapandian et al., 2020). Baking is an alternative technology to manufacture lower oil snacks. Nevertheless, compared with fried process, the baking corn snacks are less crispy than the fried ones (Colla et al., 2018; Rico et al., 2020). In order to satisfy the need of desirable texture and taste, formula should be changed (Jiang et al., 2019). Extrusion is a process method involved in high temperature and shearing. It contributes to substantial chemical and structure changes (Sara Sayanjali et al., 2019; Uribe Wandurraga et al., 2020). For some individuals, extruded snacks might be more difficult to digest due to their denser texture. Thus, as the snack food market has experienced a high rate of growth in sales worldwide, seeking for an alternative process to create a better texture, taste of corn snacks is necessary.

Puffing has studied as an alternative method for improving the texture of snacks with low oil content (Tavanandi et al., 2021). During this process of high temperature, moisture inside the food rapidly evaporate leading to a high vapor pressure in a short period of time. This phenomenon results in the compact food expands and creates voids inside the product (Prachayawarakorn et al., 2016). Puffing led to significant energy conservation compared to conventional methods like extrusion or frying. Moreover, puffed snacks exhibited higher nutrient retention, preserving essential vitamins, minerals, and antioxidants that may be lost during traditional processing techniques. In terms of sensory attributes, puffed snacks outperformed their traditionally produced counterparts. The puffing process yielded snacks with a lighter, airier texture and

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enhanced natural flavors, contributing to a more enjoyable eating experience (Natabirwa et al., 2020). However, corn snacks are rarely made by puffing method. Other methods are appeared in the published paper. For example, tortilla chips made with corn are applying for the frying process (Gutiérrez Salomón et al., 2020). Extruded corn flakes were manufactured to evaluate the physicochemical properties, sensory characteristics and so on (Dewidar et al., 2020). Thus, it is necessary to in-depth study the puffed corn flakes including the optimized puffing process, the descriptive sensory and other indexes.

Response surface methodology (RSM) is a kind of statistical method to optimize the conditions of product effected by different variables. It is widely used to develop new product or enhancing the formulation, conditions of existing product. In order to establish model that reflects the associations between response and independent variables, the statistical experiment designs of RSM such as Box-Behnken design (BBD), Central composite design (CCD) are applied (Latha et al., 2017). BBD is a collection of second order response design on the basis of three level of factorial design. Compared to other designs of RSM, it has the advantage of reducing the sample size when the number of parameters is the same (Peerkhan et al., 2021). Therefore, the application of RSM with BBD is a good choice to optimize the conditions of puffing corn flakes.

Instrumental and descriptive sensory analysis are two methods widely used in the food industry. Previous study has shown that corn flakes are evaluated by both instrumental and sensory evaluation to select the higher score of acceptability (Dewidar et al., 2018). Instrumental techniques are objective methods of description the texture and color of crispy food (Savouré et al., 2021). Color is a prominent quality attributes for evaluation the quality of corn flakes. It is the visual contact at the beginning of food consumption (Yang et al., 2018). Crispy is one of the most important characteristics to evaluate the texture of snacks (Najjaa et al., 2020). The resistance is collected when the probe compresses and ruptures the food by texture analyzer (Andreani et al., 2020). Besides, hardness is another important quality parameter of crisps. However, the most reliable method to assess the texture of food for the application in the snack market is human sensory evaluation because the consumers' preference of flakes is a complex sensory depends on multiple influencing factors, achieved by perceiving the sensations of the texture during observing, chewing and so on (Yang et al., 2019).

Consequently, the aim of this study is to select the appropriate puffing process of puffed corn flakes by optimizing the conditions including puffing time, puffing temperature and pretreated time via RSM according to the multiple variables of crispy, hardness and color. Furthermore, the microstructure and sensory attributes were investigated when compared with the other traditional process technology. Our ultimate goal is to provide consumers with a healthier, more appealing, and sustainable snacking option.

MATERIALS AND METHODS

Preparation of samples

Dried yellow corn grit (particle size: 2.04 mm- 2.24 mm), soybean oil and corn flour were purchased from Haerxin supermarket (Harbin, China). Yellow corn grit was steamed for corresponding time (5, 6, 7 min), sealed and stored in room temperature in 12 h before puffing. The yellow corn grits were pre-steamed for 6 min, sealed and stored in room temperature overnight before extrusion. The dough for baking or deep fry contains corn flour (54 % by weight) and water (46 % by weight), and in shape of round cake. The thickness was adjusted to 3.3 mm, and the diameter of corn tortilla was 55 mm. The shaped corn tortilla was placed on a flat baking tray for further process.

Puffing

The prepared corn grit was performed on a rice cake pop machine (Pan Xi NC Equipment Co. Ltd., China) with a slightly modification (Xie et al., 2008). Cake outlet was adjusted 0.5 mm higher and heating time was adjusted into larger range. Puffing was treated at a temperature of 220, 225, 230 °C for 7, 8, 10 s according to the designed procedure.

Extrusion

Extrusion was performed in a single-screw extruder (HM SPJ, Shandong, China) with a barrel at length of 16 mm, diameter of 640 mm. The protocol for extrusion has been described (S. Sayanjali et al., 2019).

Baking

The dough was prepared as mentioned above. The baking procedure has made some modification (Iribe-Salazar et al., 2018). The corn tortilla was continued to be placed and baked in a preheated electric oven at 225 °C for 5 min. After baking, the baked corn tortilla was separated and cooled down to room temperature. Subsequently, the fresh ones were collected for further sensory evaluation.

Frying

Frying is according to the literature with some modifications (Sowa et al., 2017). The corn tortilla was deep fried in 1 L soybean oil at 200 °C for 1 min using a thermo stable electric fryer ((IMACO, Suzhou, China). Fresh oil was prepared for each batch. After frying, each corn tortilla was removed excess oil and cooled down to ambient temperature.

Experimental design

The range of the conditions was based on previous study. BBD of RSM as used to optimize the puffing process of corn flakes. In this study, 3 independent variables (pretreated time, temperature, puffing time) with 3 levels each and 3 response variables (crispy, hardness, browning index) were designed for 17 experimental trials (Khatib et al., 2021).

Textural property

The texture analyzer (TA. XT. Plus, Stable Micro System, Haslemere, UK) fitted with P5 Probe was applied to measure the crispy and hardness of puffed corn flakes. The probe was completely punched through the corn flakes with the speed of 0.5 mm/s to travel over a distance of 15 mm. The trigger force was set at 5 g. The force-time curve was measured and analyzed in the Exponent (6.1) software (Deng et al., 2019).

Color

The color was observed using a color spectrophotometer (CM-5, konica minolta, Japan). The color spectrophotometer was calibrated before measuring the color of corn flakes with the white and black calibration plate. L reflects the degree of lightness (100, white) to darkness (0, black) of corn flakes, a represents the degree of greenness (-a) to redness (+a), and b was expressed as the degree of blueness (-b) to yellowness (+b) (Zhang et al., 2020).

Scanning electron microscopy (SEM) analysis

The microstructure of corn samples treated by different method was observed by a scanning electron microscope (JSM 5410LV; JEOL, Tokyo, Japan). The samples were cut into thin slices and mounted on a scanning electron microscopy aluminum specimen holder using double-sided tape. Consequently, samples were coated with a thin film of gold and examined at the acceleration of 20 kV (Suryanto et al., 2019). Corn samples are observed in the magnification of ×200.

Sensory evaluation of corn snacks

Sensory analysis was performed by 10 trained panels (6 female and 4 male), consisting of 20–35-year-old people who are regular consumers of snacks. Panelists were trained to evaluate the taste, odor, color and overall acceptability on a 1-9 scale. 1 point means extremely dislike. 9 points represented extremely like. The corn snacks were placed on white plates in random sequences at room temperature. Water at ambient temperature was provided to rinse the palate to avoid disturbance between samples (Predieri et al., 2021).

Data analysis

Design Expert version 8.0.6 was applied for designing the experiment, generating the surface response plots and analyzing the graphs. Analysis of variance (ANOVA) was applied to estimate the significance of the independent parameters and analyze the differences amongst the treatment groups. Duncan's multiple range test was further applied to compare means.

RESULTS AND DISCUSSION

Effects of puffing parameters on the quality attributes of corn flakes

RSM is applied to reveal the crispy, hardness and browning index of the puffed corn flakes under different process parameters. The BBD matrix and of RSM experiment was shown in Table 1. Analysis of variance (ANOVA) of the fitted second-order polynomial models for crispy, hardness and browning index in Table 2.

In order to show the interaction of the variables and optimize puffing conditions with minimized crispness, 3D surface plots are observed in Fig. 1. Crispy is one of the most important quality attributes for puffing snacks. The lower values presented the higher crispy of the samples. Puffing temperature and time significantly effect crispy at linear ($P<0.01$), interaction ($P<0.05$) and quadratic level ($P<0.01$) (Table 2). As shown in Fig. 1a, the relationship between crispy and various temperature and pretreated time at fixed puffing time indicated that crispy is increased with the increased heating temperature from 220-225 °C. While the heating temperature is above 225 °C, an opposite trend was observed. This is probably due to the reason that corn flakes could easily form a more crispy structure to resist the external compression force caused by the quick evaporation of water inside the corn at higher temperature (Hashempour-Baltork et al., 2018). However, when the temperature is over above 225 °C, the corn dries up at higher rate resulted in less crispy in texture. Fig. 1b indicates that crispy at various puffing time and pretreated time when heating temperature was set. Crispy increased when the puffing time extended from 8 to 9 s and then started to decrease. The similar trend is observed in peach crisps using explosion puffing that the crispy value is increased and then decreased as the puffing time enhanced when other parameters is set (Song et al., 2019).

Hardness is considered as an important textural parameter for puffing food. It is a mechanical measurement to reflect the resistance of puffing food to a localized plastic deformation (Lotfi Shirazi et al., 2020). Fig. 1 (d, e, f) indicates that hardness values of corn crisps are range from 1300 to 2100 g. Pretreated time and puffing temperature had positive effects on hardness (Table 2). Hardness tends to decrease as the increasing pretreated time at initial but continued to be enhanced with the increasing pretreated

Table 1: BBD matrix and corresponding response variables

Run	Independent variables			Response variables		
	Pretreatment time (min)	Temperature (°C)	Puffing time (s)	Crispy (nm)	Hardness (g)	Browning index
1	6 (0)	225 (0)	9 (0)	0.68	1328.88	56.85
2	5 (-1)	225 (0)	8 (-1)	0.95	1898.37	76.52
3	7 (1)	225 (0)	8 (-1)	1.04	1535.63	67.49
4	5 (-1)	220 (-1)	9 (0)	1.02	1728.47	83.71
5	6 (0)	230 (1)	8 (-1)	0.92	1641.69	71.41
6	6 (0)	225 (0)	9 (0)	0.7	1318.47	55.93
7	5 (-1)	230 (1)	9 (0)	0.96	2049.51	76.3
8	6 (0)	225 (0)	9 (0)	0.72	1301.23	56.36
9	6 (0)	220 (-1)	10 (1)	1.1	1420.56	78.23
10	6 (0)	230 (1)	10 (1)	0.82	1568.21	68.74
11	6 (0)	225 (0)	9 (0)	0.69	1339.34	56.39
12	6 (0)	225 (0)	9 (0)	0.72	1301.82	56.32
13	7 (1)	220 (-1)	9 (0)	1.1	1618.76	77.69
14	5 (-1)	225 (0)	10 (1)	1.05	1873.58	71.46
15	7 (1)	230 (1)	9 (0)	0.94	1569.38	71.35
16	6 (0)	220 (-1)	8 (-1)	0.87	1415.18	75.52
17	7 (1)	225 (0)	10 (1)	0.99	1541.27	68.61

Table 2: Analysis of variance (ANOVA) of the fitted second-order polynomial models for crispy, hardness and browning index

Source	Crispy			Hardness			Browning index		
	Coefficient	Sum of squares	p-Values	Coefficient	Sum of squares	p-Values	Coefficient	Sum of squares	p-Values
Model	0.70	0.36	< 0.0001	1317.95	822100	< 0.0001	56.37	1343.83	< 0.0001
X_1	0.011	0.0010	0.1161	-160.61	206400	< 0.0001	-2.86	65.27	< 0.0001
X_2	-0.056	0.025	< 0.0001	80.73	52135.43	< 0.0001	-3.42	93.50	< 0.0001
X_3	0.023	0.0041	0.0089	-10.91	951.57	0.2438	-0.49	1.90	0.0549
X_1X_2	-0.025	0.0025	0.0259	-92.61	34302.74	0.0001	0.27	0.29	0.4016
X_1X_3	-0.038	0.0056	0.0039	7.61	231.5	0.5502	1.55	9.55	0.0013
X_2X_3	-0.083	0.027	< 0.0001	-19.71	1554.72	0.1479	-1.35	7.24	0.0028
X_1^2	0.19	0.15	< 0.0001	312.19	410400	< 0.0001	9.22	357.83	< 0.0001
X_2^2	0.11	0.052	< 0.0001	111.39	52242.85	< 0.0001	11.67	573.80	< 0.0001
X_3^2	0.11	0.055	< 0.0001	82.07	28361.49	0.0002	5.43	124.20	< 0.0001
Residual		0.0022			4113.44			2.51	
Lack of fit		0.0009	0.4917		2996.44	0.125		2.09	0.0509
Pure error		0.0013			1117			0.43	

X_1: Pretreated time (min), X_2: Temperature (°C), X_3: Puffing time (s), X_1X_2: The interaction effects of pretreated time (min) and temperature (°C), X_1X_3: The interaction effects of pretreated time (min) and puffing time (s), X_2X_3: The interaction effects of temperature (°C) and puffing time (s), X_1^2: The quadratic effect of pretreated time (min), X_2^2: The quadratic effect of temperature (°C), X_3^2: The quadratic effect of puffing time (s).

time. It was probably because increasing pretreated time presents higher moisture in corn, which would lead to higher puffing pressure, resulting in higher expansion of corn flakes and the lower hardness value. Once the moisture is higher than the optimum, more energy is required to complete the puffing procedure, leading to the increase of hardness. In addition, puffing temperature plays an important role in puffed corn flakes. Temperature facilitates the loose water transferred from the inside of corn flakes would rapidly explode to the outer environment. The sudden loss of water in high temperature resulting in the puffing structure (Lyu et al., 2015; Smith et al., 2020). As the temperature enhanced, the air cavities in the corn crisps were getting larger (Mahanti et al., 2019). Nevertheless, as the temperature is above 225 °C, the corn tends to burn and leads to form more stronger structure.

Color is a crucial parameter for assessing the quality and acceptability of puffing products (Bai et al., 2021). Browning index (BI) is ranging from the value of 56.32 to 83.71. The BI values of protein enriched corn chips obtained from Jiang (Jiang et al., 2019) is ranging from 38.4 to 60.7. This is probably caused by the formula and processing difference. It is shown that puffing time is significantly affected the BI value of corn crisps at linear ($P<0.01$), interaction ($P<0.05$) and quadratic level ($P<0.01$), while all the three independent variables significantly affected the BI at quadratic level ($P<0.01$)

(Table 2). As shown in Fig. 1g, BI of corn crisps decreased with the increasing pretreated time up to 6 min when the temperature is set. However, BI increased slowly at longer pretreated time. This is perhaps due to the reason that as the moisture of corn increased, the corn flakes expansion and presents the light color. The low value of BI could be due to the less nonenzymatic browning reactions, such as Maillard reaction. While above certain moisture, the corns become sticky and flakes come out of the mold with longer time, thus causing the darker color (Song et al., 2019).

Response surface optimization of puffing conditions

The optimized puffing parameters are according to the following principles: lower hardness, lower crispy and lower BI (Jiang et al., 2019). In order to obtain the desired puffing corn snacks, lower hardness is related to a better biting property. Minimum crispy value means a better crispness of corn flakes, and lower BI indicated less non-enzyme browning reactions. Besides, the second-order polynomial models were applied to optimize the puffing conditions. The optimized conditions using BBD were 6 min of pretreated time, 226 °C of puffing temperature, 9 s of puffing time (Table 3). To verify the model equation, the theoretical responses of crispy, hardness and browning index of corn crispy were compared with the experimental ones. As shown in Table 3, the experimental responses of crispy, hardness and browning index are 0.73±0.05 nm, 1317.52±23.14 g, 56.91±0.87, respectively. These values are consistent with the predicted responses. The picture of the final optimized condition and a random puffing condition of puffing corn flake was compared (Fig.2).

Microstructure of corn products using different treating methods

Different process has different influences on microstructure. To compare the corn flakes treated by different methods in microstructure changes, scanning electron microscope (SEM) is applied and the corresponding photographs are shown in Fig. 3. Typical homogenous granules with small

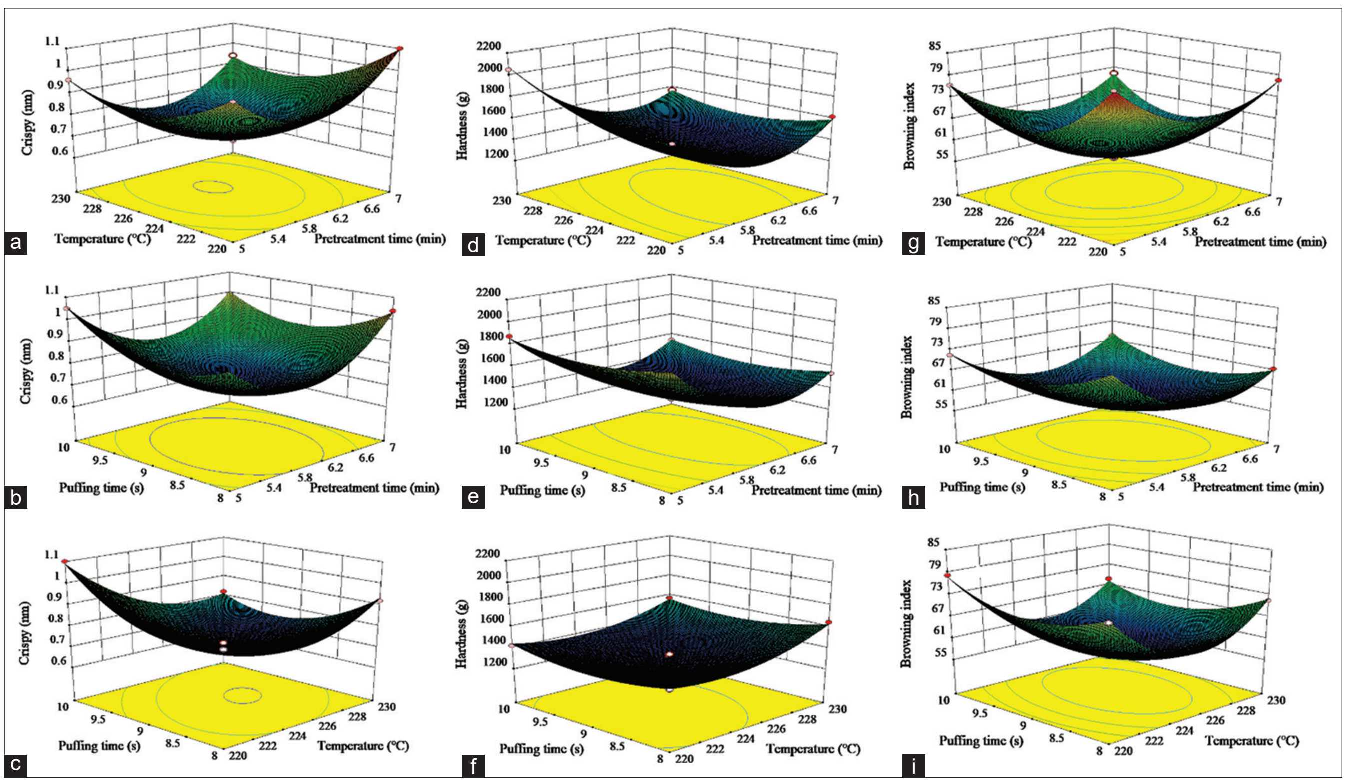

Fig 1. Response surface 3D surface plots for crispy of puffing corn flakes, as affected by puffing temperature and pretreatment time (a); puffing time and pretreatment time (b); puffing time and puffing temperature; (c) when the third factor is set at level 0. hardness of puffing corn flakes, as affected by puffing temperature and pretreatment time (d); puffing time and pretreatment time (e); puffing time and puffing temperature; (f) when the third factor is set at level 0. BI of puffing corn flakes, as affected by puffing temperature and pretreatment time (g); puffing time and pretreatment time (h); puffing time and puffing temperature; (i) when the third factor is set at level 0.

Table 3: Optimization parameters of predicted and experimental conditions

Trials	Pretreatment time (min)	Temperature (°C)	Puffing time (s)	Crispy (nm)	Hardness (g)	Browning index
Predicted	6.12	225.51	9.01	0.7	1310.97	55.93
Experimental	6	226	9	0.73±0.05	1317.52±23.14	56.91±0.87

air bubble pores were observed for raw corn (Fig. 3a). They are properly starch granules and not gelatinized due to the non-treatment of heat (Delayed Quality Deterioration of Low-Moisture Cereal-Based Snack by Storing in an Active Filler-Embedded LDPE Zipper Bag). For extrusion method, the microstructure of the corn was in shape of thin flakes with some cracks. During the extrusion, the starch-lipid matrix was gelatinized and the air bubble was exploded (Fig. 3b). Corns treated by puffing method presented porous and spongy structure with numerous cavities in small sizes. (Fig. 3c). It is possibly due to the reason that in the condition of high temperature and pressure, water inside pretreated corn grid rapidly evaporated. This resulted in that compact corn changed to the porous structure (Mom et al., 2020). Baking corns showed less porous dense matrix with relatively smooth surface in comparison of puffing and frying treated corn flakes. The protein membrane in the dough contained lots of fat crystal to attach to the air bubbles. After the procedure of baking, larger air bubble formed and the ingredients were rearranged (Fig. 3d). Corns treated by frying showed coarse and scattered structures with irregular pores and bulges. This phenomenon is possibly owing to the corn dough contacted with the hot oil leading to the instant loss of water. The similar microstructure is also observed in fried rice flour dough strands (Shanthilal et al., 2017) (Fig. 3e).

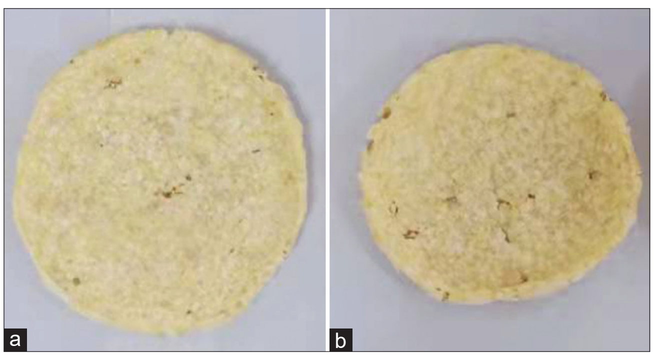

Fig 2. The picture of puffed corn flakes. (a) at the optimized condition (6 min of pretreated time, 226 °C of puffing temperature, 9 s of puffing time), (b) at the condition of 5 min of pretreated time, 220 °C of puffing temperature, 10 s of puffing time.

Sensory evaluation

The sensory evaluation of corn products treated by extrusion, puffing, baking and frying method were shown in table 4. The results showed that taste rating for corn products is ranging from 2.7±0.2 to 7.1±0.3. Each group is significantly different from each other. The highest rating was obtained by puffing corn crisps with strong corn flavor, while the lowest score was obtained from baking corn flakes. The differences in taste could be due to the changes in molecular level caused by the different process method for the corns (Dewidar et al., 2020). Another reason of the puffed corn had the highest taste score could be the microstructure with small cells and highly expanded network causing the high preference in tasting (Hicsasmaz et al., 2003). In terms of the odor, the highest evaluation score is obtained from extrusion method. The score of 6.6±0.4 for puffing method was close to the score of 6.4±0.3 for the frying treatment. The texture and color were also evaluated. Puffing corn flakes presented the highest score with rough texture and burnt yellow color, favored by the most panelists. The highest overall acceptability scores of 7.8±0.3 were recorded for puffing method. The results revealed that puffing proccess improved the taste, texture, color and overall acceptability compared with other traditional method.

Conventional corn snacks may have textural or sensory limitations, such as being too hard or having a bland taste (Lasekan et al., 1996). The advantage of the puffing

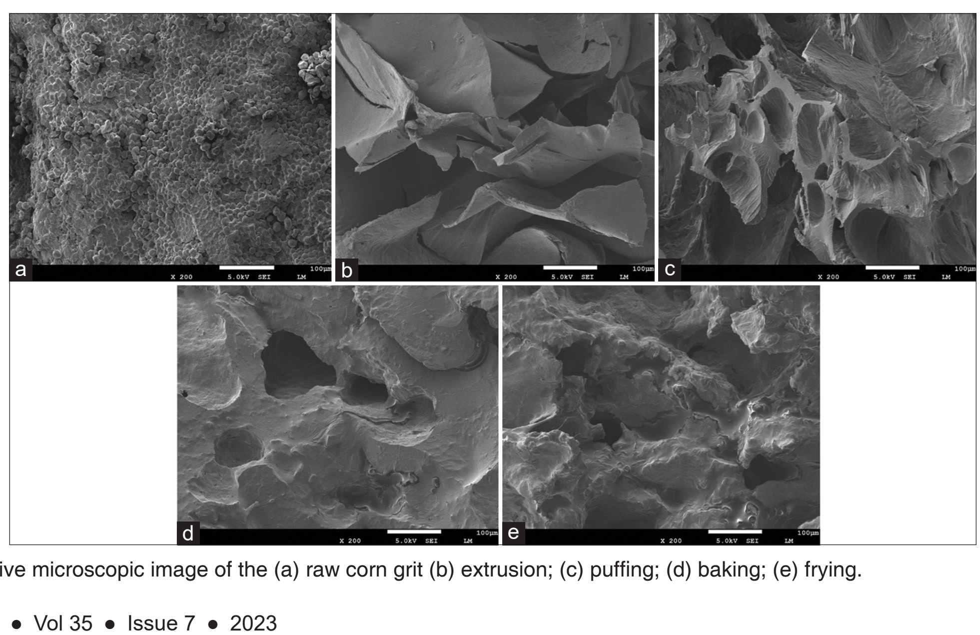

Fig 3. Representative microscopic image of the (a) raw corn grit (b) extrusion; (c) puffing; (d) baking; (e) frying.

Table 4: Sensory of evaluation scores of corn samples treated by extrusion, puffing, baking and frying

Treatment	Taste	Odor	Texture	Color	Overall acceptability
Extrusion	6.3±0.4[b]	7.2±0.6[a]	5.4±0.1[b]	7.8±0.5[a]	6.3±0.4[b]
Puffing	7.1±0.3[a]	6.6±0.4[ab]	7.3±0.7[a]	8.4±0.4[a]	7.8±0.3[a]
Baking	2.7±0.2[d]	4.1±0.2[c]	3.1±0.2[d]	5.7±0.5[b]	3.6±0.2[d]
Frying	4.8±0.3[c]	6.4±0.3[b]	4.9±0.3[c]	5.9±0.2[b]	4.5±0.2[c]

method is the improvement of sensory characteristics, such as texture and flavor. Puffed corn snacks are lighter and airier, providing a more enjoyable eating experience. Furthermore, the puffing process enhances the natural flavors of the corn, leading to a more appealing taste profile. These sensory improvements may contribute to increased consumer preference for puffed corn snacks compared to their traditional counterparts.

CONCLUSIONS

The results of the experiment indicated that puffing corn flakes is affected by puffing time, puffing temperature and pretreated time. The optimization process of puffing was 6 min of pretreated time, 226 °C of puffing temperature, 9 s of puffing time. Besides, the microstructure of corn flakes treated by various methods is observed. Corn flakes by puffing treatment presented porous and spongy structure. The sensory evaluation of those methods showed that the taste, texture, color and overall acceptability of puffing are more acceptable when compared with extrusion, baking and frying method. By adopting the puffing method, manufacturers can produce corn snacks with improved sensory characteristics. The advantages of this method demonstrate its potential to revolutionize the corn snack industry, providing consumers with a more appealing snacking option. Thus, puffing is a potential method to manufacture the corn flakes for industrial production.

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Author's contributions

Na Xu designed, performed the experiments, analyzed data, wrote the paper; Xinmiao Yao and Shuwen Lu revised the paper. All authors have read and agreed to the published version of the manuscript.

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