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Production of high quality expanded corn extrudates containing sesame seed using response surface methodology

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RESEARCH ARTICLE

Abstract

Sesame seed, which possess exceptional nutritional and antioxidant properties, was incorporated into corn expanded extrudates to improve their nutritional quality. Expanded corn extrudates with 0, 15 and 30% sesame seed were processed in a twin-screw extruder at different screw speeds (140-220 rpm) and barrel temperature (120-160 °C) levels. Response surface methodology was employed to investigate the effect of independent variables, independently or in combination, on the physical (expansion, density, hardness and colour parameters) and sensory properties of the extruded products. Results showed that increasing the sesame level produced less expanded, denser and harder extrudates with darker appearance (P<0.05) while higher screw speeds improved their physical attributes to some extent. Remarkable increases in expansion ratio, hardness and colour parameters were observed for products extruded at higher temperatures. According to sensory assessment, sesame seed could be used up to the level of 15% to produce high quality extrudates with acceptable sensory properties. The results recommended that sesame seed can be extruded with corn flour into an acceptable and nutritious snack.

Keywords: extruded snacks, physical characteristics, sesame seed, sensory properties

1. Introduction

Extrusion is an efficient food processing technique for producing numerous products such as ready-to-eat cereal, snack food and pet food. Extrusion cooking combines high temperature and high shear force to make an extruded food product with desired shape, size and porosity (Brennan *et al.*, 2013). During extrusion process, raw materials are exposed to several unit operations including mixing, melting, cooking, shearing, shaping and forming (Rahman *et al.*, 2002; Stojceska *et al.*, 2009). The major raw materials in an extruded snack involve cereal grains which are low in protein and essential amino acid contents (Majumdar and Singh, 2014). Therefore, incorporation of legumes, vegetables, fruits and oleaginous plants into the formulation can enhance the nutritional value of these products. Sesame (*Sesamum indicum* L.) is an oleaginous plant with a high nutritional value along with a high amounts of proteins rich in sulfur-amino acids, essential fatty acids, vitamins and minerals (Alobo, 2001). Sesame seeds are excellent sources of B-complex vitamins such as niacin, folic acid, thiamin, pyridoxine and riboflavin. Also, they contain health benefit phenolic compounds such as sesamol, sesaminol, furyl-methanthiol, phenylethanthiol, furaneol, vinylguacol and decadienal. Phenolics exhibit potent antioxidant and antimicrobial activities that make them an extremely valuable nutraceuticals in the formulation of health-promoting functional food products (Garavand and Madadlou, 2014). Hence, a diet rich in sesame can decrease the risk of certain cancers and cardiovascular diseases (Fremont *et al.*, 1999).

Several studies have shown that the use of pulse proteins, such as lentils, peas and chickpeas, could improve the biological protein value of cereal-based products (Anton *et al.*, 2009; Lazou and Krokida, 2010; Shirani and

Ganesharanee, 2009), but limited information is available on extrusion processing of sesame seed and/or its by-products. Nascimento *et al.* (2012) studied the effect of screw speed and semi-defatted sesame cake (SDSC) (0-20%) on the nutritional, texture features, internal microstructure and sensory attributes of corn extrudates. They observed that the addition of SDSC reduced the sectional expansion of the corn extrudates and increased compression force, which corroborated with the microstructure. Futhermore, they reported that addition of 10% SDSC increased the protein content four-fold compared with commercial puffed corn extrudates. Sensory analysis showed that puffed corn extrudates incorporated with 20% SDSC met the requirements by consumers. In another study, the effect of extrusion process on the anti-nutritional factor tannin in sesame meal was investigated (Mukhopadhyay and Bandyopadhyay, 2003). They observed that extrusion was effective to reduce the anti-nutritional factor from the sesame meal. The objective of the present investigation was to study the effect of adding sesame seed on the physiochemical and sensory properties of corn based extruded product.

2. Materials and methods

Materials

Corn grits and flour were purchased from Gold Cluster Company (Mashhad, Iran). Sesame seed, variety dezful was prepared from Karaj's Seed and Plant Improvement Institute (Karaj, Iran).

Preparation of blends

Blends were prepared by mixing corn grits and corn flour (ratio of 10:90) with sesame seed in the ratios of 100:0, 85:15 and 70:30. The blended samples were adjusted to the desired moisture content by spraying calculated amounts of distilled water and were mixed thoroughly using a mixer (Toosshekan, Mashhad, Iran) for 15 min. The samples were packed in polyethylene bags and kept refrigerated overnight to equilibrate the moisture. The samples were brought to room temperature before extrusion cooking.

Extrusion cooking

Experiments were conducted using a twin screw laboratory extruder (DS56-III; Jinan Saixin, Jinan, China P.R.) with barrel diameter of 64 cm, a length to diameter ratio (L:D) of 12:1 and die diameter of 3.6 mm. The barrel was equipped with three independent temperature controlled zones. The temperature of first zone (after the feeding section) was controlled at 50 °C, second zone (mixing part) was controlled at 100 °C and third zone temperature was adjusted to the required levels based on variables level. Constant feeding rate was kept throughout the experiments. Steady-state conditions were reached after 20 min, after which samples were collected. The cylindrical extrudates were dried using a hot air dryer (101-1EBS; Sjia Lab, Ningbo, China P.R.) at 50 °C for 24 h until a constant moisture level of 5% (±1%) was obtained. The extrudates were cooled down to room temperature and sealed in polyethylene bags till analysis.

Density

The diameter of the extrudates was measured using a vernier caliper at three points of cylindrically shaped extrudates. Density of dried extrudates was determined on 10 randomly selected extrudates as described by Ding *et al.* (2005):

$$\text{Density} = \frac{4 \times m}{\pi \times D^2 \times L} \tag{1}$$

Where m is the mass, D is the diameter and L is the length of the extrudate after cooling.

Expansion ratio

Sectional expansion of the extrudate was determined by the use of a vernier caliper to measure the diameter of extrudate as described by Stojceska *et al.* (2009) and Chanlat *et al.* (2011):

$$\text{Expansion ratio} = \frac{\text{diameter of extrudate}}{\text{diameter of die hole}} \tag{2}$$

Texture analysis

The texture properties of extrudate were measured using a texture analyser (TA.XT PLUS; Canners Ltd., Ontario, Canada) fitted with a 35 mm cylinder probeand a 50 kg cell load. Samples of 40 mm length were evaluated at crosshead speed of 1 mm/s. The highest value of force (N), i.e. the resistance of extrudate before rupture, was taken as a measurement for hardness (Ma *et al.*, 2012).

Colour evaluation

Colour measurements of the ground samples of extrudates were determined using a HunterLab colourimeter (ColourFlex EZ, CX2547; HunterLab, Reston,Virginia, USA) according to Vatankhah *et al.* (2015). Measured values were expressed as L*, a*, and b*, where the L* value is for lightness, a* for redness, and b* for yellowness.

Sensory analysis

Sensory evaluation was done using a panel of 25 semi-trained judges (25-40 years old males and females). 5 point hedonic scale (1 = extremely dislike, 3= neither like nor dislike, and 5 = extremely like) was used to determine the sensory properties of extrudates in terms of colour, taste, flavour and overall acceptability.

Experiment design

A Box-Behnken design response surface methodology was used to study the effect of independent variables (sesame seed, screw speed and temperature), independently or in combination, on the physical and sensory properties of extrudate in 17 runs of which five were for the centre point, and 12 for non-centre point as presented in Table 1.

Table 1. Process condition recorded during extrusion runs.

Run	Screw speed (rpm)	Temperature (°C)	Sesame seed level (%)
1	140	160	15
2	180	140	15
3	220	140	30
4	140	120	15
5	180	160	30
6	180	140	15
7	180	140	15
8	180	140	15
9	180	120	30
10	180	120	0
11	220	140	0
12	180	160	0
13	180	140	15
14	220	160	15
15	140	140	0
16	220	120	15
17	140	140	30

3. Results and discussion

Density

Density is an important parameter which can indicate the degree of compactness of a food matrix. Results obtained indicated a significant positive relationship (P<0.05) between sesame level and density. As can be seen in Figure 1, increasing the sesame level resulted in denser extrudates over temperature range studied. It can be attributed to the increased level of fibre and protein in the feed material which may affect the extent of starch gelatinisation and thus the rheological properties of the melted material in the extruder (Yagci and Gogus, 2008). Similary, Liu *et al.* (2000) observed an enhancement in density with increasing oat flour percentage in oat-corn extrudates. The response surface graph (Figure 1B) showes that extrudates density tended to reach a maximum with increasing screw speed up to a certain point at all temperature levels and then showed a decrease. However, increasing the barrel temperature at higher screw speeds caused a slight promotion in the product density. In disagreement with our findings, Altan *et al.* (2008) found no statistically significant relationship between screw speed and density while barrel temprature had a considerable effect on density of extruded barley-tomato pomace blends.

Expansion ratio

Expansion ratio values of extrudates incorporated with sesame seed varied from 3 to 6.33. The incorporation of sesame seed into corn-based extrudated snack had a significant effect on product expansion, as it decreased sharply with the increasing level of sesame (Figure 2). High melt viscosity is able to hold air bubbles inside the starch matrix when expelled out of the die (Nascimento *et al.*,

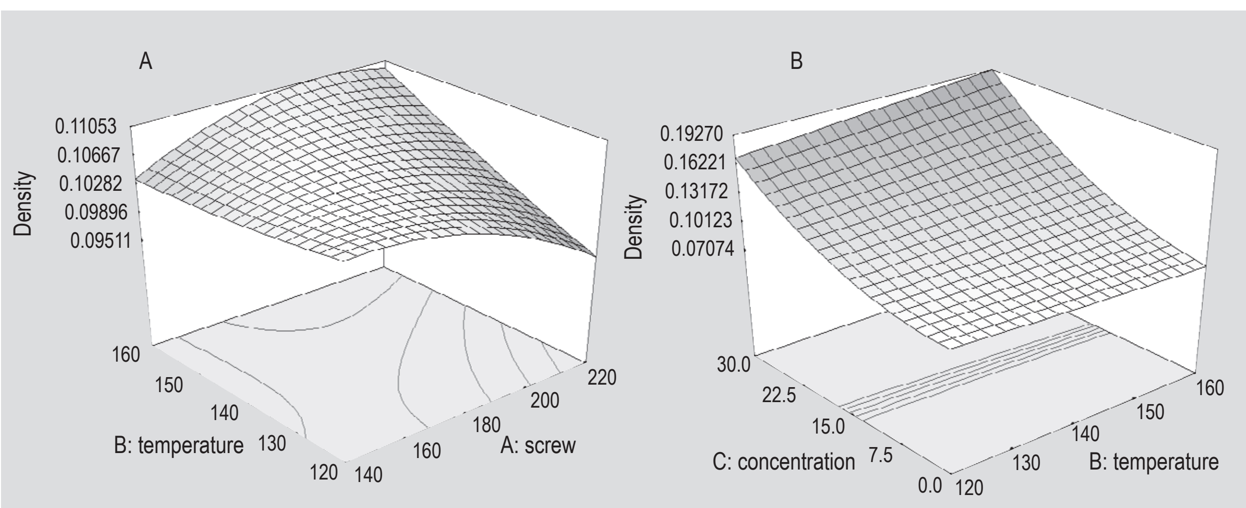

Figure 1. Response surface plots for interaction effects of (A) temperature × screw speed, and (B) temperature × sesame level (concentration) on extrudate density.

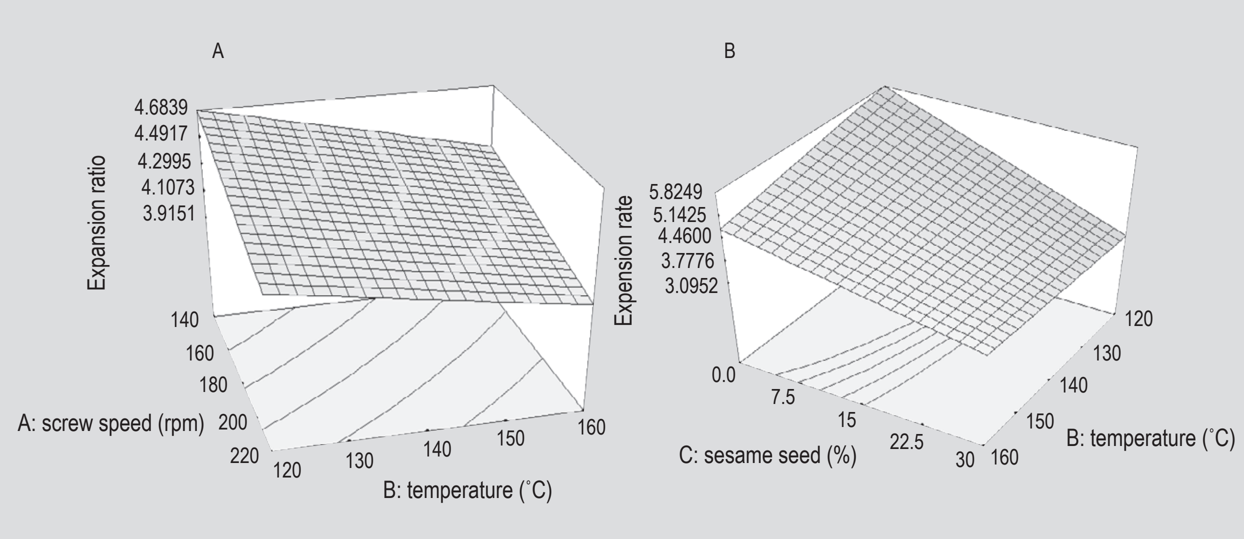

Figure 2. Response surface plots for interaction effects of (A) temperature × screw speed, and (B) temperature × sesame level (concentration) on extrudate expansion ratio.

2012). A considerable amount of protein, fat and dietary fibre of sesame seed can decrease the material viscosity which in turn might cause a decreased expansion. This may also accont for reduction of available starch surrounded by protein resulting in extrudates with reduced expansions (Onwulata *et al.*, 2001). As observed by Nascimento *et al.* (2012), the addition of SDSC led to extrudates with lower expansion. Deshpande and Poshadri (2011) reported that expansion ratio decreased with increased level of Foxtail millet flour as a result of increasing dietary fibre content. Similar results have been obtained by Suknark *et al.* (1997), Grenus *et al.* (1993), Veronica *et al.* (2005) and Lazou and Krokida (2010) for expanded corn extrudates with added partially defatted peanut flour (10% fat), rice bran, defatted soybean and lentil, respectively.

The expansion ratio decreased slightly with an increase in the screw speed and temperature. The effect of temperature and screw speed on expansion ratio as shown in Figure 2. The lowest expansion was observed at highest screw speed and temperature values. According to Chinnaswamy and Hanna (1990), higher screw speed which is accompanied by reduced residence time decreased the levels of gelatinisation of starch leading to extrudates with lower expansion. Similar results were reported by Lee *et al.* (1999) for corn starch extrudates expanded using supercritical CO_2 injection. Maximum expansion values occurred at the lowest temperature value (120.61 °C) for the 0% sesame content (Figure 2). High temperatures could cause weakening of the structure of feed material and make it unable to retain air bubbles, therefore expansion ratio is reduced. The results are in agreement with the results of Lue *et al.* (1990) and Ferreira *et al.* (2011).

Textural properties

Hardness is an imprtant index describing textural attributes of extruded products. Statistical analysis revealed that the main terms affecting the extrudates hardness were sesame content, screw speed and the interactions between temperature and sesame level. Product hardness was profoundly affected by sesame level ($P<0.05$). Extrudates with higher sesame content had higher hardness most probably due to presence of fat, protein and fibre as reported by Lazou and Krokida (2010) and Stojceska *et al.* (2008). However, hardness of the product was negatively correlated to the screw speed. This could be explaind by the fact that higher screw speeds lower the melt viscosity of mixture which in turn may lead to a softer extrudate (Ding *et al.*, 2006). In contrary with our results, Chanlat *et al.* (2011), found no significant effect of screw speed on the product hardness. The decreasing effect of screw speed can also be explained in the 3D surface plot of interactive effect of screw speed and temperature on hardness (Figure 3). As it was observed, extrudate hardness tended to increase sharply with increasing barrel temperature but at higher screw speed, increased temperature caused only a slight promotion in hardness. Dehghan-Shoar *et al.* (2010) suggested that hardnees tendency to increase at higher temperature might be as a result of changes in the chemistry of the melted material due to higher temperature. The interactive effect of temperature and sesame level on hardness is shown in Figure 3. At lower temperatures, an increase in sesame seed up to 15% decreased hardness, but beyond that it was affected conversely; however, at the highest temperatures, hardness steadily increased with increasing sesame concentration. It seems that extrudate hardness had a tendency to decrease with increasing the sesame seed up to an optimum concentration and then

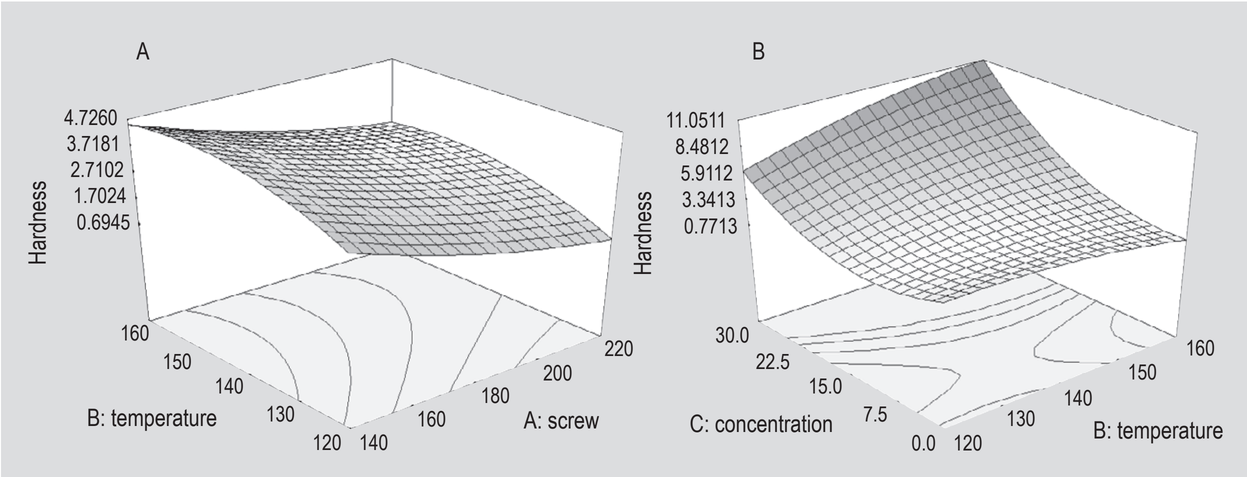

Figure 3. Response surface plots for interaction effects of (A) temperature × screw speed, and (B) temperature × sesame level (concentration) on extrudate hardness.

increased. This optimum level must be mostly dependent on barrel temperature; that is, higher barrel temperature, lower level of sesame was optimum concentration.

Colour

Colour is a major quality attribute of a food to attract consumers (Francis, 1991). Ingredients and extrusion parameters have important roles on the colour of the final product. Statistical analysis revealed that the main terms affecting the L* value of extrudate were sesame seed level, temperature, the interactions between temperature and sesame level and screw speed and sesame seed. The extrudate lightness (L* value) was found to be strongly influenced by quantity of sesame seed ($P<0.05$). As expected, an increase in sesame level at all levels of screw speed decreased the lightness (Figure 4) because of the high content of brown pigments present in the sesame coating (Nascimento *et al.*, 2012). Our result is in agreement with those of Nascimento *et al.* (2012) who obtained darker expanded extrudate with addition of SCSD. Similar findings were achieved by Altan *et al.* (2008) and Zasypkin and Lee (1998). From the response surface graph (Figure 4), by increasing the temperature at low sesame level, L* parameter showed a rapid rise while extrudates incorporated with higher sesame level experienced a reduction in lightness with increasing temperature. Ferreira *et al.* (2011) observed a reduction in L* parameter for corn-based expanded extruded snacks at higher barrel temperature. They speculated that severe thermal process might lead to degeredation of pigments resulting in loss of colour. The negative relationship between barrel temperature and L* parameter might be as well related to browned compounds formed through. Maillard reactions or caramelisation which would be accelerate over higher sesame levels.

Redness (a* value) of the product decreased linearly with increasing sesame level. Our results are not in accordance with those found by Altan *et al.* (2008) and Liu *et al.* (2000), who reported an increase in redness of tomato pomace-barley extrudate and oat-corn extrudate, respectively. Stojceska *et al.* (2008), however, reported the lower value of redness for ready-to-eat products containing cauliflower by-products. Later, Yagcı and Gogus (2008) obtained that increasing the partially defatted hazelnut flour ratio decreased the redness of extrudate. Statistical analysis showed no significant influence for temperature and screw speed on redness product. This accords with observations of Obatolu *et al.* (2005) who found no statistically significant correlation between screw speed and a* value of the extruded crab-based snack. The results indicated that with increasing the sesame level the product looked more yellow but this trend did not continued with further increase in sesame concentration (Figure 4). Rampersad *et al.* (2003) reported that addition of pigeon pea flour to cassava flour resulted in products with more yellowness. The results of interaction effect of screw speed and barrel temperature revealed that the extrudates showed a higher b* with increasing temperature over all screw speeds. Atlan *et al.* (2008) found that an increase in temperature caused a decrease in b* value. They pointed out that severe heat treatment might have damaged the caratenoids and thereby caused loss of yellowness. Maximum value of product yellowness was obtained at 159.68 °C and 8.16% sesame content.

Sensory evaluation

Organoleptic properties play an important role for a food to be acceptable to its target market (Francis, 1991). The results of sensory evaluation indicated that increasing the level of barrel temperature drastically reduced the consumer acceptance whereas, the extrudates processed

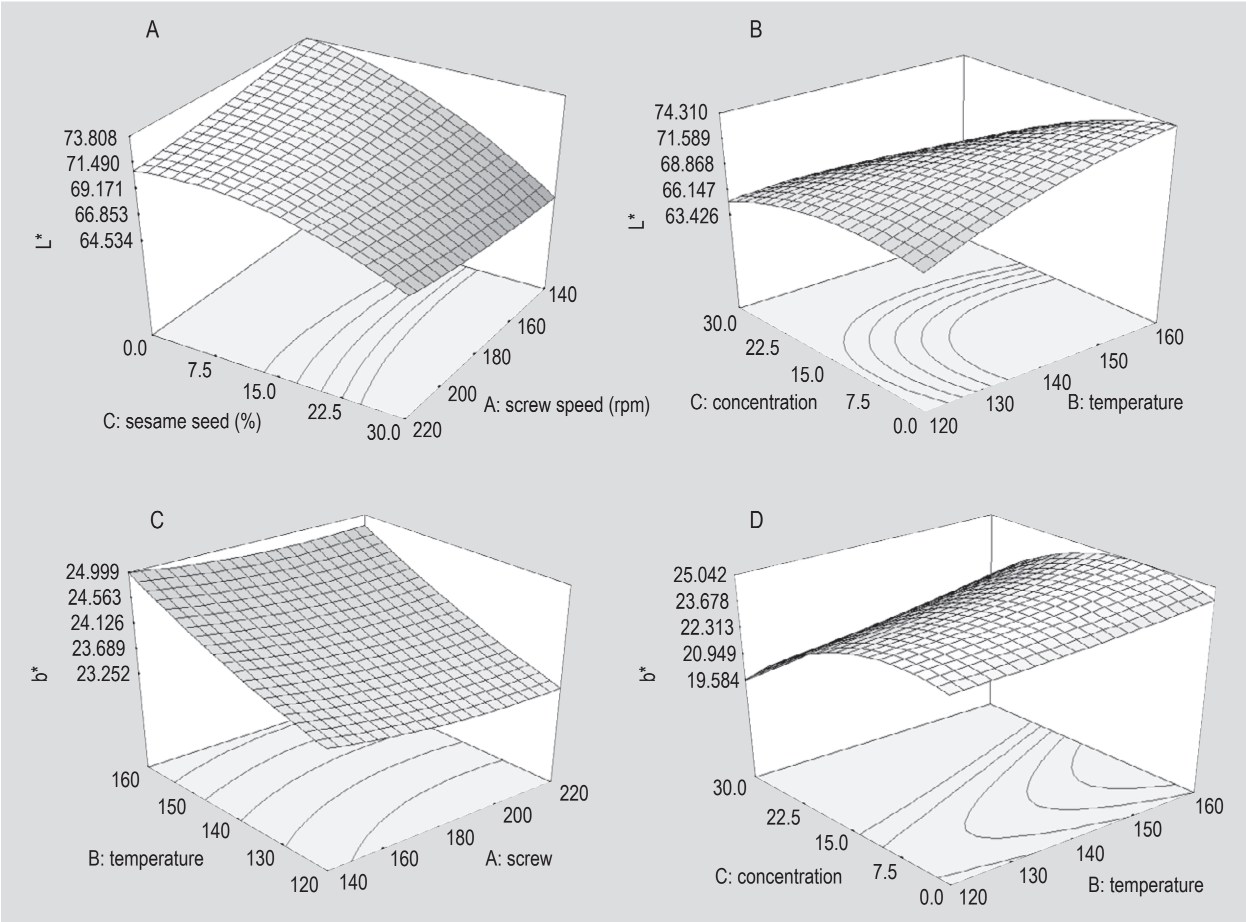

Figure 4. Response surface plots for interaction effects of (A) screw speed × sesame level, (B) temperature × sesame level on extrudate lightness (L*), (C) temperature × screw speed, and (D) temperature × sesame level (concentration) on extrudate yellowness (b*).

at higher screw speeds gave the better performance in sensory analysis (Figure 5). As the extrudates extruded at higher barrel temperatures were denser, less expanded, and harder as well as showing darker appearance, receiving the lower sensory scores by consumers would be expectable. The interaction effect of sesame level and temperature on overall acceptability of extrudates is depicted in Figure 5. It is obvious from the figure that extrudates incorporated with

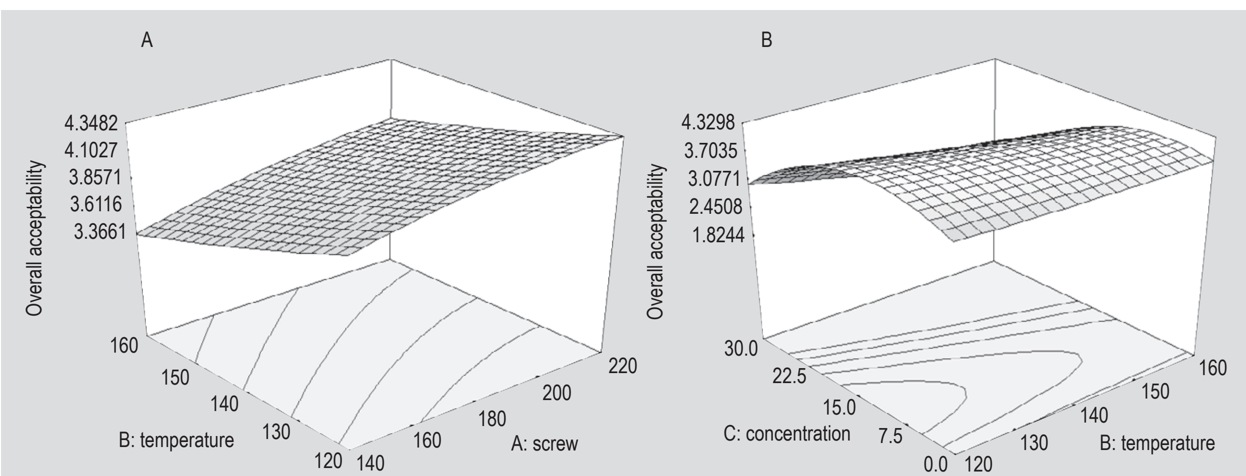

Figure 5. Response surface plots for interaction effects of (A) temperature × screw speed, and (B) temperature × sesame level (concentration) on extrudate overall acceptability.

a certain level (~15%) of sesame seed met high standards in organoleptic quality from the consumer acceptance perspective but increasing the sesame level byond that, caused a reduction in product acceptability. This is in consistent with the results of Nascimento *et al.* (2012) who considered that an increase in sesame oil cake in corn expanded extrudates formulation up to 20% could keep good sensory characteristics.

4. Conclusions

The results obtained in this study indicated that it is possible to enrich extruded snacks with sesame seed which is rich in protein and fibre. On the other hand, incorporation of sesame in extruded corn based products lead to change in several micro-structural, physical, and nutritional parameters. Sensory evaluation has indicated that the final products are acceptable to the consumers.

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