CO-EXTRUSION OF CORN MEAL AND POLYDEXTROSE FOR MAKING HIGH FIBER SNACK FOOD: EFFECTS OF EXTRUSION SCREW SPEED ON THE PRODUCT QUALITY

Jin Han Yang, Thi Thu Tra Tran, Van Viet Man Le

Ho Chi Minh City University of Technology,
Vietnam National University - Ho Chi Minh City (VNU-HCM); lvvman@hcmut.edu.vn

Abstract - High fiber snack foods are attracting consumers' attention due to their health benefits. In this research, corn meal and polydextrose are co-extruded with a twin-screw extruder and the screw speed is varied from 150 to 190 rpm. The objective of the research is to evaluate the effects of screw speed on the product quality. As the screw speed is increased, the expansion ratio and crispness of the fried extrudate are enhanced while the bulk density and hardness are reduced. Increase in screw speed results in increased water absorption index and water solubility index of the product. As the screw speed is increased, the mechanical energy of the extrusion process is also increased. The screw speed has significant correlation with the expansion index, bulk density and texture properties of the fried extrudate ($p < 0.05$).

Key words - Extrusion; high fiber snack; polydextrose; screw speed.

1. Introduction

Extrusion cooking is a versatile, low-cost and efficient technology in food processing since it involves in simultaneous mixing, kneading, cooking and forming operations. Nowadays, extruded snack food is produced worldwide and high consumption of extruded snack food is mainly due to its convenience, attractive appearance and specific texture. Novel ingredients and extrusion cooking technology make new snack products that are increasingly attractive to health-conscious consumers who are seeking for different mouth feelings and textures with convenience [1]. Indeed, the addition of dietary fiber ingredients to the blend in extruded snack food processing can be beneficial to the health of consumers. However, use of dietary fiber often leads to reduced expansion volume, high density, hard texture, low crispness and thus less preferred products [2]. Therefore, increasing dietary fiber content in extruded snack food is a challenging work. During extrusion cooking, the raw materials undergo many structural and chemical transformations such as protein denaturation, starch gelatinization, complex formation between lipid and amylose, degradation reactions of pigments and vitamins [3]. The quality of extruded snack food depends on material properties and process conditions such as the extruder type, feed rate, temperature profile in the barrel sections and screw speed [4]. It was reported that soluble fibers provide higher expansion volume and more favorable texture properties for extruded snack food than insoluble fibers [5]. Polydextrose is a soluble fiber which has been widely used in food processing due to its multi-functionality. However, the use of this dietary fiber ingredient in snack processing has not been thoroughly considered in prior studies.

In this study, commercial poly-dextrose preparation was co-extruded with corn meal to make high fiber content fried snack. The objective of the research is to investigate the impacts of extrusion screw speed on approximate composition, physical properties, instrumental color, water absorption index, water solubility index and sensory scores of the fried extrudate as well as specific mechanical energy of the extrusion process.

2. Materials and methods

2.1. Materials

Corn flour was purchased from Le Huyen company (Dong Nai, Viet Nam); its proximate composition was as follows (g/kg): 123 for moisture, 7 for ash, 60 for protein, 6 for lipid, 45 for fiber and total 758 for carbohydrate. Poly-dextrose was supplied by STA-LITE®Tate and Lyle PLC, (Decatur plant, The United States) with the following approximate composition (g/kg): moisture: 40, polydextrose: 900, protein: 1 and ash: 5. Palm olein was purchased from Tuong An Vegetable Oil J.S Company (Ho Chi Minh City, Vietnam).

2.2. Extrusion process

In this study, the material mixture consisted of 87.8% corn meal, 7.5% poly-dextrose, 4.0 % sugar and 0.7% salt (All value were analyzed on dry weight basis). Water was added to the material mixture and blended to obtain the final moisture content of 22.5% before extrusion. The experiments were carried out using an APV Baker twin-screw extruder (Model: MPF 80/15, Peterborough, The United Kingdom) with the productivity of 300 kg per hour. The screw speed of extruder was varied in the range of 150 to 190 rpm. The injection speed was fixed at 1.07 and 1.23 kg/h for water and oil, respectively. The barrel had 6 heating zones and the blend temperature of zone 1, 2, 3, 4, 5 and 6 was fixed at 48, 60, 77, 93, 116 and 92°C, respectively. The diameter of the die opening is 9.6 mm. The Sam Jung rotary knife cutter (Model: SJ-CC 200, Incheon, Korea) is used to cut the extrudates as they exist from the die nozzle.

When the twin-extruder was stabilized in process, the produced extrudates were sampled and deep fat fried by the Leo 1606 continuous fryer (Leo Tech Co, Ik san, Korea) at the temperature of 190°C for 12 sec. The fried extrudates were used immediately for quality analysis.

2.3. Chemical analysis

The moisture content of fried extrudate was quantified by ISO 665 drying method at 105°C for 3 h [6]. Ash content was determined by ISO 763 method [7]. Crude protein content was measured by AOAC2001.11 Kjeldahl method [8]. Total lipid content was evaluated by the modified AOAC 996.01 Soxhlet method [8]. Total dietary fiber content was quantified by the AOAC Official Method 2000 [9]; polydextrose content was measured by AOAC method 2000.11 [8].

Water absorption index (WAI) and water solubility index (WSI) were evaluated by the AACC 56-20 method with slight modification [10]. Two grams of sample and 30 ml of distilled water were added to a centrifugal tube. The mixture was vigorously shaken. The suspension was left to rest for 5 min and then centrifuged at 2200 x g for 15 min. Ten mL of the supernatant was dried to constant weight. WSI was evaluated by the following formula:

$$\text{WSI (\%)} = \frac{\text{Weight of dried supernatant } \times (30\text{mL}/10\text{mL})}{\text{Dry weight of sample}} \times 100\%$$

After removing 10 ml of the supernatant, the remaining supernatant was carefully decanted. The obtained wet sample was then weighed. WAI was quantified by the following formula:

$$\text{WAI (\%)} = \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Dry weight of sample}} \times 100\%$$

2.4. Physical analysis

The size of the fried products was measured with the average value of 15 random measurements using Vernier calipers to determine expansion ratio. Axial and radial expansion ratios (%) were evaluated as follows:

$$[(L_2 - L_1)/L_1] \times 100$$

where, L_1 was length or width of the fried extrudate; L_2 was length or width of the extrudate before the frying process [11].

Fried extrudates were placed in a 1,000 ml graduated cylinder to measure bulk density. The bulk density was quantified by dividing the weight of the sample (g) by the occupied volume of the cylinder [12].

The TA-XT Plus Texture analyzer (Texture Technologies Corp., Godalming, The United States) is used to determine crispness and hardness of the fried extrudates. The count peak (times) was measured to analyze crispness for 15 g of extrudates using Ottawa cell. The test speed was 2 mm/sec with a distance of 52 mm. The Exponent software program was used to evaluate force–time curve. The measurement was repeated 10 times to calculate the mean value. Hardness was evaluated by measuring the maximum force using the HDP/WBV probe (Warner Bratzler set with "V" slot blade for USDA Standard). The test speed was 2 mm/sec with distance of 5 mm. For each sample, 10 fried extrudates were measured [10].

2.5. Color analysis

Konica Minolta spectrophotometer (CR 410 model, Konica Minolta Inc, Osaka, Japan) is used to determine instrumental color of the extrudates. Instrumental color data was exhibited by CIE L*, a*, b* coordinates, indicating lightness, green-red and blue-yellow, respectively. Three measurements were made for each sample and averaged [10].

2.6. Specific mechanical energy (SME)

Specific mechanical energy of the extrusion process was evaluated by the following equation [13]:

$$SME\ (kJ/kg) = \frac{SS\ \times \text{P} \times \text{T}}{SS_{\text{max}} \times \text{Q} \times 100}$$

where, SS: screw speed (rpm); P: power rating of the extruder (150 kJ/s); T: average torque recorded over sampling time (%); SS_{max}: maximum screw speed (450 rpm); Q: mass flow rate (kg/s).

2.7. Scanning Electron Microscopy (SEM)

The samples were observed using a Jeol scanning electron microscope (JSM-7500, Jeol, Ltd., Akishima, Japan). The extrudate was placed on an SEM stub using double sided adhesive tape and was coated with thin film of gold. An accelerating potential of 5 kV was used in the scanning mode during micrography.

2.8. Sensory analysis

Ten well-trained staffs of Orion Food Vina Co., Ltd. (Ho Chi Minh City, Vietnam) were chosen as the sensory panelists. Crispness and hardness of the extrudates were determined by using a 9 point scale method [14]. Orion nacho chip and Nongshim banana kick snack were selected as standard products for the highest (score 9) and the lowest (score 1) intensity, respectively. The three-digit random numbers are given to five samples and served to each panelist sequentially. Before sensory evaluation, water was served to cleanse the palate. Sensory evaluation was conducted at 22°C under controlled illumination.

2.9. Statistical analysis

The analysis was done by running duplicate on each test and the average value was recorded. Each test was conducted in triplicate independently. The test data was presented as averages ± standard deviation (n = 3). Multiple range tests with the least significant difference were used to analyse which means were significantly different from others ($p < 0.05$).

The software Statgraphics Centurion XV (Manugistic Co., Rockville, Maryland, U.S.A.) is used to analyze one-way of variance.

3. Results and discussion

3.1. Effects of extrusion screw speed on approximate composition of the fried extrudate

Table 1 shows that increase in screw speed resulted in increase in moisture content of the fried extrudate.

Table 1. *Effects of extrusion screw speed on approximate composition (%) of the fried extrudate* (The mixture consisted of 87.8% corn meal, 7.5% poly-dextrose, 4.0% sugar and 0.7% salt; the ratio was calculated on dry weight basis)*

Screw speed (rpm)	Moisture	Ash	Protein	Lipid	Total fiber
150	0.81 ± 0.08^a	0.65 ± 0.02^a	4.11 ± 0.09^a	34.82 ± 0.12^a	7.56 ± 0.10^a
160	0.94 ± 0.03^b	0.65 ± 0.01^a	4.18 ± 0.15^a	34.60 ± 0.15^a	7.55 ± 0.21^a
170	1.12 ± 0.04^c	0.64 ± 0.02^a	4.27 ± 0.15^a	32.86 ± 0.03^b	7.52 ± 0.21^a
180	1.27 ± 0.05^d	0.64 ± 0.03^a	4.29 ± 0.10^a	32.95 ± 0.09^b	7.47 ± 0.12^a
190	1.25 ± 0.07^d	0.65 ± 0.01^a	4.30 ± 0.17^a	32.29 ± 0.56^c	7.57 ± 0.33^a

[*]The data is the average values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different ($p < 0.05$).

When the screw speed increased from 150 to 190 rpm, the retention time of the material in the extrusion barrel decreased from 7.9 to 5.8 seconds. Similar results are reported when corn flour and distillers dried grains are co-extruded [15]. When the screw speed increased from 150 to 180 rpm, the lipid content of the extrudate gradually decreased. Increase in air bubble size is associated with reduction in capillary pressure and that decreases lipid content of the extrudate [16]. Figure 1a-d reveals that the air cell wall in the extrudate became thinner and less compact while the air bubble size became larger when the screw rotating speed rose from 150 to 180 rpm. Nevertheless, further increase in screw speed from 180 to 190 rpm led to more coalesced structure and thicker cell wall of the obtained product (Figure 1e). The reduced air bubble size increases capillary pressure and enhances oil absorption. Similar results are reported for deep-fat fried batter prepared from ball-milled wheat flour [17]. Table 1 also presents that the ash, protein and fiber content of the product remained constant as the extrusion screw speed was varied. Obatolu, et al. [18] reported that the protein and ash contents of the extrudate from corn-meal and crab led do not change as the screw speed increases. It can be noted that the obtained snack can be considered as high fiber product since the total fiber content was approximately 7.5%.

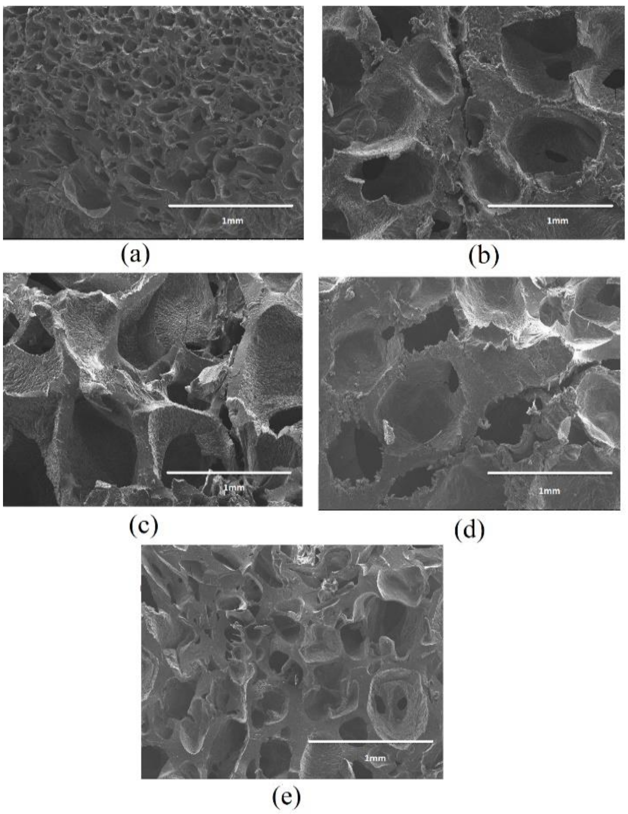

Figure 1. *Scanning electronic micrographs of the fried pellet on screw rpm variables: (a) 150rpm, (b) 160rpm, (c) 170rpm, (d) 180rpm, (e) 190rpm (The mixture consisted of 87.8% corn meal, 7.5% poly-dextrose, 4.0% sugar and 0.7% salt; the ratio was calculated on dry weight basis)*

3.2. Effects of extrusion screw speed on physical properties of the fried extrudate

Table 2 shows the effects of screw speed on expansion ratio of the fried extrudate. When the screw speed increased from 150 to 180 rpm, both radial and axial expansion ratio gradually increased. It can be explained that higher screw speed during extrusion may result in lower dough viscosity and greater elasticity, leading to more expanded extrudate [19, 20]. However, further increase in screw speed from 180 to 190 rpm significantly reduced the expansion ratio of the extrudate. Reduction in expansion ratio is also reported when screw speed is increased in the co-extrusion of corn meal and soybean fiber [21]. It can be noted that the effects of screw speed on expansion properties of the extruded snack food are still not clear. According to Katta et al. [28], expansion ratio of the extrudate could either increase or decrease and that depends on the range of screw speed and the approximate composition of feed. Similar results are reported when cassava is co-extruded with maize flour in snack processing [22].

The bulk density of the extrudate gradually decreased when the screw speed increased. Increase in screw speed results in an increase in shear rate for starch gelatinization. According to Alam, et al. [23], high degree of starch gelatinization enhances the volume of cereal-based extruded product, resulting in a decrease in bulk density. In addition, bulk density is closely related to expansion ratio of the extrudate [24]. Our results reveal that the higher the expansion ratio, the lower the bulk density of the obtained extrudate.

Changes in instrumental textural properties of the product under different extrusion screw speeds are also visualized in Table 2. Hardness and crispness are representative characteristics of fried extrudate. The hardness of the extrudate was reduced as the screw speed increased from 150 to 180 rpm. According to Tsokolar-Tsikopoulos et al. [20], the co-extrusion of rice flour and inulin, similar decrease in hardness is also reported when the extrusion screw speed increased. In addition, texture is linked to bulk density, expansion ratio and thickness of air cell wall.

Table 2. *Effects of extrusion screw speed on physical properties of the fried extrudate* (The mixture consisted of 87.8% corn meal, 7.5% poly-dextrose, 4.0% sugar and 0.7% salt; the ratio was calculated on dry weight basis)*

Screw speed (rpm)	Radial expansion ratio	Axial expansion ratio	Bulk density (g/L)	Hardness force (g)	Crispiness count pick (times)
150	143±17^{a}	136±9^{a}	100±1^{a}	736±23^{a}	69±2^{a}
160	149±7^{ac}	138±6^{ab}	68±2^{e}	556±27^{e}	78±5^{b}
170	164±11^{b}	141±5^{b}	65±1^{d}	490±11^{b}	97±3^{d}
180	169±11^{b}	145±6^{c}	58±1^{c}	448±27^{c}	120±12^{c}
190	153±12^{c}	139±7^{ab}	61±1^{b}	478±26^{b}	100±4^{d}

** The data is the average values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different ($p < 0.05$).*

Increased bulk density and increased thickness of air cell wall resulted in increased hardness of the obtained extrudate (Figure 1 and Table 2). However, further increase in screw speed from 180 to 190 rpm increased the hardness of the product. The sudden increase in hardness at 190 rpm is probably due to the collapsed inner cell structure as well as the reduced air bubble size (Figure 1e). The crispness gradually increased with the increase in screw speed. According to Tsokolar-Tsikopoulos, et al. [20], the increased screw speed has great impact on the formation of less dense and less thick cell walls of the extrudates. The crispness of such products is expected to be increased. Nevertheless, the crispness at the screw speed of 190 rpm was significantly lower than that at the screw speed of 180 rpm. Similar trends are observed when sorghum was co-extruded with soya blends: the crispness increases with increasing screw speed from 250 to 400 rpm, whereas it decreases at screw speed of 450 rpm [25].

3.3. Effects of extrusion screw speed on sensory score of the fried extrudate

Hardness and crispness are main characteristics of sensory quality of snack foods. The hardness and crispness results are shown in Table 3. The hardness score decreased by 48% when the screw rotating speed rose from 150 to 180 rpm. However, increase in screw speed from 180 to 190 rpm led to a significant increase in hardness score of the extrudate. The crispness score was significantly improved as the screw speed rose from 150 to 180 rpm but reduced as the screw rotating speed varied from 180 to 190 rpm. The correlation between the instrumental measurement data (Table 2) and the organoleptic data (Table 3) were evaluated. The instrumental forces correlated positively with the organoleptic scores for both hardness and crispness; the correlation coefficient was 0.691 ($p < 0.05$) for hardness and 0.492 ($p < 0.05$) for crispness. Similar results are reported when oat flour and yellow corn flour are co-extruded in snack processing [26].

Table 3. *Effects of extrusion screw speed on sensory score of the fried extrudate* (The mixture consisted of 87.8% corn meal, 7.5% poly-dextrose, 4,0% sugar and 0.7% salt; the ratio was calculated on dry weight basis)*

Screw speed (rpm)	150	160	170	180	190
Hardness	8.4 ± 0.69^{b}	5.3 ± 0.72^{c}	5.7 ± 0.81^{c}	4.4 ± 1.10^{d}	6.6 ± 0.90^{e}
Crispiness	4.8 ± 0.41^{b}	5.5 ± 0.52^{cd}	5.6 ± 0.51^{d}	6.1 ± 0.76^{e}	5.1 ± 0.80^{c}

** The data is the average values ± standard deviation (n = 3). Values with different small letters in the same row are significantly different (p < 0.05).*

3.4. Effects of extrusion screw speed on instrumental color, water absorption index, water solubility index of the fried extrudate and specific mechanical energy of the extrusion process

Effects of extrusion screw speed on instrumental color, water absorption index, solubility index of the fried extrudate and specific mechanical energy of the extrusion process were described in Table 4.

The color variation of fried extrudate provides information on the degree of browning reactions such as Maillard reaction, caramelization as well as the extent of cooking and pigment degradation during the extrusion process [3]. The effects of screw speed on the extrudate color are shown in Table 4. The L* value slightly increased when the screw speed increased. The a* value decreased when the screw speed rose from 150 to 160 rpm; however, the a* value was unchanged when the screw speed varied from 160 to 190 rpm. For all samples, the b* value was constant ($p>0.05$). Similar changes in lightness (L*) and chromatic coordinates (a* and b*) are also reported when bivolare bean was extruded with einkorn wheat and buck-wheat [27]. However, two opposite effects of screw speed on extrudate color was reported by Katta, et al. [28]: an increase in screw rotating speed decreased the material residence time, which result in reduced the extrudate browning, and, conversely, screw rotating speed augmented the shear and enhanced the temperature, which in turn led to browning. Change in color is therefore mostly dependent on the screw speed range, barrel temperature as well as approximate composition of the feed.

Water absorption index and water solubility index of the product are also shown in Table 4. They can be used to estimate the functional characteristics of snack food. Both water absorption and solubility index gradually increased when the screw speed rose from 150 to 190 rpm. According to Ainsworth, et al. [24], at high screw speed, increased shear effects would enhance gelatinization or mechanical destruction of starch molecules in the products, resulting in increased water holding capacity of the product. Likewise, the quantity of water soluble substances in the samples would increase with increased screw speeds with more starch molecules being soluble. Similar results are reported when barley flour and tomato pomace are co-extruded [10].

Table 4. *Effects of extrusion screw speed on instrumental color, water absorption index (WAI) and water solubility index (WSI) of the fried extrudate and specific mechanical energy (SME) of the extrusion process# (The mixture consisted of 87.8% corn meal, 7.5% poly-dextrose, 4.0% sugar and 0.7% salt; the ratio was calculated on dry weight basis)*

Screw speed (rpm)	L*	a*	b*	WAI	WSI	SME (KJ/Kg)
150	65.5 ± 0.5^{a}	8.9 ± 0.3^{a}	32.5 ± 0.5^{a}	253 ± 4^{a}	12.8 ± 0.4^{a}	226 ± 1^{a}
160	67.9 ± 0.2^{bc}	7.2 ± 0.1^{b}	32.3 ± 0.7^{a}	284 ± 4^{b}	13.9 ± 0.6^{b}	230 ± 2^{a}
170	66.7 ± 0.5^{b}	7.4 ± 0.4^{b}	32.2 ± 1.2^{a}	296 ± 5^{c}	16.7 ± 0.3^{d}	236 ± 1^{c}
180	68.5 ± 0.7^{c}	7.6 ± 0.1^{b}	32.9 ± 0.9^{a}	296 ± 5^{c}	18.8 ± 0.6^{c}	244 ± 2^{d}
190	67.8 ± 0.6^{bc}	7.3 ± 0.3^{b}	31.7 ± 1.0^{a}	327 ± 7^{d}	19.9 ± 0.3^{e}	265 ± 4^{e}

 # The data is the average values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0.05).

Table 4 also reveals that when the screw speed rose from 150 to 190 rpm, the specific mechanical energy of the extrusion process increased by 17%. Increase in specific mechanical energy by increasing the screw speed is also reported when barley flour and tomato pomace were processed in a co-rotating twin-screw extruder [10].

In this study, the result of correlation test showed that the specific mechanical energy of the extrusion process correlated positively with various attributes of the product. The correlation coefficients between specific mechanical energy and water absorption index, water solubility index and bulk density were 0.913, 0.881 and -0.606, respectively.

4. Conclusions

In this research, poly-dextrose was used as a source to make snack food with high dietary fiber content. The physical properties and sensory scores of the fried extrudate were shown to be significantly influenced by the screw speed.

Increase in screw speed resulted in increased expansion ratio, crispness, water absorption and solubility index as well as reduced hardness and bulk density of the product. High specific mechanical energy was observed at high screw speed. The specific mechanical energy correlated well with the extrudate properties such as water absorption index, water solubility index and bulk density. Further studies on transformation of poly-dextrose under different extrusion conditions are essential to clarify the impacts of this potential fiber on physico-chemical properties of snack food.

REFERENCES

[1] M. Alam, J. Kaur, H. Khaira, and K. Gupta, "Extrusion and extruded products: changes in quality attributes as affected by extrusion process parameters: a review", *Critical reviews in food science and nutrition,* vol. 56, 2016, pp. 445-473.

[2] S. Lue, F. Hseih, I. Peng, and H. Huff, "Expansion of corn extrudates containing dietary fiber: a microstructure study", *Lebensmittel Wissenschaft und Technology,* vol. 23, 1990, pp. 165-173.

[3] S. Ilo, Y. Liu, and E. Berghofer, "Extrusion Cooking of Rice Flour and Amaranth Blends", *LWT - Food Science and Technology,* vol. 32, 1999, pp. 79-88.

[4] G. Bisharat, V. Oikonomopoulou, N. Panagiotou, M. Krokida, and Z. Maroulis, "Effect of extrusion conditions on the structural properties of corn extrudates enriched with dehydrated vegetables", *Food research international,* vol. 53, 2013, pp. 1-14.

[5] F. Robin, H. P. Schuchmann, and S. Palzer, "Dietary fiber in extruded cereals: Limitations and opportunities", *Trends in Food Science & Technology,* vol. 28, 2012, pp. 23-32.

[6] ISO, "Oil seeds-Determination of moisture and volatile matter content", in *Oilseeds* vol. ISO 665, ed. Geneva, Switzerland: International Organization for Standardization (ISO), 2000.

[7] ISO, "Fruit and vegetable products - Determination of ash insoluble in hydrochloric acid", in *Fruits, vegetables and derived products in general* vol. ISO 763, ed. Geneva, Switzerland: International Organization for Standardization (ISO), 2003.

[8] G. W. Latimer Jr, "Official methods of analysis of AOAC INTERNATIONAL 20th edition, Appendix D, Guidelines for collaborative study procedures to validate characteristics of a method of analysis", in *Gaithersburg, MD, USA*, ed, 2016.

[9] B. V. McCleary, A. Draga, and N. Sloane, "Dietary fibre analysis in foods", in *Fibre-rich and wholegrain foods: improving quality,* J. A. Delcour and K. Poutanen, Eds., ed Cambridge: Woodhead Publishing Limited, 2013, pp. 25-60.

[10] A. Altan, K. L. McCarthy, and M. Maskan, "Evaluation of snack foods from barley–tomato pomace blends by extrusion processing", *Journal of Food Engineering,* vol. 84, 2008, pp. 231-242.

[11] S. Yu, "Acceptability of fish crackers (keropok) made from different types of flour", *ASEAN Food Journal,* vol. 6, 1991, pp. 114-116.

[12] A. O. Obadina, O. B. Oyewole, and O. E. Williams, "Improvement in the traditional processing method and nutritional quality of traditional extruded cassava-based snack (modified Ajogun)", *Food Science & Nutrition,* vol. 1, 2013, pp. 350-356.

[13] J. G. Waramboi, M. J. Gidley, and P. A. Sopade, "Influence of extrusion on expansion, functional and digestibility properties of whole sweetpotato flour", *LWT-Food Science and Technology,* vol. 59, 2014, pp. 1136-1145.

[14] H. Larsen, P. Lea, and M. Rødbotten, "Sensory changes in extruded oat stored under different packaging, light and temperature conditions", *Food Quality and Preference,* vol. 16, 2005, pp. 573-584.

[15] P. Fallahi, K. A. Rosentrater, K. Muthukumarappan, and M. Tulbek, "Effects of Steam, Moisture, and Screw Speed on Physical Properties of DDGS-Based Extrudates", *Cereal Chemistry,* vol. 90, 2013, pp. 186-197.

[16] M. Mellema, "Mechanism and reduction of fat uptake in deep-fat fried foods", *Trends in food science & technology,* vol. 14, 2003, pp. 364-373.

[17] P. Thanatuksorn, K. Kajiwara, and T. Suzuki, "Characteristics and oil absorption in deep-fat fried batter prepared from ball-milled wheat flour", *Journal of the Science of Food and Agriculture,* vol. 90, 2010, pp. 13-20.

[18] V. Obatolu, D. Skonberg, M. Camire, and M. Dougherty, "Effect of moisture content and screw speed on the physical chemical properties of an extruded crab-based snack", *Food Science and Technology International,* vol. 11, 2005, pp. 121-127.

[19] J. M. R. Diaz, L. Sundarrajan, S. Kariluoto, A. M. Lampi, S. Tenitz, and K. Jouppila, "Effect of Extrusion Cooking on Physical Properties and Chemical Composition of Corn-Based Snacks Containing Amaranth and Quinoa: Application of Partial Least Squares Regression", *Journal of Food Process Engineering,* vol. 40, 2017, p. e12320.

[20] K. C. Tsokolar-Tsikopoulos, I. D. Katsavou, and M. K. Krokida, "The effect of inulin addition on structural and textural properties of extruded products under several extrusion conditions", *Journal of food science and technology,* vol. 52, 2015, pp. 6170-6181.

[21] Z. Jin, F. Hsieh, and H. Huff, "Extrusion cooking of corn meal with soy fiber, salt, and sugar", *Cereal Chemistry,* vol. 71, 1994, pp. 227-233.

[22] F. Fayose, "Expansion characteristics of selected starchy crops during extrusion", *The West Indian Journal of Engineering,* vol. 35, 2015, pp. 58-64.

[23] M. S. Alam, S. Kumar, and H. Khaira, "Effects of extrusion process parameters on a cereal-based ready-to-eat expanded product formulated with carrot pomace", *Cereal Foods World,* vol. 60, 2015, pp. 287-295.

[24] P. Ainsworth, Ş. İbanoğlu, A. Plunkett, E. İbanoğlu, and V. Stojceska, "Effect of brewers spent grain addition and screw speed on the selected physical and nutritional properties of an extruded snack", *Journal of Food Engineering,* vol. 81, 2007, pp. 702-709.

[25] A. T. V. Kumar, D. V. K. Samuel, S. K. Jha, and J. P. Sinha, "Twin Screw Extrusion of Sorghum and Soya Blends: A Response Surface Analysis", *Journal of Agricultural Science and Technology,* vol. 17, 2015, pp. 649-662.

[26] Y. Liu, F. Hsieh, H. Heymann, and H. Huff, "Effect of process conditions on the physical and sensory properties of extruded oat-corn puff", *Journal of Food Science,* vol. 65, 2000, pp. 1253-1259.

[27] I. Y. Bakalov, T. Petrova, M. Ruskova, K. Kalcheva–Karadzhova, and N. Penov, "The effect of extrusion variables on the colour of bean-based extrudates", *Bulgarian Chemical Communications,* vol. 48, 2016, pp. 407-411.

[28] S. Katta, L. Jackson, S. Sumner, M. Hanna, and L. Bullerman, "Effect of temperature and screw speed on stability of fumonisin B1 in extrusion-cooked corn grits", *Cereal Chemistry,* vol. 76, 1999, pp. 16-20.

(The Board of Editors received the paper on 05/3/2019, its review was completed on 17/5/2019)