Journal of Food Science and Technology (Iran)

Homepage:www.fsct.modares.ir

Scientific Research

Evaluation of macrostructural, functional and color characteristics of high fiber extruded snack enriched with fresh cauliflower

Niki zarghani, Arash Koocheki., Elnaz Milani

1- M.Sc in Food Science and Technology, Faculty of Agriculture, Ferdowsi University, Mashhad, Iran.
2-Professor, Department of Food Science, Faculty of Agriculture, Ferdowsi University, Mashhad, Iran.
3-Associated professor, Department of Food Processing, Iranian Academic Center for Education Culture and Research (ACECR) of Mashhad, Iran.

ARTICLE INFO

Article History:
Received:2023/10/9
Accepted:22023/12/28

Keywords:

snack,

porosity,

water solubility index,

water absorption index,

color

DOI: 10.22034/FSCT.21.157.1.

*Corresponding Author E-
e.milani@jdm.ac.ir

ABSTRACT

In this research, extrusion technology was used to produce high-fiber snacks made from fresh cauliflower, corn starch, and corn flour. For this purpose, a central composite design and the response surface method (RSM) effects of various factors, including screw speed (120 to 180 rpm), cauliflower percentage (15%, 20%, 25%), and their impact on macrostructural, functional and color characteristics, such as expansion ratio, porosity, water solubility, water absorption index, and color changes of the snacks were investigated. The results demonstrated increasing the percentage of cauliflower increased the water absorption index ($P<0.05$) and whiteness index ($P<0.0001$) and also decreased the expansion ratio ($P<0.0001$) and porosity ($P<0.0001$) of the snack. It had no significant effect on the water solubility index. Increasing the screw speed led to an increase in the expansion ratio ($P<0.0001$), porosity ($P<0.0001$), solubility index in water($P<0.0001$), and decreased whiteness index($P<0.0001$) and water absorption index ($P<0.05$). The optimal sample was obtained by considering the maximum amount of cauliflower, the maximum water absorption index and the expansion ratio equivalent to the amount of cauliflower of 25% and the screw speed of 180 revolutions per minute with a desirability of 0.81 And after performing the test on the predicted values of the software, the non-significance of the average difference between the actual sample analysis results and the predicted sample values was observed, and The observations of the study indicate the promising potential of extruded snacks for enrichment purposes.

1- Introduction

In today's world, changes in lifestyle and dietary patterns have led to a more prominent role of snacks in consumers' diets [1]. Snack consumption has become a part of children's daily lives [2]. Snacks come in various forms, including fresh foods, packaged foods, and processed products. Some common snacks include biscuits, cakes, sandwiches, ready-made salads, vegetables and fruits, nuts and seeds, popcorn, various chips, and extruded products [3, 4]. Although ready-to-eat snacks are often high-calorie food products with low nutritional value [5], fresh and unprocessed fruits and vegetables can be used to improve nutritional balance, as they are the richest sources of bioactive components and health-promoting substances [6]. Nutrition is a matter of both quantity and quality, and vegetables in all their forms ensure adequate intake of most vitamins and nutrients, dietary fibers, and phytochemicals that can help address many nutritional issues [7]. Among the numerous studies conducted on plants, significant attention has been focused on the health-promoting compounds of the Brassica family due to their bioactive compounds and high fiber content, which play a special role in preventing diseases [8]. Cauliflower, scientifically known as *Brassica oleracea var. Botrytis*, is the most popular member of the Brassica family and is widely grown in India. The edible part of cauliflower is its flower head [9], and it is an excellent source of protein (16.1%), cellulose (16%), and hemicellulose (8%) [10]. It is considered a rich source of dietary fiber and possesses antioxidant and anti-cancer properties [11]. The extrusion process is used to produce expanded products, which constitute a significant portion of snacks [12]. Extrusion cooking technology is applied in the development of ready-to-eat products from cereal flours, tubers, and legumes, such as breakfast cereals, puffed snacks, and instant powders [13]. Due to shear stress, pressure, and heat during extrusion cooking, gelatinization and depolymerization of starch molecules occur, along with the breakdown of lateral branches in fibers, significantly enhancing the digestibility of proteins, starches, and their soluble fiber fractions [14]. Lotfi Shirazi et al. (2020) examined the characteristics of snacks based on barley flour and carrot pomace. With an increase in carrot pomace, the expansion ratio, lightness, water absorption index, and overall acceptability decreased. Meanwhile, with increased moisture, the expansion ratio and water solubility index decreased while lightness and water absorption index increased [15]. Additionally, research by Lisika et al. (2021) on the effect of adding fresh green onion or leek pomace on the selected properties of potato-based pellets and puffed snacks showed that adding leek or onion pomace significantly affected the color determinants of pellets and fried snacks, apparent density, and water absorption of the pellets. Furthermore, the speed of the twist significantly impacted water absorption and solubility in water, as well as coordinates L* and b* regarding onion puffs [16]. Milani et al. (2020) examined the possibility of reusing by-products from processing industries (coffee grounds and wheat bran) to produce fibrous solid foam using extrusion technology. The results showed that the final moisture content of the product and the water activity of the produced fibrous foam increased with the interactive increase in the levels of adding coffee grounds and rice bran and the initial moisture content. With the increase in the levels of coffee grounds, the texture hardness increased due to the rise in insoluble fiber, and the expansion ratio of the solid foam significantly decreased. Simultaneously, with a reduction in feed moisture and an increase in screw speed, texture hardness decreased while the expansion ratio significantly increased [17]. The aim of the recent study was to investigate the effect of formulation variables, including the percentage of fresh cauliflower and screw speed of the extruder, on the characteristics of snacks made from fresh cauliflower, corn starch, and corn flour. Additionally, due to the addition of fresh cauliflower and the elimination of drying stages for cauliflower, along with the reintroduction of water during the extrusion process, there was a significant reduction in water and energy consumption throughout the process, leading to a decrease in the final product cost.

2- Material and methods

2-1- Preparation of raw materials

The corn flour, corn starch, maltodextrin (DE= 19) and fresh cauliflower were purchased from

[DOI: 10.22034/FSCT.21.157.1]

the local market in Mashhad. Then the cauliflowers were manually cut into smaller pieces, washed and completely drained at room temperature. Then, they were ground using the industrial mill of Toos Khorasan, in such a way that for each batch, the cauliflower was first mixed with maltodextrin in a blender. After that, corn starch was added, and finally, corn flour was incorporated. The resulting mixture was sifted to ensure uniformity, and the flour samples were stored in polyethylene bags to prevent moisture exchange [18].

2-2- Extrusion cooking

To produce the product, a co-rotating twin-screw extruder Jinan Saxin (model 56DS, made in China) was used. Based on the pre-treatments conducted, the optimal fixed conditions for the extrusion process were determined to be a feed rate of 40 kg per hour, a temperature of 140 degrees Celsius, and a die diameter of 3 mm. The moisture content of the feed entering the extruder was adjusted according to the levels of added cauliflower, which were 15% (20.51), 20% (22.9), and 25% (27.7). After exiting the extruder die, the samples were placed in an oven at a temperature ranging from 110 to 120 degrees Celsius for 10 minutes to dry. Subsequently, the collected samples were stored in coded zip-lock bags to maintain moisture, aroma, and flavor until testing was performed.

Table 1- Independent variables and their values

Independent variables	Symbol	-1	0	+1
Cauliflower (%)	A	15	20	25
Screw speed	B	120	150	180

Table 2- Chemical properties of the optimized sample before and after extrusion

	Protein (%)	Fat (%)	Moisture (%)	Crude fiber (%)	Antioxidant activity (g/100g)	Total phenol (mg/100g)
Before extrusion	3.55[a]	1.37[a]	28.7[a]	12.89[a]	5.17[a]	69.84[a]
After extrusion	3.93[b]	0.6[b]	10.03[b]	19.33[b]	7.18[b]	170.03[b]

In each column, the means with the same letters were not significantly different from each other (P>0.05).

2-3- Expansion Ratio

Ten samples were randomly selected from each treatment, and the diameter of each sample was measured at five different locations using a digital caliper. To determine the average thickness of the product, the results were averaged. The expansion ratio is calculated by dividing the average diameter of the sample by the diameter of the extrusion die [19].

$$\text{Expansion ratio} = \frac{\text{Extrudate diameter}}{\text{Die diameter}}$$

2-4- Porosity

Porosity is defined as the volume of voids within the particles relative to their total volume. Porosity will be calculated using the following equation [20]:

[DOI: 10.22034/FSCT.21.157.1]

$$\text{porosity} = \frac{(\text{bulk density} - \text{particle density})}{\text{particle density}} \times 100$$

2-5- Water Absorption Index

This index measures the amount of water absorbed by the granule or starch polymer after swelling. To determine this index, 2.5 grams of pre-weighed powder was first added to a Falcon tube, then 25 ml of distilled water was added and stirred at room temperature for 30 minutes at a speed of 2000 revolutions per minute. The resulting mixture was then centrifuged at 3000 g for 15 minutes. Finally, the upper liquid was removed from the Falcon tube, and the remaining gel was weighed. The water absorption index was calculated using the following equation [19]:

$$\text{WAI} = \frac{\text{Weight of wet sediment(g)}}{\text{Weight of dried sample(g)}}$$

2-6- Water Solubility Index

Initially, the upper liquid from the Falcon tube during the measurement of the water absorption index was transferred to a pre-weighed plate. Then, it was placed in a hot air oven at a temperature of 105 degrees Celsius. Finally, the plate, along with the existing residues, was weighed, and the solubility was calculated using the following equation [19]:

$$\text{WSI (\%)} = \frac{\text{Weight of dried supernatant (g)}}{\text{Weight of dried sample (g)}} \times 100$$

2-7- Color

The color of the product produced was measured using a Hunter Lab device (Color Flex VA, Hunter Lab Reston, Made in U.S.A). Each powder sample was placed so that it completely covered the bottom of the device's container, and the values of L*, a*, and b* were determined. Here, L* indicates the brightness of the sample, varying from zero (black) to 100 (white). Positive and negative values of a* represent redness and greenness, respectively, while positive and negative values of b* indicate yellowness and blueness. For each sample, three images were taken, and three sections from each image were analyzed. The whiteness index was determined using the following equation [21]:

$$\text{Whiteness index} = 100 - \sqrt{(100 - \text{L}*)^2 + \text{a}*^2 + b*^2}$$

2-8- Statistical analysis

In this study, a central composite rotatable design and response surface methodology (RSM) with 2 factors and 3 levels were employed to investigate the effect of independent variables on the physical and functional properties of the intermediate product. The modeling of the results obtained from this research was conducted using Design Expert software version 7, and three-dimensional curves were plotted to examine the relationship between the independent variables and the responses.

3- Result and discussion

3-1- The effect of formulation and process variables on expansion Ratio

The expansion ratio indicates the volume formed by the molten material exiting the extruder [22]. The range of variation in the expansion ratio of the samples was from 2.609 to 4.418. fitted linear model for this parameter is significant ($P< 0.0001$), and any lack of fit associated with the model was not significant. The calculated R^2 value was 0.96, and the significant terms included the percentage of cauliflower and the screw speed ($P< 0.0001$). The effect of extrusion variables on the expansion ratio is shown in the fig 1. Simultaneous increases in both the cauliflower ratio and screw speed resulted in a decrease in expansion ratio, which was due to a greater impact of the cauliflower ratio compared to the rotation speed. The highest expansion ratio was observed for the sample containing 15% (weight/weight) cauliflower at 180 (rpm), while

[DOI: 10.22034/FSCT.21.157.1]

the lowest expansion ratio was found for the sample containing 25% (weight/weight) cauliflower extruded at 120 (rpm). By increasing the amount of fresh cauliflower due to the increase in fiber and subsequently decreasing the share of starch, the amount of expansion decreased; The presence of fiber in the air cell walls reduces the potential of starch expansion and starch gelatinization, and as a result, it leads to a decrease in expansion [23]. The reason for the limited expansion of snack products combined with fresh vegetable paste can be the effect of the water content in vegetable pulps and also the reduction of starch content due to its replacement with fiber [24]. With an increase in fiber, the walls of air cells become loose and thin, rapidly disintegrating. This prevents the formation and expansion of air cells, resulting in a denser structure that causes a reduction in expansion [25]. In another theory, fiber limits water access for starch gelatinization, increases the viscosity of the molten material, and ultimately reduces the expansion ratio of the final product [26]. The moisture content of the input feed is one of the main factors affecting the expansion ratio [27]. An increase in cauliflower through increased moisture reduces the temperature in the chamber, which leads to a decrease in starch gelatinization and ultimately results in a reduced expansion ratio of the extruded product [28]. A similar relationship was observed for extruded corn products with the addition of dried tomatoes, which was attributed to a reduction in starch content and resulted in a decrease in the expansion ratio [29]. In another study, the addition of carrot pomace up to 25% and an increase in the moisture content of the input feed reduced the final product's expansion. In all samples, an increase in screw speed led to an increase in the expansion ratio. Hagenimana et al. (2006) found that increasing the screw speed, along with an increase in temperature and shear force due to more energy entering the materials inside the extruder chamber, reduced the viscosity of the molten dough and increased moisture evaporation at the die exit, thereby increasing the expansion ratio [30]. Similarly, Seker (2005) also found that an increase in screw speed consistently raised the expansion ratio [31].

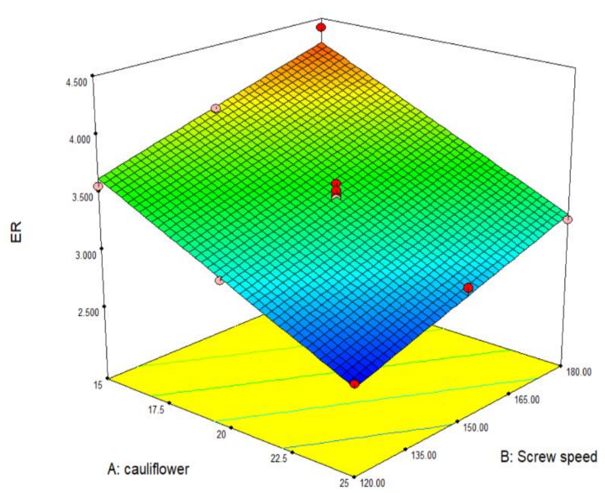

Fig 1 Response surface diagram for the effect of the variables of cauliflower percentage and screw speed on the expansion ratio (ER).

3-2- The effect of formulation and process variables on porosity

Trapped air within the dough creates pores in the extruded material. Several factors contribute to the formation of cavities of various sizes in the products. The reason for the formation of a porous and spongy structure in these products is the sudden release of steam

[DOI: 10.22034/FSCT.21.157.1]

from within the dough. The differing functional properties of the dough, the composition of the input feed, and process variables determine the size and number of pores [32]. Nucleation is the first stage of expansion. Soluble fibers, with their increased volume, and insoluble fibers, due to their hydrophobic properties, are nucleating agents [33]. The range of porosity in the samples varied from 0.635 to 0.8278. fitted linear model for this parameter was significant ($P< 0.0001$), and any lack of fit associated with the model was not significant. The calculated R^2 value was 0.91, and the effects of cauliflower ratio and screw speed on porosity were significant ($P< 0.0001$). At constant screw speeds, an increase in cauliflower content led to a decrease in porosity. As the amount of cauliflower increased, so did the water and fiber content in the system, while the starch proportion decreased. The presence of fiber caused the walls of gas bubbles to collapse, resulting in reduced expansion and porosity. Basharat et al. (2013) also reported that the reason for reduced porosity in corn-based snack products with olive paste from oil extraction was due to added fiber in the formulation [23]. Research by Sun et al. (2002) on extruded products containing defatted soybean pulp showed that an increase in fiber content led to a reduction in air cell size while simultaneously increasing the number of pores in air cells, resulting in tissue densification and decreased porosity [34]. Lotfi Shirazi et al. (2020) observed that increasing carrot pomace from 15% to 25% led to a reduction in porosity due to the high fiber content in carrot pomace [15]. Increasing the moisture content of the input feed by adding fresh cauliflower leads to a reduction in the temperature of the chamber. A lower processing temperature results in decreased starch gelatinization, which ultimately causes a reduction in porosity and expansion of the extruded product [28]. On the other hand, with increased moisture content in the input feed, the likelihood of particles coming closer together and adhering increases, resulting in the filling of empty spaces between them and consequently reducing porosity [35]. In all samples, an increase in screw speed significantly increased porosity. The effect of screw speed on porosity can be attributed to the shear stress applied to the extruded materials during extrusion [36]. Excessive shear stress can lead to over-degradation and dextrinization of starch, reducing its ability to swell and gelatinize. It is claimed that the starch center is one of the primary nucleation sites for bubble formation. If starch is damaged, it cannot absorb water, thereby diminishing its ability to carry steam and initiate nucleation [37]. Additionally, Basharat et al. (2013) reported that increasing screw speed raises the absolute pressure generated within the chamber. When the molten dough exits the extruder die, a sudden drop in pressure causes increased moisture evaporation at the die exit, leading to greater expansion and increased porosity [23]. Hagenimana et al. (2006) found that increasing screw speed, along with an increase in temperature and shear force due to more energy entering the materials inside the extruder chamber, reduced the viscosity of the molten dough and increased moisture evaporation at the die exit, resulting in greater expansion and increased porosity [30].

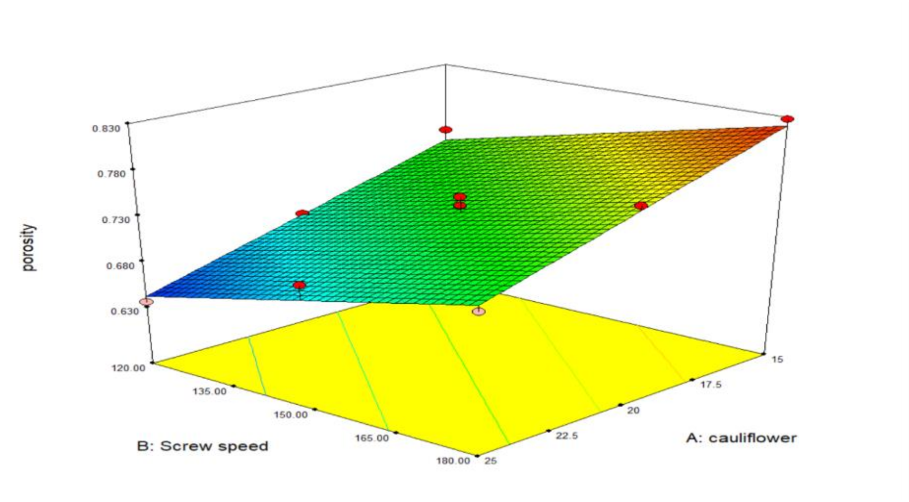

Fig 2 Response surface diagram for the effect of the variables of cauliflower percentage and screw speed on the porosity

3-3- The effect of formulation and process variables on water absorption Index

The Water Absorption Index (WAI) indicates the amount of water retained by starch after swelling [38]. The fitted second-degree model was significant ($P< 0.05$), and any lack of fit associated with the model was not significant. The R^2 value and standard deviation were obtained as 0.92 and 1.96, respectively. The regression coefficients for the linear effects of cauliflower ratio and screw speed, as well as the second-degree effect of cauliflower ratio on WAI, were significant ($P< 0.05$). The water absorption index for the samples ranged from 5.36 to 6.47. The highest water absorption was observed for the sample containing 25% (weight/weight) cauliflower at 150 (rpm), while the lowest water absorption was seen for the sample containing 15% (weight/weight) cauliflower extruded at 180 (rpm). Water absorption significantly increased ($P< 0.05$) with an increase in the percentage of cauliflower and significantly decreased ($P< 0.05$) with an increase in screw speed, which is consistent with the findings of Hang et al. (2014) [39]. As the percentage of cauliflower in the feed composition increased, the fiber content of the samples also increased, and the water-absorbing properties of fiber [40] could significantly influence the increase in WAI for samples with higher percentages of cauliflower. Additionally, as the ratio of fresh cauliflower increased, moisture content also rose, leading to a significant increase in WAI for the final product. Water acts as a plasticizer during extrusion cooking and reduces the degradation of starch granules in the dough, thereby increasing water absorption capacity by starch and WAI [30, 41]. Kaisangsri et al. (2016) investigated the effects of adding carrot pomace on the quality of extruded corn products. Their observations indicated that adding carrot pomace increased the water absorption index, attributing this to the presence of hydroxyl groups in the structure of carrot pomace. Since there are also many hydroxyl groups present in cauliflower structure [42], it can be inferred that increased water absorption with higher percentages of cauliflower is related to these hydroxyl groups interacting with water through hydrogen bonds, facilitating greater water absorption. The results by Birguy et al. (2018) also showed that increasing sesame percentage in the feed composition led to an increase in protein and fiber content in extruded corn and sesame samples, suggesting that the water-absorbing properties of these two components could significantly influence the increase in WAI for samples with higher sesame percentages [43]. WAI decreased with an increase in screw speed. Higher rotation speeds lead to the degradation of proteins and starch, reducing water absorption in extruded products [37,44,45]. It can be expected that with increased speed, the polymer chains of starch become dextrinized, making hydrophilic groups less accessible. As a result, the reduced number of hydrophilic groups and lower water binding lead to a decrease in WAI [44]. As shown in the graph, the simultaneous increase

[DOI: 10.22034/FSCT.21.157.1]

in cauliflower content and screw speed also resulted in a decrease in the water absorption index due to a reduction in the expansion ratio. Water moves through air cells on the surface and inside the product; therefore, the fewer air cells there are, the less water can be absorbed [46]. The negative effect of screw speed on WAI, as well as the positive effect of moisture, was reported by Altan et al. (2009) in extruded products based on tomato pomace and barley [25]. Singh et al. (2015) also reported similar results regarding the relationship between screw speed and water absorption index [44].

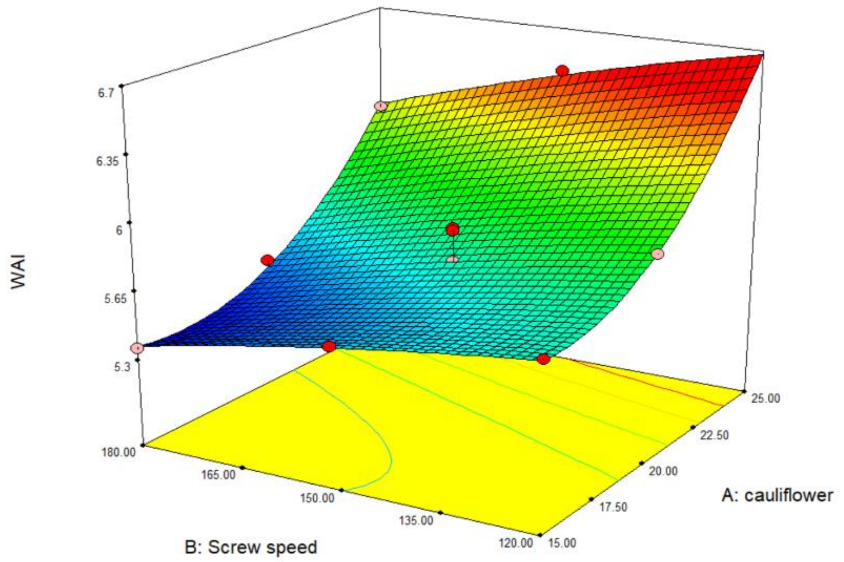

Fig 3 Response surface diagram for the effect of the variables of cauliflower percentage and screw speed on water absorption index

3-4- The effect of formulation and process variables on water solubility Index

The solubility index in water is fundamentally used as an indicator of the degradation of molecular components and measures the amount of polysaccharide released from the starch component after extrusion [47]. The fitted second-degree model was significant ($P< 0.0001$), and any lack of fit for this factor was not significant. The calculated R^2 value was 0.96, and the significant terms included screw speed ($P< 0.0001$), the interaction effect of cauliflower ratio and screw speed, and the second-degree effect of screw speed ($P < 0.05$). No significant effect of cauliflower percentage on this factor was found.These findings align with the study by Stojceska et al. (2008), where malted grain byproducts were used to produce extruded products[48]. Additionally, another study reported similar results indicating that cauliflower levels had no effect on the water solubility index in snacks made from cauliflower byproducts [49]. The simultaneous increase in screw speed and cauliflower levels led to an increase in the Water Solubility Index (WSI) of the extruded products. The increase in WSI with higher screw speeds may be related to an increase in specific mechanical energy (SME) at high screw speeds. High mechanical shear causes the degradation of macromolecules into smaller molecules with higher solubility [50]. The increase in WSI with rising screw speed was consistent with findings reported by other researchers on extruded rice flour and quinoa products [51-53]. These results were also in accordance with research by

[DOI: 10.22034/FSCT.21.157.1]

Altan et al. (2008) on producing snacks from barley-tomato pomace [25].

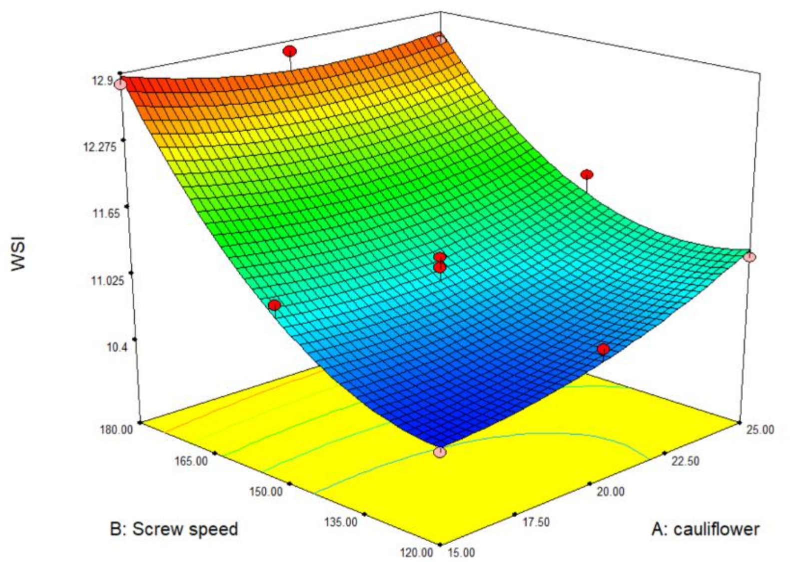

Fig 4 Response surface diagram for the effect of the variables of cauliflower percentage and screw speed on water solubility index

3-5- The effect of formulation and process variables on the changes in the color components of the product

Color is an important quality factor that is directly related to the acceptability of food products and is a significant physical characteristic to report for extruded products [25]. Table 3 shows the values of the coordinates L*, a*, and b*, as well as the whiteness index (WI) for the produced snacks. The results of the analysis of variance indicated that the fitted linear model was significant (P< 0.0001), and any lack of fit was not significant. The R^2 value for this factor was obtained as 0.86. Significant terms included the percentage of cauliflower and screw speed (P< 0.0001). The whiteness index of the samples varied from 68.65 to 72.96. The effect of extrusion variables on the whiteness index is shown in Figure 5. With an increase in screw speed, the whiteness index significantly decreased (P< 0.0001). The highest whiteness index was found for the sample containing 25% (weight/weight) cauliflower at 120 (rpm). The reduction in the whiteness index with increasing screw speed is attributed to greater degradation of proteins and starch at higher speeds. As a result, more Maillard reactions occur, leading to a decrease in brightness and whiteness indices [19,54]. Conversely, the whiteness index significantly increased with an increase in cauliflower percentage, confirming a positive correlation between increased whiteness and fiber addition. The increase in cauliflower, due to higher moisture content and lubricating effects, resulted in less degradation of compounds and consequently reduced Maillard reactions and caramelization [23]. Lotfi Shirazi et al. (2020) also reported similar results, indicating that increased moisture led to enhanced brightness in the produced snacks [15].

Table 3- The result of L*, a*, b* color coordinates and the whiteness index of the extruded snack

[DOI: 10.22034/FSCT.21.157.1]

Cauliflower (%)	Screw speed	L*	a*	b*	whiteness index
15	120	83.23	-0.37	26.06	71.02
	150	84.28	-1.89	24.82	70.23
	180	83.39	-1.02	25.38	68.65
20	120	83.58	-1.08	23.84	71.32
	150	83.67	-1.5	24.29	70.95
	180	83.17	-0.37	26.3	68.8
25	120	86.27	-1.46	22.2	72.96
	150	83.03	-1.31	22.81	71.6
	180	85.5	-1.03	24.95	70.09

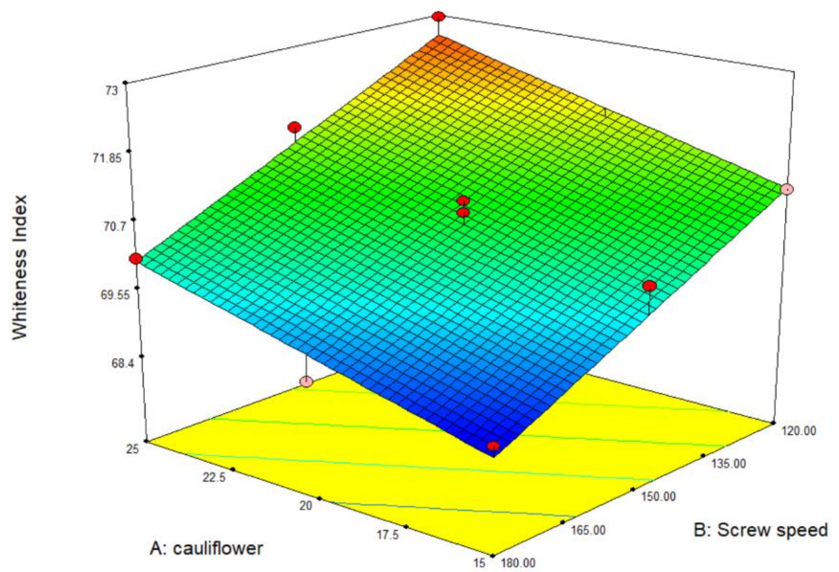

Fig 5 Response surface diagram for the effect of the variables of cauliflower percentage and screw speed on whiteness index

3-6-Optimization

In this study, the goal of optimization was to achieve a product with desirable characteristics, which was conducted using Design Expert software and a central composite rotatable design. The results obtained from the optimization, considering the maximum cauliflower content (25%), maximum water absorption (6.47), and maximum expansion ratio (4.418), were determined to be equivalent to a cauliflower content of 25%, a screw speed of 180 (rpm), with a desirability of 0.81.

4-Conclusion

The need to produce functional food products is one of the primary concerns for manufacturers. Since fresh, unprocessed cauliflower is rich in dietary fiber and polyphenols, its use in

[DOI: 10.22034/FSCT.21.157.1]

extruded products presents a promising opportunity to enhance grain snacks with health-beneficial ingredients. Additionally, incorporating fresh vegetables eliminates the processing and drying stages, thereby reducing the overall production costs. The produced snack, due to its high fiber content, contributes to better digestive performance, supports the immune system, and aids in weight and diabetes management. Furthermore, because of its porous structure, suitable texture, and high fiber content, it can serve as a raw material in the formulation of other food products such as dietary products, ready-to-eat meals, and instant powders. Among the production methods, extrusion cooking technology was employed due to its positive effects on digestibility and minimal loss of nutritional quality during processing for producing this product. According to the results, fresh cauliflower can be used in formulations up to 25% to achieve desirable nutritional and technological characteristics. Following tests on the predicted values from the software, no significant differences were observed between the mean results of the actual sample analysis and the predicted sample values. The observations from this research indicate the potential of extruded snacks for fortification programs.

5-References:

[1] Nath, A. and P. Chattopadhyay, Effect of process parameters and soy flour concentration on quality attributes and microstructural changes in ready-to-eat potato–soy snack using high-temperature short time air puffing. LWT-Food Science and Technology, 2 (4)41 .008p. 707-715.

[2] Potter, R., V. Stojceska, and A. Plunkett, The use of fruit powders in extruded snacks suitable for Children's diets. LWT-Food science and technology, 2013. **51**(2): p. 537-544.

[3] Brennan, M.A., et al., Ready-to-eat snack products: the role of extrusion technology in developing consumer acceptable and nutritious snacks. International journal of food science & technology, 2013. **48**(5): p. 893-902.

[4] Tumuluru, J., Snack Foods: Role in Diet in: Encyclopedia of Food and Health. 2016 ,Elsevier.

[5] Sayanjali, S., et al., Extrusion of a curcuminoid-enriched oat fiber-corn-based snack product. Journal of food science, 2019. **84**(2): p. 284-291.

[6] Tiwari, S., et al., Organic solvent-free extraction of carotenoids from carrot bio-waste and its physico-chemical properties. Journal of food science and technology, 2019. **56**: p. 4678-4687.

[7] Dias, J.S., Major classes of phytonutriceuticals in vegetables and health benefits: A review. Journal of Nutritional Therapeutics, 2012. **1**(1): p. 31-62.

[8] Beecher, C., Cancer preventive properties of varieties of Brassica oleracea: a review. The American journal of clinical nutrition, 1994. **59**(5): p. 1166S-1170S.

[9] Kowsalya, S. and S. Mohandas, Acceptability and nutrient profile of cauliflower leaves (Brassica oleracea, var. botrytis). The Indian journal of nutrition and dietetics, 1999. **36**(7): p. 332-338.

[10] Wadhwa, M., S. Kaushal, and M. Bakshi, Nutritive evaluation of vegetable wastes as complete feed for goat bucks. Small Ruminant Research, 2006. **64** (3)p. 279-284.

[11] Podsędek, A., Natural antioxidants and antioxidant capacity of Brassica vegetables: A review. LWT-Food Science and Technology, 2007. **40**(1): p. 1-11.

[12] Campbell, G.M., M. Ross, and L. Motoi, Bran in bread: effects of particle size and level of wheat and oat bran on mixing, proving and baking, in Bubbles in food 2. 2008, Elsevier. p. 337-354.

[13] James, S. and T.U. Nwabueze, Quality evaluation of extruded full fat blend of African breadfruit-soybean-corn snack. 2013.

[14] Hashemi, N., et al., Microstructural and textural properties of puffed snack prepared from partially deffated almond powder and corn flour. Journal of Food Processing and Preservation, 2017. **41**(5): p. e13210.

[15] Lotfi Shirazi, S., et al., Production of high fiber ready-to-eat expanded snack from barley flour and carrot pomace using extrusion cooking technology. Journal of food science and technology, 2020. **57**: p. 2169-2181.

[16] Lisiecka, K., et al., New type of potato-based snack-pellets supplemented with fresh vegetables from the Allium genus and its selected properties. Lwt, 2021. **145**: p. 111233.

[17] Mialni, E., et al., A feasibility study of fiber solid foam based on food by products (Spent coffee–wheat bran). Journal of food science and technology (Iran), 2020. **17** :(103)p. 67-81.

[18] Khan, M., et al., Optimization of feed moisture and sugar content in the development of instant rice porridge mix using extrusion technology. Journal of Food Processing & Technology, 2019. **10**(12): p. 850-862.

[19] Alam, M.S., S. Pathania, and A. Sharma, Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings. LWT, 2016. **74**: p. 135-144.

[20] Jinapong, N., M. Suphantharika, and P. Jamnong, Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. Journal of food engineering, 2008. **84**(2): p. 194-205.

[DOI: 10.22034/FSCT.21.157.1]

[21] Duan, X., et al., Browning behavior of button mushrooms during microwave freeze-drying. Drying Technology, 2016. **34**(11): p. 1373-1379.
[22] Asare, E.K., et al., Application of response surface methodology for studying the product characteristics of extruded rice–cowpea–groundnut blends. International Journal of Food Sciences and Nutrition, 2004. **55**(5): p .. 431-439.
[23] Bisharat, G., et al., Effect of extrusion conditions on the structural properties of corn extrudates enriched with dehydrated vegetables. Food research international, 2013. **53**(1): p. 1-14.
[24] Lisiecka, K., et al., Design of new gluten-free extruded rice snack products supplemented with fresh vegetable pulps: The effect on processing and functional properties. International Agrophysics, 2020. **35**(1): p. 41-60.
[25] Altan, A., K.L. McCarthy, and M. Maskan, Evaluation of snack foods from barley–tomato pomace blends by extrusion processing. Journal of Food Engineering, 2008. **84**(2): p. 231-242.
[26] Yanniotis, S., A. Petraki, and E. Soumpasi, Effect of pectin and wheat fibers on quality attributes of extruded cornstarch. Journal of food engineering :(2)80 . 2007 ,p. 594-599.
[27] Yao, N., et al., Physical and sensory characteristics of extruded products made from two oat lines with different β-glucan concentrations. Cereal Chemistry, 2006. **83**(6): p. 692-699.
[28] Ding, Q.-B., et al., The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. Journal of food engineering, 2006. **73**(2): p. 142-148.
[29] Wójtowicz, A., et al., Chemical characteristics and physical properties of functional snacks enriched with powdered tomato. Polish Journal of Food and Nutrition Sciences, 2018. **68**.(3).
[30] Hagenimana, A., X. Ding, and T. Fang, Evaluation of rice flour modified by extrusion cooking. Journal of Cereal Science, 2006. **43**(1): p. 38-46.
[31] Seker, M., Selected properties of native or modified maize starch/soy protein mixtures extruded at varying screw speed. Journal of the Science of Food and Agriculture, 2005. **85**(7): p. 1161-1165.
[32] Suknark, K., R. Phillips, and M. Chinnan, Physical properties of directly expanded extrudates formulated from partially defatted peanut flour and different types of starch. Food Research International, 1997. **30**(8): p. 575-583.
[33] Van der Sman, R. and J. Broeze, Structuring of indirectly expanded snacks based on potato ingredients: A review. Journal of Food Engineering, 2013. **114**(4): p. 413-425.
[34] Sun, Y. and K. Muthukumarappan, Changes in functionality of soy-based extrudates during single-screw extrusion processing. International Journal of Food Properties, 2002. **5**(2): p. 379-389.
[35] Koc, B., I. Eren, and F.K. Ertekin, Modelling bulk density, porosity and shrinkage of quince during drying: The effect of drying method. Journal of food engineering, 2008. **85**(3): p. 340-349.
[36] Frame, N.D. and J.M. Harper, The technology of extrusion cooking. 1994: Springer.
[37] Moraru, C. and J. Kokini, Nucleation and expansion during extrusion and microwave heating of cereal foods. Comprehensive reviews in food science and food safety, 2003. **2**(4): p. 147-165.
[38] Mason, W.R. and R. Hoseney, Factors affecting the viscosity of extrusion cooked wheat starch. 1985, Kansas State University.
[39] Huang, J., W.-B. Lui, and J. Peng, Effects of screw speed and sesame cake level on optimal operation conditions of expanded corn grits extrudates. International journal of food engineering, 2014. **10**(2): p. 317-328.
[40] Wang, C., et al., Modification of insoluble dietary fiber from ginger residue through enzymatic treatments to improve its bioactive properties. Lwt, 2[1]020. **125**: p. 109220.
[41] Suksomboon, A., et al ,.Effect of extrusion conditions on the physicochemical properties of a snack made from purple rice (Hom Nil) and soybean flour blend. International journal of food science & technology, 2011. **46**(1): p. 201-208.
[42] Favela-González, K.M., A.Y. Hernández-Almanza, and N.M. De la Fuente-Salcido, The value of bioactive compounds of cruciferous vegetables (Brassica) as antimicrobials and antioxidants: A review. Journal of Food Biochemistry, 2020. **44**(10): p. e13414.
[43] Beiraghi-Toosi, S., M. Mohebbi, and M. Varidi, Effect of feed mixture and process variables on physicochemical properties of solid foams made from corn starch and sesame seed by extrusion. Iranian Food Science and Technology Research Journal, 2018. **14**(5): p. 865-876.
[44] Singh, B., S.Z. Hussain ,and S. Sharma, Response surface analysis and process optimization of twin screw extrusion cooking of potato-based snacks. Journal of Food Processing and Preservation, 2015. **39**(3): p. 270-281.
[45] Yağcı, S. and F. Göğüş, Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. Journal of food engineering, 2008. **86**(1): p. 122-132.
[46] Lee, J.-S., et al., Physico-chemical characteristics of rice protein-based novel textured vegetable proteins as meat analogues produced by low-moisture extrusion cooking technology. LWT, 2022. **157**: p. 113056.
[47] Ding, Q.-B., et al., The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. Journal of Food engineering, 2005. **66**(3): p. 283-289.
[48] Stojceska, V., et al., The recycling of brewer's processing by-product into ready-to-eat snacks

using extrusion technology. Journal of Cereal Science, 2008. **47**(3): p. 469-479.
[49] Stojceska, V., et al., Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. Journal of Food Engineering, 2008. **87**(4): p. 554-563.
[50] Singh, B., et al., Response surface analysis and process optimization of twin screw extrusion cooking of potato-based snacks. Journal of Food Processing and Preservation, 2015. **39**(3): p. 270-281.
[51] Doğan, H. and M. Karwe, Physicochemical properties of quinoa extrudates. Food Science and Technology International, 2003. **9**(2): p. 101-114.
[52] Guha, M., S.Z. Ali, and S. Bhattacharya, Twin-screw extrusion of rice flour without a die: Effect of barrel temperature and screw speed on extrusion and extrudate characteristics. Journal of Food Engineering, 19 :(3)32 . 97p. 251-267.
[53] Sebio, L. and Y. Chang, Effects of selected process parameters in extrusion of yam flour (Dioscorea rotundata) on physicochemical properties of the extrudates. Food/Nahrung, 2000. **44**(2): p. 96-101.
[54] Asghari-pour, S., et al ,.Optimization of physicochemical and functional properties of corn-based snacks containing date kernel flour. Journal of Food Processing and Preservation, 2018. **42**(11): p. e13821.

[DOI: 10.22034/FSCT.21.157.1]

مجله علوم و صنایع غذایی ایران

سایت مجله: www.fsct.modares.ac.ir

مقاله علمی_پژوهشی

ارزیابی ویژگی های ماکروساختاری، عملکردی و رنگ میان وعده حجیم فیبری غنی شده با گل کلم تازه

نیکی زرقانی[۱]، آرش کوچکی[۲] و الناز میلانی[۳]

۱) دانش آموخته شکارشناسی ارشد گروه علوم و صنایع غذایی، دانشکده کشاورزی، دانشگاه فردوسی مشهد.

۲) استاد، گروه علوم و صنایع غذایی، دانشکده کشاورزی، دانشگاه فردوسی مشهد.

۳) دانشیار پژوهشکده علوم و فناوری مواد غذایی جهاد دانشگاهی خراسان رضوی.

اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۲/۷/۱۷

تاریخ پذیرش: ۱۴۰۲/۱۰/۷

کلمات کلیدی:

میان وعده،

تخلخل،

شاخص حلالیت در آب ،

شاخص جذب آب،

رنگ

DOI:10.22034/FSCT.21.157.1.

* مسئول مکاتبات:

e.milani@jdm.ac.ir

چکیده

در این پژوهش از فناوری اکستروژن به منظور تولید میان وعده با فیبرالا بر پایه گل کلم تازه، نشاسته ذرت و آرد ذرت استفاده شد. بدین منظور از طرح مرکب مرکزی چرخش پذیر و روش سطح پاسخ (RSM) اثر تیمارهای سرعت چرخش ماریپچ (۱۲۰ تا ۱۸۰ دور در دقیقه)، سطوح افزودن گل کلم تازه (۱۵، ۲۰، ۲۵ درصد)، بر ویژگی های ماکروساختاری وعملکردی و رنگ شامل نسبت انبساط، تخلخل، حلالیت در آب، انحلال در آب و شاخص تغییرات رنگی میان وعده بررسی گردید. نتایج نشان داد، افزایش درصد گل کلم سبب افزایش شاخص جذب آب (P <۰/۰۵) و شاخص سفیدی (P <۰/۰۰۰۱) شد و نیز باعث کاهش ضریب انبساط (P <۰/۰۰۰۱) و تخلخل (P <۰/۰۰۰۱) میان وعده شد و بر شاخص حلالیت در آب بی تاثیر بود. افزایش سرعت ماریپچ منجر به افزایش ضریب انبساط (P <۰/۰۰۰۱) ، تخلخل (P <۰/۰۰۰۱) و شاخص حلالیت در آب (P <۰/۰۰۰۱) شد و شاخص سفیدی (P <۰/۰۰۰۱) و جذب آب (P <۰/۰۵) را کاهش داد. نمونه بهینه با در نظر گرفتن بیشینه مقدار گل کلم، بیشینه شاخص جذب آب و نسبت انبساط، معادل مقدار گل کلم ۲۵ درصد و سرعت چرخش ۱۸۰ دور در دقیقه با مطلوبیت ۰/۸۱به دست آمد و پس از انجام آزمون برروی مقادیر پیش بینی شده نرم افزار، عدم معنی داری اختلاف میانگین میان نتایج آنالیز نمونه واقعی و مقادیر نمونه پیشگویی، مشاهده گردید و نیز مشاهدات پژوهش، بیانگر پتانسیل مطلوب میان وعده اکسترود برای برنامه غنی سازی بود.