European Journal of Nutrition & Food Safety

12(12): 112-122, 2020; Article no.EJNFS.65477
ISSN: 2347-5641

Effect of Flaxseed Oil Inclusion and Extrusion Cooking Parameters on Extruded Snack-food Physical and Functional Properties

Pravin M. Ganorkar[1], Preyash K. Desai[1], Rahul C. Ranveer[2*] and Anil S. Nandane[1]

[1]Department of Food Processing Technology, A.D. Patel Institute of Technology, P.O.Box 52, New Vallabh Vidya Nagar, Anand – 388121, Gujarat, India.
[2]PG institute of post harvest Management (Dr. BSKKV, Dapoli), Killa- Roha, Dist. Raigad, Maharashtra – 402 116, India.

Authors' contributions:

This work was carried out in collaboration among all authors. Author PMG conceived the idea, designed the study, wrote the protocol and wrote the first draft of the manuscript. Author PKD managed experimental runs and analysis of the study. Authors RCR and ASN managed the literature searches, statistical analysis of the study and formatted the manuscript as per journal guidelines. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/EJNFS/2020/v12i1230371
Editor(s):
(1) Dr. Michael Lokuruka, Karatina University, Kenya.
Reviewers:
(1) Coldea Teodora Emilia, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Romania.
(2) Wu Kam Chau, The Open University of Hong Kong, Hong Kong.
Complete Peer review History: http://www.sdiarticle4.com/review-history/65477

Original Research Article

Received 25 October 2020
Accepted 29 December 2020
Published 31 December 2020

ABSTRACT

Aims: Attempts were made to study flaxseed oil incorporated extruded snack by adopting response surface methodology (RSM) approach.
Study Design: Central Composite Rotatable Design (CCRD).
Place and Duration of Study: Department of Food Processing Technology, A.D. Patel Institute of Technology, Po Box 52, New Vallabh Vidya Nagar, Anand.
Methodology: Feed moisture (12 -16%, wb), flaxseed oil (3-7%), extruder barrel temperature (115-145°C and screw speed (345 – 375 rpm) were selected as independent variable at three levels. The Central Composite Rotatable Design (CCRD) was employed to study linear, interactive and quadratic effect of selected independent variables on measured responses (expansion ratio ER, breaking strength BS, overall acceptability score OAA, starch-lipid complexing index CI).

**Corresponding author: Email: rahul.ranveer@gmail.com;*

Results: The physical properties of extrudate (ER at 0.05 and BS at 0.10 level) and functional properties (OAA at 0.05 and CI at 0.01 level) were significantly influenced by flaxseed oil inclusion level. The quadratic effect of feed moisture and barrel temperature were found to be significant on each response (p<0.01). After numerical optimization, flaxseed oil of 6%, feed moisture content of 14.5% (wb), barrel temperature of 130^{0}C and screw speed of 355 rpm were optimized.

Keywords: Extrusion; response surface methodology; expansion ratio; breaking strength; overall acceptability; complexing index.

1. INTRODUCTION

Hot extrusion technology is a versatile and dominant concerning energy efficiency, product acceptability, ability to adopt varied blend of cereal/ pulses flours, to manufacture wide range of shape, size and flavored products. Extruded snack product market made remarkable progress in the last decade. According to Research and Market report, Indian extruded snack market is expected to grow at CAGR (Compound annual growth rate) of more than 10% in the near future [1]. But, on other hand increasing consumption of snack products specifically among children is criticized by health organizations as snack products generally contains higher oil and salt levels [2]. Moreover, consumer demands more health suiting products. These compel snack manufactures to diversify products and to explore new functional ingredient, so that value addition can be achieved with improved and desirable physiological impact. Among functional food ingredients, flaxseed has emerged as frontrunner in the last decade.

Flaxseed oil is the richest vegetarian source of omega-3 fatty acid, ALA - alpha linolenic acid [3,4]. Consumption benefits of omega-3 fatty acid in human being like prevention of cardiovascular disease, hypertension, atherosclerosis, diabetes, cancer, arthritis, osteoporosis, autoimmune and neurological disorders, are well established [5-8]. Moreover, a balanced intake ratio 5:1 to 10:1 of omega-6 to omega-3 fatty acid is required. General diets are having around or more than 10:1 omega-6 to omega-3 fatty acid ratio [4]. Higher omega-6 to omega-3 ratio in regular consumption may lead to cardiovascular disease, cancer and inflammatory autoimmune diseases [9]. Therefore, flaxseed oil can be effectively used as functional ingredient in food product to reduce omega-6 to omega-3 fatty acid ratio. Studies on whole flaxseed incorporated food products like cookies, muffins, bread and extruded product are reported [10-13]. Flaxseed oil incorporation in food products like fermented sausages [14], bread [15] and cookies [16] are also reported. But, incorporation of flaxseed oil in hot extruded snack products seems to be very scanty. Therefore, the present investigation was undertaken to develop flaxseed oil incorporated extruded snack product and to study the effect on extrudate characteristics. Extrusion cooking technology is consisting of multiples process and product variables. Response surface methodology can be effectively used for optimization of multiple variables and responses.

2. MATERIALS AND METHODS

Flaxseed var. Padmini was procured from Seed Processing Plant, C.Z. Azad Agricultural University, Kanpur, India. The procured flaxseed were cleaned and subjected for oil extraction. Oil was extracted by using laboratory scale hand operated oil expeller (M/s Rajkumar Agro Engineers, Nagpur, India). Extracted flaxseed oil was stored in air tight container at temperature of 25°C till further use in experimental work. Rice flour, corn flour, edible salt and black pepper powder was procured from local market. Reagents and chemicals used were of analytical grade.

Acid value, iodine value, oil density and peroxide value (PV) of flaxseed oil was estimated as per ISI methods (IS: 1011–1981). Fatty acid profile of flaxseed oil and optimized extruded product oil were carried out by Gas Chromatography (GC) instrument (Make – Perkin Elmer, Model – Auto System XL) and according to the method suggested by Rangrej et al. [16].

2.1 Extrusion Feed Preparation

Flaxseed oil was incorporated in rice – corn flour (75:25) blend by substituting rice flour. Extruder feed flour blends were prepared according to the experimental design at three level combinations. The moisture content of each flour blend was determined by Infra red moisture analyzer. Calculated amount of water was added to raise initial moisture to desirable moisture level in each flour blend. Flour blends were mixed well by ribbon blender and sieved through 40 mesh screen. Prepared flour blends were packed in polyethylene bags and stored at 4^0C for 24 h to achieve uniform moisture distribution.

2.2 Twin Screw Extruder

Extrusion was performed on intermeshed and co-rotating high shear twin screw extruder (7.5 HP motor, 400 V, 5, L-TSE Model, Basic Technologies Private Ltd., Kolkata, India). Length and diameter of screw were 350 mm and 30 mm respectively. Each screw had 20 mm constant pitch and 3.5 mm flight. The extruder was operated at 35 rpm feeder speed equivalent to 10.5 kg/h feed rate. Feeding zone extruder barrel temperature of 60°C and die of 4 mm diameter opening was used in all experimental runs. In each experimental run, steady-state conditions were assumed to have been reached when there were no visible drifts in torque and product temperature at the die for at least 5 min. Cutter speed of 85 rpm was maintained for each experimental run. Extrudate products (cylindrical rod shaped) were collected on stainless steel plate and dried at 60°C for 30 minutes in hot air circulated tray drier. Dried extrudate samples were packed in low density polyethylene – aluminum laminates having 60 µ thickness.

2.3 Statistical Design of Experiments

Design Expert Software Version 8 (STAT-EASE Inc., Minneapolis, USA) was used for RSM experimental designs and regression model. The Central Composite Rotatable Design (CCRD) was used to design experimental runs in one block at three different levels. Quadratic model was employed [17]. Four independent variables namely flaxseed oil (%), moisture Content (%), screw rpm and barrel temperature (°C) were chosen. Each independent variable had three levels which were −1, 0 and +1. Based on preliminary trials, the level of independent variables like flaxseed oil (3 - 7%), moisture content (12–16%), screw speed (345–375 rpm) and barrel temperature (115-145°C) were established. Six replicates of centre point assigned the coded value of 0, were selected in random order as per CCRD configuration for four independent variables. The α-values in the design outside the ranges were selected for rotability of the design [18]. The experimental design in actual levels and the coded levels (x) of variable is shown in Table 1. The response function measured were expansion ratio (ER), breaking strength (BS), overall acceptability (OAA) and starch-lipid complexing index (CI).

2.4 Extruded Product Characteristics

2.4.1 Expansion ratio (ER)

ER was determined as the ratio of average cylindrical extrudate diameter to extruder die opening diameter (4 mm) [19]. Ten random extrudate samples (40 mm in length) from each experimental run were chosen. Each extrudate diameter is measured at three locations (Two ends and one centre of extrudate) using vernier caliper (M/s Mitutoyo, Tokyo, Japan). Mean value of total 30 measurements was reported as ER of extrudate.

2.4.2 Breaking strength (BS)

Snap test in Texture analyzer (Model TA Plus, Make M/s Lloyd Insturments Ltd., Hampshire, UK) was employed for determining BS. Ten random samples from each experimental run were analyzed by using Warner-Bratzler cutting blade probe (Inverted V shaped blade). Probe speed of 2 mm/s, trigger force of 0.1 N, load cell capacity of 100 KN and probe movement limit of 15 mm were set parameters [20]. Mean value of ten determinations were reported as BS in kgf.

2.4.3 Hedonic - Overall Acceptability score (OAA)

Hedonic rating test was employed for confirming sensory quality of extrudates [21]. Each experimental extrudate product was assessed for OAA score using 9-point hedonic scale (1 – Dislike extremely to 9-Like extremely). Ten panel members were trained for evaluating sensory quality of extrudate product in terms of appearance, texture, taste, flavor and then assigned composite score (out of 9) for OAA. Mean value of ten judges score for each experimental sample were reported.

2.4.4 Starch-lipid Complexing Index (CI)

All experimental samples were ground and defatted by using soxhlet apparatus and petroleum ether solvent to remove uncomplexed lipids. All defatted samples were further analyzed for CI [22]. Weighed sample of 5 g was dispersed well with 25 ml DW in a test tube and mixed for 2 minutes on vortex mixer. The test tube was centrifuged at 3000 rpm for 15 min. 500 µl of the supernatant from centrifuged test tube was pipette out in a test tube and then added with 15 ml of DW. 2 ml of iodine solution was added to this test tube solution. The test tube was well

Table 1. RSM experimental design with actual level of independent variables and corresponding responses values

Run	Independent variables				Dependent variables (responses)			
	Feed moisture, % (x)	Flaxseed oil, % (x)	Barrel temperature, ^{0}C, (x)	Screw speed, rpm (x)	ER	BS (kgf)	OAA	CI (%)
1	16 (+1)	3 (-1)	145 (+1)	375 (+1)	2.83	2.11	7	13.24
2	16 (+1)	7 (+1)	115 (-1)	345 (-1)	2.68	2.48	6.3	17.32
3	16 (+1)	3 (-1)	145 (+1)	345 (-1)	2.82	2.23	6.6	10.92
4	16 (+1)	3 (-1)	115 (-1)	345 (-1)	2.86	2.38	7.8	17.8
5	16 (+1)	3 (-1)	115 (-1)	375 (+1)	2.53	2.74	6.2	21.8
6	14 (0)	5 (0)	130 (0)	360 (0)	2.98	1.78	7.8	10.2
7	16 (+1)	7 (+1)	145 (+1)	375 (+1)	2.57	2.28	6.3	32.13
8	16 (+1)	7 (+1)	145 (+1)	345 (-1)	2.76	2.39	6.7	26.83
9	12 (-1)	3 (-1)	115 (-1)	345 (-1)	2.71	2.52	6.6	18.68
10	12 (-1)	3 (-1)	145 (+1)	375 (+1)	2.71	2.48	6.5	14.14
11	14 (0)	5 (0)	130 (0)	360 (0)	2.87	2.07	7.2	21.94
12	12 (-1)	3 (-1)	145 (+1)	345 (-1)	2.73	2.49	6.8	16.84
13	12 (-1)	7 (+1)	145 (+1)	345 (-1)	2.42	2.85	6	22.06
14	12 (-1)	7 (+1)	145 (+1)	375 (+1)	2.48	2.96	6.1	33.08
15	14 (0)	5 (0)	130 (0)	360 (0)	3.05	1.32	7.8	14.65
16	14 (0)	5 (0)	130 (0)	360 (0)	2.98	1.73	7.9	13.23
17	16 (+1)	7 (+1)	115 (-1)	375 (+1)	2.69	2.52	5.7	24.19
18	12 (-1)	7 (+1)	115 (-1)	375 (+1)	2.72	2.52	6.8	28.79
19	12 (-1)	7 (+1)	115 (-1)	345 (-1)	2.75	2.32	7	31.17
20	12 (-1)	3 (-1)	115 (-1)	375 (+1)	2.88	2.15	7.4	22.5
21	10 (-α)	5 (0)	130 (0)	360 (0)	2.42	2.92	5.9	28.92
22	14 (0)	5 (0)	160 (+α)	360 (0)	2.42	2.85	6	21.88
23	14 (0)	5 (0)	130 (0)	360 (0)	2.92	1.78	7.8	14.11
24	14 (0)	9 (+α)	130 (0)	360 (0)	2.58	2.83	6.3	31.47
25	14 (0)	5 (0)	100 (-α)	360 (0)	2.27	2.97	5.8	22.95
26	18 (+α)	5 (0)	130 (0)	360 (0)	2.69	2.27	6.6	17.11
27	14 (0)	5 (0)	130 (0)	330 (-α)	2.86	2.11	7.2	12.21
28	14 (0)	1 (-α)	130 (0)	360 (0)	2.84	2.29	7	2.19
29	14 (0)	5 (0)	130 (0)	360 (0)	3.1	1.69	8.1	14.64
30	14 (0)	5 (0)	130 (0)	390 (+α)	2.34	3.12	6	15.13

Note: (x) – Coded value

shaken and absorbance was measured at 690 nm through spectrophotometer. CI was calculated using the following equation 1.

$$CI\ (\%) = \frac{ABc - ABs}{ABc}\ X\ 100 \qquad (1)$$

where,

ABc – Absorbance of control sample (Rice: Corn flour blend without flaxseed oil).
ABs – Absorbance of experimental sample (Rice: Corn flour blend with flaxseed oil).

3. RESULTS

3.1 Flaxseed Oil Analysis

Flaxseed var. Padmini oil density of 0.919±0.013, acid value of 2.18±0.33, iodine value of 181±1.9 and peroxide value (PV) of 0.7 meq/kg of oil were determined. Similar results are reported by Rangrej et al. [16] for flaxseed oil. Fatty acid profile of flaxseed var. Padmini oil is depicted in Table 2. α-Linolenic acid content was found to 55.27% in the extracted oil. This result is in well agreement with values reviewed by Goyal et al. [8]. The extracted oil was further utilized for development of extruded product.

3.2 Model Fitting

Second order model fitted to the independent and response variables. All models were examined for the goodness of fit. The regression coefficient analysis for each response variable is given in Table 3. Models for all response variables were adequate. No significant lack of fit in all response variables was observed. Therefore, the predicted models can be suitably used for forecasting at any values of the parameters within experimental range.

3.3 Response (Dependent Variables) Results

The ER of extruded product varied between 2.27 to 3.1 (Table 1). The data presented in the Table 3 depicted that ER was negatively related to linear effects of flaxseed oil level ($p < 0.05$) and screw rpm ($p < 0.05$). ER was also negatively related to the quadratic effect of feed moisture content and temperature at 0.01% significant level, quadratic effect of screw rpm at 0.05% and feed moisture at 0.10% significance level. The multiple regression models for predicting ER showed R^2 value of 0.81. BS of experimental products were found to be in the range of 1.32 kgf to 3.12 kgf (Table 1). BS was negatively related with linear effects of feed moisture level and positively to flaxseed oil at 0.10% significance level. The quadratic effects of feed moisture, flaxseed oil, temperature and screw speed were positively related with BS at 0.01% significance level. The interaction effect of feed moisture and temperature was negatively related with BS at 0.05% significance level (Table 3). The multiple regression models for predicting BS showed R^2 value of 0.83. OAA ranged in 5.7 to 8.1 (Table 1). OAA is negatively related with linear effects of flaxseed oil ($p<0.05$) and screw speed ($p<0.10$). OAA is also negatively related with quadratic effect of feed moisture content ($p<0.01$), flaxseed oil ($p<0.05$), barrel temperature ($p<0.01$) and screw speed ($p<0.05$). The multiple regression models for predicting OAA showed R^2 value of 0.79 (Table 3). The data (Table 1) pertaining with CI (%) varied between 2.19 to 33.08. CI was negatively related with linear effects of feed moisture ($p<0.05$) and positively related with flaxseed oil level ($p<0.01$). Further, CI was positively related with interaction effect of flaxseed oil and barrel temperature ($p<0.05$). Moreover, it was positively related quadratic effect of feed moisture content ($p<0.01$), and barrel temperature ($p<0.01$). The multiple regression models for predicting CI showed R^2 value of 0.85 (Table 3).

Table 2. Fatty acid profile of flaxseed oil extracted from variety Padmini

Fatty acid	Palmitic acid	Palmitolic acid	Stearic acid	Oleic acid	Linoleic acid	α-Linolenic acid	Other fatty acids
Result, %	5.83	0.06	5.68	21.09	11.39	55.27	0.68

Table 3. Regression coefficient analysis

Parameter	Estimated regression coefficients			
	ER	BS (kgf)	OAA	CI (%)
Intercept	2.965	1.756	7.740	14.375
Feed moisture (b1)	0.036	-0.102***	0.033	-1.943**
Flaxseed oil level (b2)	-0.633**	0.095***	-0.225**	5.758*
Temperature (b3)	-0.008	-0.003	-0.058	-0.631
Screw RPM (b4)	-0.056**	0.088	-0.175***	1.420
b12	0.02	-0.05	-0.075	-0.389
b13	0.058***	-0.148**	0.187	1.064
b14	-0.042	0.015	-0.162	0.545
b23	-0.045	0.070	0.025	2.391**
b24	0.001	0.023	-0.025	0.835
b34	0.002	-0.022	0.087	0.226
b11	-0.083*	0.182*	-0.335*	2.552*
b22	-0.044***	0.173*	-0.235**	1.006
b33	-0.135*	0.261*	-0.422*	2.402*
b44	-0.071**	0.187*	-0.247**	0.216
R^2 value	0.817	0.833	0.798	0.855
P- value for quadratic model	0.004	0.002	0.007	0.001
P- value for lack of fit	0.213	0.641	0.161	0.623
Mean	2.715	2.371	6.773	19.737
SD	0.126	0.251	0.452	4.077

*Note: *Significant at 0.01 level, **Significant at 0.05 level, ***Significant at 0.10 level*

4. DISCUSSION

4.1 Expansion Ratio (ER)

The response surface plot for ER (Fig. 1a) showed that as the flaxseed oil level increased, ER decreased. Expansion phenomena are basically dependent on the viscous and elastic properties of melted dough [23]. Lipids act as plasticizer in the extrusion process. During extrusion cooking, an increase in oil content contributes to lowering of shear due to the lubrication effect of oil [24]. Starch experienced minimum degradation during extrusion in the presence of lipid in comparison with the absentia of lipids [25]. Formation of amylose lipid complex during extrusion in the presence of lipids exaggerated the character of the matrix (i.e. visco-elastic properties of the molten extrudate) [26]. Consequently, the matrix was not capable to hold much water vapor, led to lower expansion. Moreover, lubrication effect of oil also reduces specific mechanical energy dissipation which consequently protects the distribution of starch molecules in the melted matrix leading to less degree of starch gelatinization and low ER [13,27]. It is also evident from Fig. 1a that as the screw speed increased, ER decreased. Higher screw speed reduced retention time of matrix in the extruder. Before reaching to favorable gelatinization temperature, the matrix would have come out from the die leading to undercooked mass and consequently less ER value. Moreover, higher screw speed would have imparted higher shear force responsible for breaking starch structure and producing lower molecular weight starch fragments. These fragments did not have the ability to stretch during expansion. Higher screw speed smears out oil on starch granules and on the barrel surface at very fast rate rather than oil absorption by starch granules [28]. Therefore, low ER was observed at higher screw speed.

Even though individual effect of feed moisture and barrel temperature was found insignificant, interactive effect of these both was found to be significant ($p<0.10$). At higher moisture level and lower temperature, ER found to be decreased. This can be attributed to dilution of matrix with water, lowering matrix temperature at the level not enough to achieve cooking of mass, resulting lower ER. At the same time, if higher moisture level was employed with higher temperature, an acceptable ER value was obtained (approx. 2.8). Quadratic effects of each independent variable on ER were found to be negatively significant. Higher and acceptable ER value could be obtained at almost all centre points combinations.

4.2 Breaking Strength (BS)

The force (kgf) required to break the extrudate expressed as BS. It can be well correlated with texture of extrudate [20,29]. Moreover, it correlates with simulation of incisors impact during biting [30,31]. It is evident from Fig. 1(c) that at higher flaxseed oil level, higher BS value could be obtained. Conversely, at higher moisture level, lower BS value could be obtained. Higher flaxseed oil level did not allow starch granule to achieve desired gelatinization by imparting protective layer on starch granules. Consequently, crystalline starch molecules had been aggregated. For a better extrusion, starch must be converted to amorphous phase which results in fluid mass. This fluid mass has higher ability to retain water vapors releasing at die exit end [28,32]. Moreover, formation of amylose lipid complexes might have led to the low degree of gelatinization and consequently higher BS values. If the product expands well, lower BS value can be obtained [20]. Further, micro-structure of extrudate plays a vital role. Micro-structure depends on number of air cells present in the extrudate and thickness of air cell wall. Higher the number of air cells presence, better the product texture. But if these air cells have thicker cell walls, more shear force would have required for breaking [33]. Consequently, higher BS values can be observed. Decrease in BS values with increase moisture content could be attributed to the presence of more water available for creating more nucleation sites. When there are more nucleation sites, many small bubbles might have formed, and resulting the product more porous [19]. More porous product means higher ER and consequently less force to shear.

4.3 OAA Score

Hedonic scale of 9 point (Extremely dislike - 1 to extremely like- 9) used to evaluate OAA. OAA is well correlated with sensory acceptable quality of the product. It is observed from Fig. 1 (d) that as the flaxseed oil and screw speed increased, OAA score decreased. Flaxseed oil acted as an insulating agent preventing water from being absorbed by starch granules. Higher oil content is expected to have a stronger insulating effect and higher screw speed imparted smearing effect on starch granules (discussed ER section), further depressed starch gelatinization [34]. Therefore, at higher flaxseed oil levels and screw speed, ER, being the most dominant quality attribute, decreased. Consequently, OAA score decreased.

4.4 Starch – Lipid Complexing Index (CI)

CI (%) measures the extent of starch–lipid complex formation. It involves the formation of starch–iodine complex. Iodine cannot form the complex if part of starch gets bind with lipid. So, the part of starch complexed with iodine is correlated with absorbance [35]. It is evident from Fig. 1(e) that as flaxseed oil increased, CI increased. This can be attributed straightway to the increased availability of oil for complex formation. The formation of complexes between starches and lipids are due to the ability of the

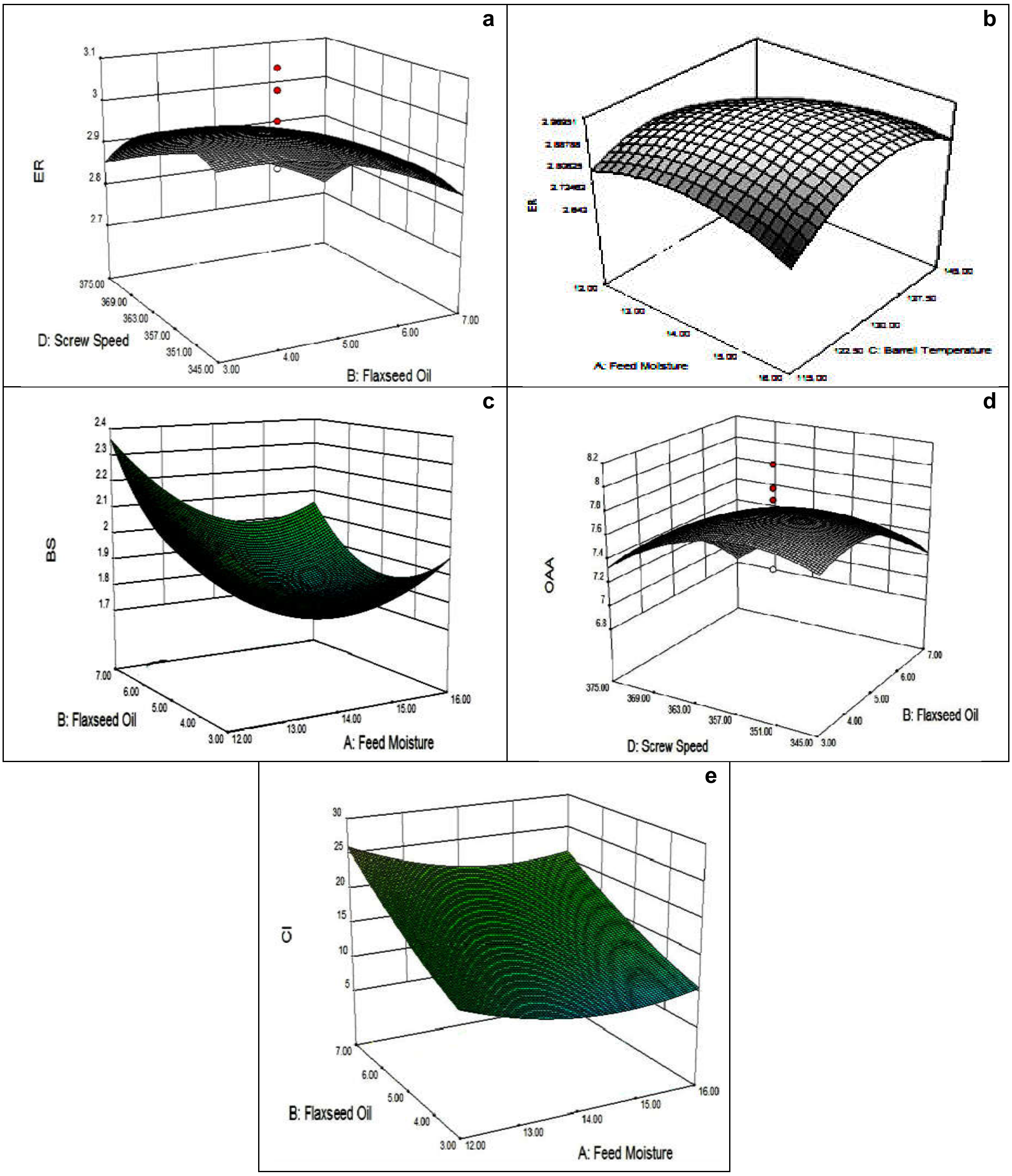

Fig. 1. Response surface plots for ER (a and b), BS (c), OAA (d) and CI (e)

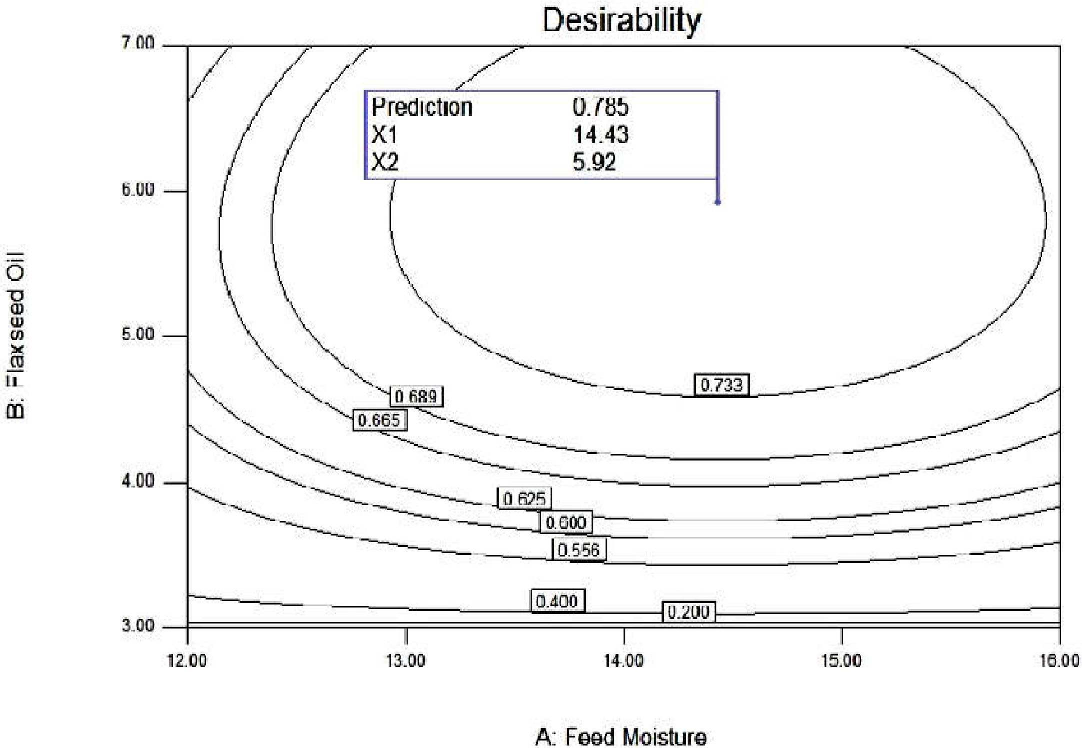

Fig. 2. Desirability contour plot as function of feed moisture and flaxseed oil

amylose to bind lipids than amylopectin. Optimum ratio of amylose and amylopectin is desirable for well expanded product [36]. Starch-lipid complex would have altered amylose to amylopectin ratio. Swelling is generally considered a property of amylopectin. Amylose is considered as a diluting agent. The amylose and added oil might have inhibited swelling of amylopectin under specific conditions when amylose–lipid complexes are likely to be formed [37]. It is rational to hypothesize that the addition of oil affected the characteristics of starch matrix (visco-elastic properties of molten mass) which could no longer hold water vapor resulting higher binding of iodine with the starch portion. Further, at higher moisture level, CI (%) was found to be lowered. This can be attributed to well dispersal of starch granules throughout the matrix at higher moisture levels. The presence of more water dominated over oil and further diminishing insulating effect of oil on starch granules. This effect might have helped to maintain the favorable conditions for starch gelatinization. Similar results are reported for extrusion cooking of almond flour [35].

4.5 Optimization

Numerical optimization of all independent variables using Design Expert (Version 8) STAT EASE software was carried out. All the levels of independent variables were kept in range. Desired goals were assigned for all response parameters (ER- Maximum; BS – minimum; OAA – maximum; CI – in the range) for obtaining the numerical optimum values for the responses. The actual processing independent variables for the best combination of the responses suggested by the software were 14.43% feed moisture, 5.92% flaxseed oil, 129.20°C barrel temperature and 353.45 screw speed rpm. The predicted responses at this combination for ER, BS, OAA and CI were 2.94, 1.8 kgf, 7.6 and 16.06 % respectively. Desirability found to be 0.79 (Fig. 2). In actual practice, feed moisture content, flaxseed oil, barrel temperature and screw speed was rounded off to 14.5% , 6% , 130°C and 355 rpm as optimized parameters and adopted for run.

5. CONCLUSION

Response surface analysis of the conducted study revealed that flaxseed oil level was the most affecting parameter on extrudate characteristics followed by feed moisture content and screw speed. At higher flaxseed oil level inclusion, extrudate characteristics like ER and OAA decreased while BS and starch-lipid complexing index increased. But, flaxseed oil incorporated at lower to moderate level, cereal flour based extrudate product can be manufactured without affecting much sensory quality. Omega-3 fatty acid enrichment in extruded product by the use of flaxseed oil shows the potential way for developing functional snack food. Further studies are required on processing stability and storage stability of omega-3 fatty acid enriched extrudate products.

ACKNOWLEDGEMENTS

This research project was financially supported by Ministry of Food Processing Industries through Science and Engineering Research Board (SERB), Department of Science and Technology, Government of India, New Delhi (SERB/MOFPI/0037/2013).

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. India Extruded Snacks Market Overview; 2018-2023.
   Available:https://www.businesswire.com/news/home/20181205005830/en/India-ExtrudedSnacks-Market-Overview-2018-2023
2. Shaviklo GR, Olafsdottir H, Sveinsdottir K, Thorkelsson G, Rafipour F. Quality characteristics and consumer liking of a high fish protein puffed corn-fish snack. J Food Sci. Technol. 2011;6:668–76.
3. Morris DH. Flax – a health and nutrition primer. 4th ed., Flax Council of Canada: Winnipeg, MB; 2007.
4. Ganorkar PM, Jain RK. Flaxseed – a nutritional punch. Int Food Res J. 2013;20:519–25.
5. Cunnane SC, Ganguli S, Menard C. High α-linolenic acid flaxseed (Linum usitatissimum): Some nutritional properties in humans. British Journal of Nutrition. 1993;69:443–53.
6. Simopoulos AP. Human requirement for omega-3 polyunsaturated fatty acids. Poul Sci. 2000;79:961–70.
7. Gogus U, Smith C. n-3 Omega fatty acids: A review of current knowledge. Int J Food Sci Technol. 2010;45:417–36.
8. Goyal A, Sharma V, Upadhyay N, Gill S, Sihag M. Flax and flaxseed oil: An ancient medicine and modern functional food. J Food Sci Technol. 2014;51:1633–53.
9. Lazic M, Inzaugarat ME, Povero D, Zhao IC, Chen M, Nalbandian M et al. Reduced dietary omega-6 to omega-3 fatty acid ratio and 12/15-lipoxygenase deficiency are protective against chronic high fat diet-induced steatohepatitis. PLoS ONE. 2014;9:e107658.
   DOI:10.1371/journal.pone.0107658
10. Chen ZY, Ratnayake WMN, Cunnane SC. Oxidative stability of flaxseed Lipids during baking. JAOCS. 1994;71:629-32.
11. Pohjanheimo T, Hakala M, Kallio H. Effect of baking process and storage on volatile composition of flaxseed breads. In: Bredie, WLP, Petersen MA, editors. Flavour Science: Recent Advances and Trends. Netherland: Elsevier Publication. 2006;339-42.
12. Rajiv J, Indrani D, Prabhasankar P, Rao GV. Rheology, fatty acid profile and storage characteristics of cookies as influenced by flax seed. J Food Sci and Tech. 2012;49:587-93.
13. Ganorkar PM, Jain RK. Development of flaxseed fortified rice – corn flour blend based extruded product by response surface methodology. J Food Sci Tech. 2015;52:5075-83.
    DOI: 10.1007/s13197-014-1541-1
14. Pelser WM, Linssen JPH, Legger A, Houben JH. Lipid oxidation in ω- 3 fatty acid enriched Dutch style fermented sausages. Meat Science. 2007;75(1):1–11.
15. Aguiar ACD, Boroski M, Monteiro ARG, Souza NED, Visentainer JV. Enrichment of whole wheat flaxseed bread with flaxseed oil. J Food Process Preserv. 2011;35:605–09.

16. Rangrej V, Shah V, Patel J, Ganorkar PM. Effect of shortening replacement with flaxseed oil on physical, sensory, fatty acid and storage characteristics of cookies. J Food Sci Technol. 2015;52:3694–700.
17. Box GEP, Draper N. Empirical model building and response surfaces. John Wiley and Sons Inc.; New York; 1987.
18. Thompson D. Response surface experimentation. J Food Processing and Preservation. 1982;6:155-88.
19. Pankyamma V, Basu S, Bhadran SS, Chouksey MK, Gudipati V. Fish oil-fortified extruded snacks: Evaluation of physical properties and oxidative stability by response surface methodology. J Food Process Eng. 2014; 37:349-61.
20. Ganorkar PM, Patel JM, Shah V, Rangrej VV. Defatted flaxseed meal incorporated corn-rice flour blend based extruded product by response surface methodology. J Food Sci Tech. 2016;53: 1867-77.
21. Ranganna S. Handbook of analysis and quality control for fruits and vegetable products. 2nd Edn. New Delhi, India: Tata Mc Graw Hill Publishing Co. Ltd. 2001;623-27.
22. Guraya H, Kadan R, Champagne E. Effect of rice starch–lipid complexes on in vitro digestibility, complexing index, and viscosity. Cereal Chemistry. 1997;74:561–65.
23. Launay B, Lisch LM. Twin screw extrusion cooking of starches: Flow behavior of starch pastes, expansion and mechanical properties of extrudates. J Food Eng. 1983;2:259–80.
24. Iwe MO. Effects of extrusion cooking on some functional properties of soy-sweet potato mixtures – a response surface analysis. Plant Foods Hum. Nutr. 2000;55:169–84.
25. Raphaelides SN, Arsenoudi K, Exarhopoulos S, Xu ZM. Effect of processing history on the functional and structural characteristics of starch–fatty acid extrudates. Food Res Int. 2010;43:329–341.
26. Thachil MT, Chouksey MK, Gudipati V. Amylose–lipid complex formation during extrusion cooking: Effect of added lipid type and amylose level on corn-based puffed snacks. Int J Food Sci Technol. 2014;49:309–16.
27. Ilo S, Liu Y, Berghofer E. Extrusion cooking of rice flour and amaranth blends. LWT Food Sci Tech. 1999;32(2): 79–88.
28. Ilo S, Regine S, Berghofe E. Role of lipids in the extrusion cooking processes. Grasas y Aceites. 2000;51:97-110.
29. De Angelis D, Kaleda A, Pasqualone A, Vaikma H, Tamm M, Tammik M et al. Physicochemical and sensorial evaluation of meat analogues produced from dry-fractionated pea and oat proteins. Foods. 2020;9:1754.
Available:https://doi.org/10.3390/foods9121754
30. Van Hecke E, Allaf K, Bouvier JM. Texture and structure of crispy-puffed food products. Part II: Mechanical properties in puncture. J Texture Stud. 1998;29:617–32.
31. De Pilli T, Legrand J, Derossi A, Severini C. Study on the interaction among extrusion cooking process variables and enzyme activity: Evaluation of extrudate structure. J Food Processing Engineering; 2010.
Available:http://doi.org/10.1111/j.1745-4530.2008.00260.x
32. Pasqualone A, Costantini M, Teodora Emilia Coldea TE, Carmine Summo C. Use of legumes in extrusion cooking: A review. Foods. 2020;9:958.
Available:https://doi.org/10.3390/foods9070958
33. Jin Z, Hsieh F, Huff HE. Effects of soy fiber, salt, sugar and screw speed on physical properties and microstructure of corn meal extrudates. Journal of Cereal Science. 1995;22:185–94.
34. Lin S, Hsieh F, Huff HE. Effect of Lipids and processing conditions on degree of starch gelatinization of extruded dry pet food. LWT - Food Sci. and Technology. 1997;30:754-61.
35. De Pilli T, Carbone BF, Derossi A, Fiore AG, Severini C. Effects of operating conditions on oil loss and structure of almond snacks. Int J Food Sci and Tech. 2008;43:430–39.

36. Chinnaswamy R, Hanna MA. Macromolecular and functional properties of native and extrusion-cooked corn starch. Cereal Chemistry. 1990;67:490–99.

37. Tester RF, Morrison, W.R. Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose and lipids. Cereal Chemistry. 1990;67:551–57.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/65477