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Process Optimization of Sorghum Based Extruded Snack Incorporated with Tilapia (*Oreochromis niloticus*) Mince using RSM

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Abstract

A study was carried out to optimize processing condition for developing an acceptable ready to eat extruded snack using Response Surface Methodology. Tilapia mince was incorporated with a composite blend of sorghum grits and corn flour,which was used as base material for this study. The snack was prepared with composite flour mixture of Sorghum (40-70%) and corn (20-40%) with tilapia fish mince (10-20%) using twin screw extruder. The effect of independent variables such as temperature (120-130ºC) any screw speed (300-400 rpm) on dependent variables such as bulk density, expansion ratio, hardness, specific mechanical energy was analysed. Mixture response design with 27 trials were carried out to study optimisation of physical parameters and found that sorghum 44.87%, corn 40%, tilapia mince 15.13%, at 130ºC and 343 rpm screw speed was found to be ideal for the expanded extruded snack The physical properties of the product were statistically significant with R^2 value >0.85, for all models. The study explores the possibility of utilization of low-cost underutilised sorghum and freshwater fish tilapia in product development with improved nutritional quality.

Keywords: *Oreochromis niloticus*, mixture response design, ready to eat snack

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Introduction

Developments in the ready-to-eat snack food industry are significant and the trend has been ever changing due to fast urbanization, changing lifestyle and preferring convenience over other factors (Adem et al., 2019). As compared to the conventional methods, shorter processing time, superior flexibility, better retention of nutrients, inactivation of anti-nutritional compounds and cheaper products made extrusion process popular among consumers (Brennan et al., 2011). Consumption of cereal based extruded snacks with poor biological value on account of low protein content and limited essential amino acids would lead to protein energy malnutrition and various metabolic disorders. To overcome this, diversification and fortification with essential amino acids, enrichment with good quality protein, dietary fibres, antioxidants, etc. has been recommended by UN FAO (Cortez et al., 2014; Espinoza-Moreno et al., 2016; Chavez et al., 2017).

Importance of Maize and Sorghum as a base for extruded products has been well reported (Khan et al., 2013; Mkandawire et al., 2015; Wu et al., 2018) for its expansion properties (Malik et al., 2015; Vanier et al., 2016). Sorghum (Sorghum bicolor L.), the world's fifth cereal, is drought-tolerant, adaptable to various soil conditions (Jafari et al., 2017), is a substitute for common cereals, with 70 percent starch similar to corn (Singh & Singh, 1995; Escobar-Puentes et al., 2019). Sorghum is a slowly digestible cereal with high resistant starch (Mkandawire et al., 2015; Teixeira et al., 2016), source of antioxidant phenolics and cholesterol-lowering waxes (Taylor et al., 2006) and is effective in controlling obesity, diabetes, dyslipidaemia, cardiovascular disease and cancer (Yang et al., 2012). Since, sorghum is also gluten free, it is a good substitute for people suffering from celiac disease (Fenster, 2003; Pontieri et al., 2013). Corn with high starch and good expansion properties (Malik et al., 2015) is an ingredient commonly used for manufacture of ready to eat snacks and breakfast cereal. Though gluten free and rich in antioxidants, protein, fibre and resistant starch (Prinyawiwatkul et al., 1996), corn is deficient in essential amino acids like lysine and tryptophan (Jorge et al., 2006).

Incorporation of fish, rich in high-quality protein and balanced mixture of all essential amino acids improve the nutritional quality of food products (Maluf et al. 2010), cited as a remedy for protein energy malnutrition, is highly relevant in Indian context and has also been recommended by UN FAO (2015). Nile tilapia *Oreochromis niloticus* with wide consumer acceptance, often used for filleting, contains crude protein, ash, calcium, iron, phosphorus and most importantly 23 fatty acids including n-3 polyunsaturated fatty acid, eicosapentaenoic acid and docosahexaenoic acid (Souza, 2006).

Extruded products containing fish have been reported in various combinations with grains and pulses (Netto et al., 2014; Rajesh et al., 2014; Homchoudhury et al., 2011). However, there are only a few reports of sorghum-maize blend enriched with fish as protein source. The aim of the study was to optimize processing conditions with a composite blend of tilapia mince, Sorghum grits and corn flour to develop an acceptable ready to eat extruded snack using response surface methodology.

Materials and Methods

Sorghum (Jowar Rava) was procured from Indian Institute of Millets Research, Hyderabad. Yellow corn powder was purchased from local market. Tilapia was collected from CMFRI, Cochin, and made to fillets manually by removing skin and bone and was minced. These materials were weighed in different proportions as per experimental runs as shown in Table 1. Ingredients were then mixed using blender. Final moisture was adjusted to 15% after determining moisture content using infrared moisture analyser. The composite mixture was sieved through a mesh and kept for equilibration for thirty minutes at 24°C before extrusion. The RSM trials were carried out using 500 gram of composite blends as per the experimental design given in Table 2.

A co-rotating twin screw extruder (Model EB-10, M/s Basic Technology Pvt. Ltd., Kolkata, India) was used for extrusion. To optimise and study the effect of varied level of sorghum grits, corn flour, and Tilapia mince on the physical properties of extruded snack D-optimal mixture response surface design with 27 runs were formulated. Independent variables were sorghum grits (40-70), corn flour (20-40), Tilapia mince (10-20). Bulk density, expansion ratio, hardness, specific mechanical energy, L*(lightness), a*(redness), and b*(brightness) were the response variables studied.

The experiment used a D-optimal mixture response surface design with two numerical factors. For the development of extruded snack product, the effect of three mixed input variables (A-sorghum, B-corn, C-fish) and a quadratic model with two numeric components interaction temperature and screw speed, were optimised.

Expansion ratio: ER is defined as the ratio of the diameter of the extrudate to the diameter of the die (Ding et al., 2005). The average of ten randomly selected extrudates were measured using a digital Vernier calliper.

Expansion ratio was calculated as: ER=Diameter of extrudate / Diameter of die

Bulk Density (BD): Bulk density was measured by displacement method of Seker (2005) with slight modification. Extrudates were cut uniformly and added up to 100 ml in a 250 ml measuring cylinder and tapped. This was followed by addition of ragi seeds and tapped again to fill up the voids and made up to 250 ml mark. The extrudates and ragi seeds were taken out to a tray. Extrudates were weighed in gm. The ragi seeds were transferred back to measuring cylinder, tapped and the volume (ml) of the ragi seeds was noted. This was repeated thrice and mean value noted. Bulk density was calculated as follows.

Bulk density = Weight of the sample/ (250- Volume of the millet after tapping)

Specific mechanical Energy (SME): Measurement of specific mechanical energy was calculated as defined by Gogoi et al. (1996). Net torque was multiplied with 3.95 and expressed as kilo Joules per kilogram. Mean of two values were noted.

Colour: The instrumental colour analysis of the powdered extruded flours was performed by

Table 1. Experimental design and responses

RSM	A	B	C	D	E	B. D gm/ml	E. R	HaN	SME KJ/kg	L* Value	a* Value	b* Value
1	40	40	20	110	300	0.27	2.70	1062	178	60.80	2.70	17.80
2	65	20	15	110	300	0.19	2.90	920	143	59.52	1.05	13.90
3	70	20	10	130	300	0.23	2.70	476	143	63.24	1.29	15.96
4	65	20	15	110	400	0.19	3.21	1062	190	67.99	0.68	15.04
5	70	20	10	110	300	0.27	2.73	592	143	63.62	1.56	15.26
6	65	20	15	130	400	0.33	2.70	983	190	63.44	2.42	16.63
7	70	20	10	110	400	0.18	2.81	555	190	63.49	1.28	15.60
8	50	40	10	130	400	0.16	3.09	397	189	63.89	0.71	17.03
9	55	30	15	130	400	0.31	2.65	901	189	61.55	2.52	17.05
10	40	40	20	130	300	0.30	2.53	1030	142	64.16	2.87	20.18
11	50	40	10	110	300	0.19	2.92	563	142	60.57	2.37	16.34
12	50	30	20	130	350	0.44	1.48	1090	165	54.09	3.66	17.26
13	60	20	20	110	300	0.31	2.41	1073	142	56.70	2.33	15.08
14	45	40	15	120	350	0.22	2.80	746	166	64.15	1.17	15.61
15	60	30	10	110	400	0.17	3.01	368	190	65.73	1.65	17.44
16	50	40	10	130	400	0.25	3.00	611	142	63.65	1.72	18.25
17	40	40	20	130	400	0.14	2.87	629	190	64.31	2.27	19.04
18	60	20	20	130	400	0.33	2.59	878	191	62.94	2.17	16.14
19	40	40	20	110	400	0.25	2.62	804	190	62.91	3.18	19.36
20	70	20	10	120	350	0.19	2.61	640	166	63.82	2.24	15.36
21	60	20	20	130	300	0.38	2.08	1059	142	60.59	2.78	17.32
22	50	40	10	110	400	0.28	2.58	815	190	63.92	1.62	17.78
23	60	20	20	110	400	0.30	2.17	856	190	59.15	3.23	17.48
24	50	30	20	110	300	0.29	2.55	1051	143	59.94	2.83	16.89
25	60	30	10	130	300	0.23	3.01	514	142	62.21	1.81	16.69
26	55	30	15	130	300	0.28	2.71	816	143	60.97	3.74	19.58
27	70	20	10	130	400	0.16	2.87	420	190	62.69	2.59	16.67

A: Sorghum (%), B: Corn (%), C: Fish mince (%), D: Temperature, E: Screw speed, B.D: Bulk Density, E.R: Expansion ratio, Ha: Hardness, SME: Specific Mechanical Energy, L*: Lightness, a*: Redness, b*: Yellowness

transmittance using a Hunter Lab colorimeter (Mini Scan XE Plus, Hunter Associates Lab Inc., Reston, Virginia, USA) which indicated degree of lightness (L*), degree of redness (+)/greenness (-) (a*) and the degree of yellowness (+) or blueness (-) (b*). Each sample was analysed thrice and mean value was calculated.

Hardness (N): Hardness (Rhee et al. 2004) in terms of shear force was measured by placing 3 cm strands of extrudates in to texture analyser (Lloyd Instruments, Model TA Plus, UK). The conditions of the texture determination were as follows: 60mm/min speed; trigger force: 5N).

Sensory Evaluation: Evaluation of the optimised extrudates was carried out using a panel of 10 members on 9-point hedonic scale (Ranganna, 2002) ranging from 1 (dislike) to 9 (like extremely) to indicate the level of acceptance of the product. Average score was reported.

Statistical analysis: D - optimal mixture response surface design with two numerical factors were considered for the experiment to optimise and study the effect of ingredients on response variables such as expansion ratio, bulk density, hardness, SME and colour of extrudate. Experimental data fitted to quadratic model D-optimal design with 27 runs were carried out given in equation

Quadratic model with two factors interaction was fitted to the response variable as a function of input values

$Y=\beta_1 A+\beta_2 B+\ \beta_3 C+\ \beta_4 AB+\ \beta_5 AC+\ \beta_6 AD+\ \beta_7 AE+\ \beta_8 BC+\ \beta_9 BD+\ \beta_{10} BE+\ \beta_{11} CD\ \ \beta_{12} CE+\beta_{13}\ ABD+\ \beta_{14} ABD+\beta_{15}\ ACD+\beta_{16}\ ACE+\beta_{17}\ ADE+\beta_{18} BCD+\ \beta_{19}\ BCE+\beta_{20} BDE\ \ \beta_{21} CDE+\ \beta_{22} ABDE+\ \beta_{23} ACDE+\ \beta_{24} BCDE + e$

where Y is the response Components β_1 (Sorghum grits– A), β_2 (corn flour– B), β_3 (Fish mince – C) D (Temperature) E (Screw speed)], β_1i is linear regression coefficient, β_{ij} is quadratic regression coefficient, $£_{ij}$ is cubic regression coefficient, and e is error term.

The coefficient of determination (R^2) was used to evaluate the fitted model's adequacy. The response variable was predicted as a function of independent variables using the statistical software tool Design-Expert (version 7.1.5, State-Ease, Minneapolis, MN).

Results & Discussion

Expansion ratio: Expansion is an important characteristic of extruded product and describes the degree of puffing undergone by the sample as during extrusion (Asare et al., 2012; Seth & Rajamanickam, 2012). The expansion ratio of the extruded snack ranged between 1.48 to 3.21 noted for RSM12 and RSM4. R^2 value for expansion was 0.86 which showed that quadratic model was fitted to indicate the composition of ingredients (Fig. 1, Table 2). Starch content leads to dough expansion and eventually cause an increase at die exit (Peksa et al., 2016). The maximum expansion ratio of 3.21 was observed with combinations of 65% Sorghum, 20% corn flour and 15% fish mince at a screw speed of 400 rpm at 110ºC. Based on this, expansion ratio of 3.5 was attained during optimisation. As screw speed increased, ER also increased. Screw speed positively affects the shear stress in the extruder as reported by Ilo et al. (1999). Ganorkar (2016) also proved this on his study on defatted flax seed incorporated corn rice blend and found that increasing screw speed and barrel temperature positively improved shear stress with increased shear environment which might increase the extent of starch gelatinization process with more expansion.

Minimum expansion ratio of 1.48 was noted with 50% Sorghum, 30% corn and 20% fish mince at 130ºC and 350 rpm. An important factor affecting expansion ratio was amount of fish protein added to the composite mixture. It was reported that increasing level of fish protein resulted in a significant decrease in the expansion ratio (Kamalakanth et al., 2007; Dileep et al., 2010) in feed material. Increase in fish from 10% to 15% or 20% resulted in a decrease in expansion ratio.

Bulk density (BD): BD, defined as the ratio of mass of extrudates to the apparent volume of a specific container, directly influences the storage space of manufacturing unit and shipping containers (Guy, 2001). The BD of the extrudates varied from 0.14g/cc to 0.44 g/cc depends on fish meat concentration (Table1). The lowest BD value was obtained at a screw speed of 400 rpm, and barrel temperature of 130p C. This is in accordance with study on barley based extruded product by Reshi et al. (2020).

During this study, by incorporation of fish mince from 10% to 20%, bulk density increased by 42%. This finding was in agreement with Hood-Niefer & Tyler (2010) who studied the relationship between

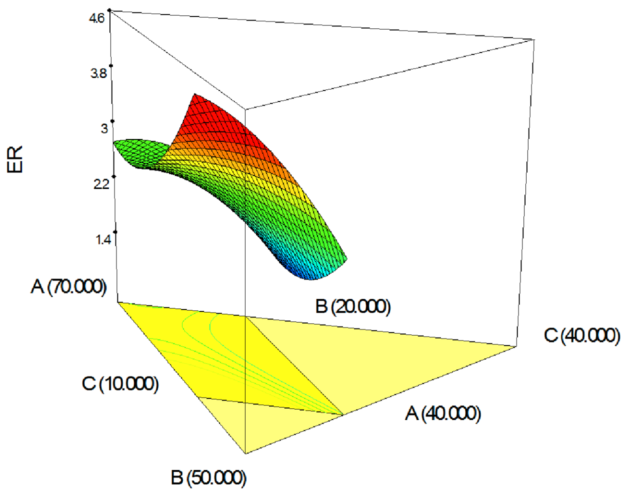

Fig. 1. Response surface for the effect of sorghum corn and fish mince and temperature, screw speed on expansion ratio of Extrudates

protein and expansion ratio, and found that higher the protein content, the smaller the expansion and the greater the BD. It was found that sorghum and fish mince have significant influence on bulk density of extrudate. Increasing fish mince caused a quadratic increase in bulk density of extrudates. Similar findings were observed by previous researchers, where an increase in bulk density was reported in sorghum extrudates containing increasing amounts of cowpea flour and other protein sources (Pelembe, 2002; Seth & Rajamanickam, 2012). This was confirmed by Dlamini et al. (2016) while studying the effect of incorporating soyabean protein concentrate into Sorghum, Maize blend which increased the bulk density. It was observed that the quadratic model was fitted to the experimental data which affected the composition of ingredients on the bulk density with a coefficient of (R^2) 0.92 (Table 2 and Fig. 2). Under optimised condition, bulk density obtained was 0.132 g/ml.

Colour: Colour is one of the significant parameters affecting quality of extruded products, and was measured as L*, a*, b* indicating brightness, redness and yellowness, respectively.

Table 2. Regression coefficients of fitted Quadratic models with R^2 values

Regression coefficients		Response Variables						
		B.D gm/ml	E.R	SME kJ/kg	Hardness N	L*Value	a*Value	b*Value
A	β 1	-0.03	2.7	23.3	-87.30	14.21	2.51	6.33
B	β 2	1.12	4.5	219.78	-387.81	-81.7	20.63	37.58
C	β 3	-4.34	34.05	-627.2	-18209.00	546.8	8.20	45.46
AB	β 4	-0.02	-0.14	-5.54	-5.30	1.38	-0.32	-6.54
AC	β 5	0.07	-0.49	8.89	237.81	-8.2	-0.09	-0.61
AD	β 6	0.00	-0.02	-0.15	1.14	-0.10	-0.02	-0.05
AE	β 7	0.00	-0.01	-0.03	1.10	-0.045	-0.00	-0.01
BC	β 8	0.02	-0.38	6.87	251.27	-4.85	-0.66	-1.47
BD	β 9	-0.01	-0.03	-1.75	-1.94	0.76	-0.19	-0.34
BE	β 10	-0.00	-0.02	-0.53	4.06	0.15	-0.05	-0.10
CD	β 11	0.05	-0.29	5.67	168.23	-4.37	-0.10	-0.40
CE	β 12	0.02	-0.11	2.06	62.89	-1.60	0.06	0.00
ABD	β 13	0.00	0.00	0.04	0.13	-0.01	0.00	0.01
ABE	β 14	0.00	0.00	0.01	-0.04	-0.00	0.00	0.00
ACD	β 15	-0.00	0.00	-0.08	-2.24	0.07	0.00	0.01
ACE	β 16	-0.00	0.00	-0.03	-0.83	0.02	-0.00	-0.00
ADE	β 17	-0.00	0.00	0.00	-0.01	0.00	0.00	0.00
BCD	β 18	-0.00	0.00	-0.06	-2.15	0.03	0.01	0.01
BCE	β 19	-0.00	0.00	-0.02	-0.91	0.01	0.00	0.00
BDE	β 20	0.00	0.00	0.00	-0.09	-0.00	0.00	0.00
CDE	β 21	-0.00	0.00	-0.02	-0.57	0.01	-0.00	0.00
ABDE	β 22	-0.00	-0.00	-0.00	0.00	0.00	-0.00	-0.00
ACDE	β 23	0.00	-0.00	0.00	0.01	-0.00	0.00	-0.00
BCDE	β 24	0.00	-0.00	0.00	0.01	-0.00	-0.00	-0.00
		R^2 = 0.93	R^2= 0.86	R2=0.91	R^2= 0.98	R^2= 0.93	R^2= 0.96	R^2= 0.92

A-Sorghum %, B-Corn%, C-Fish mince %, D-Temperature, E-Screw speed, B.D-Bulk Density, E.R-Expansion ratio, Ha-Hardness, SME-Specific Mechanical Energy, L*-Lightness, a*Redness, b* Yellowness

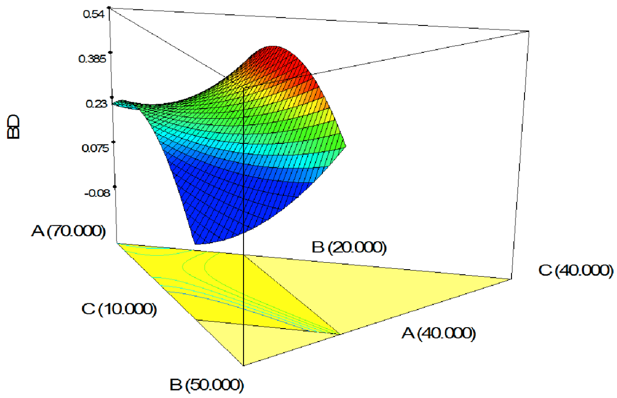

Fig. 2. Response surface for the effect of sorghum corn and fish mince and temperature, screw speed on Bulk Density of Extrudates

L*a*b* varied significantly with ingredients (Fig. 3a, 3b, 3c) and it was noted that, with increase in fish mince addition, L* values decreased. On further addition of fish mince, a* values increased. This is in accordance with addition of shrimp protein hydrolysate to extrudates as reported by Jeyakumari et al. (2016). Quadratic model was fitted to explain lightness of products with an R^2 value of 0.9288 which indicates that 92 percent of variability in lightness could be explained (Table 2). Higher amount of reducing sugars and proteins enhances in browning reaction. Quadratic model was fitted to explain the trend of extrudate with a* b*. R^2 value of 0.95, 0.917, (Table 2) respectively indicates that variability in redness (a*) and yellowness (b*) could be explained by quadratic model. The b*value increased when level of corn was proportionately increased. On an average when the concentration of corn was increased from 20 to 40% level, the b* value increased by 12.7%. An optimum colour value noted was 69.58, 1.29.18.58, for L*a*b* respectively with about 40% level of corn incorporation.

Specific mechanical energy: During extrusion cooking, the mechanical energy delivered by motor is important in conversion of starch. Higher the energy applied, higher the degree of gelatinization and greater the rate of starch conversion (Pardhi et al., 2017). For obtaining the expanded extruded products, higher SME is desirable as suggested by Hussain et al. (2017)

During this study, it was found that, on addition of different proportions of sorghum, corn and fish, in blend formulation, specific mechanical energy varied from 142.24 KJ/kg to 191.14 KJ/kg (Table 1, Fig. 4). As proportions of Sorghum increased, SME also increased, probably due to gelatinisation that took place resulting in greater expansion. High SME was observed at screw speed of 400rpm. Quadratic model was fitted with an R^2 value of 0.90 to the experimental data on changes of SME. The findings

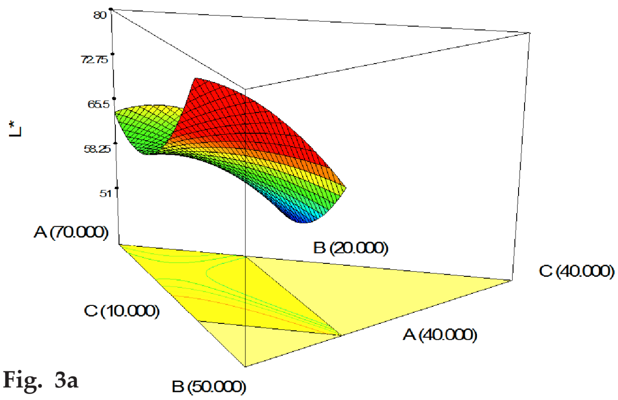

Fig. 3a

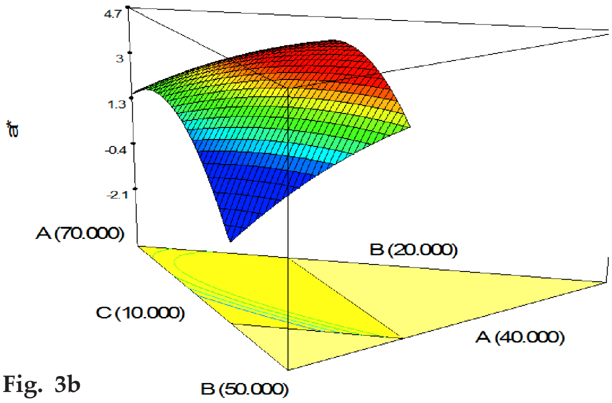

Fig. 3b

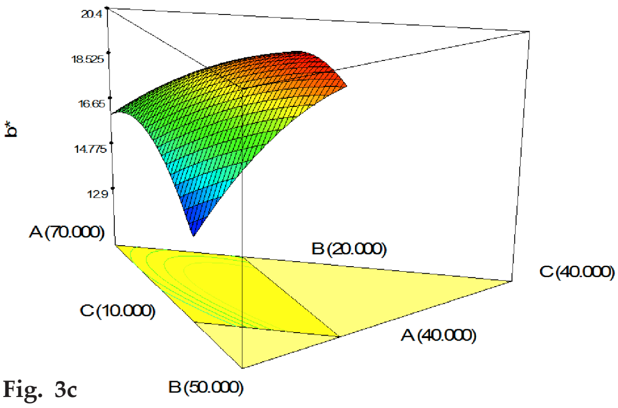

Fig. 3c

Fig. 3a, 3b, 3c Response surface for the effect of sorghum corn fish mince and temperature, screw speed on L*a*b* values of extrudates

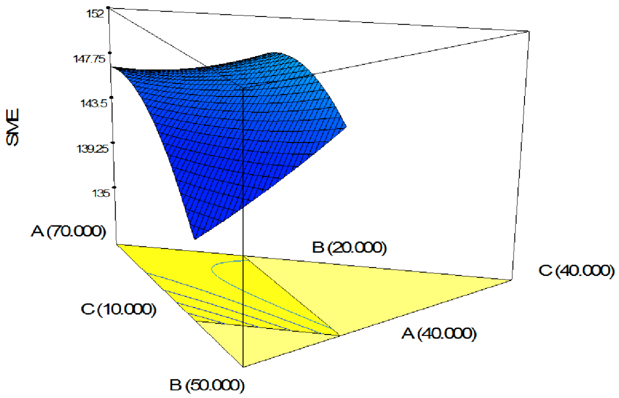

Fig. 4. Response surface for the effect of sorghum,corn,fish mince and temperature, screw speed on SME ofextrudates

were in agreement with report of Meng et al. (2010) that higher SME usually results in greater degree of starch gelatinization and extrudate expansion. Increase in screw speed increases the SME as screw delivers more energy at higher screw shear rate leading to increase in SME, consistent with previous findings of Baik et al. (2004). Optimum value for SME was 165.41 KJ/kg.

Hardness: Hardness, measured as an instrumental indicator of the product texture, can be considered as strength of expanded snack as well as the degree of porosity and pore distribution, which depends on the composition. The shear force needed to break the extrudate varied from 1090 N to 368.33 N (Table 1, Fig. 5). With increase in fish mince, from 10 to 20%, increase in hardness was noticed.

In the present study, highest hardness of 1062 N was observed with 40% sorghum, 40% corn and 20% fish

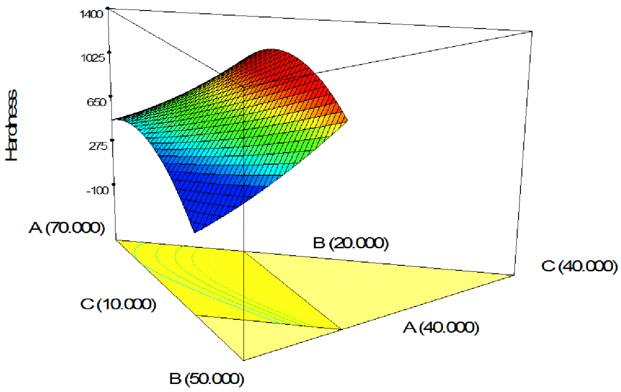

Fig. 5. Response surface for the effect of sorghum, corn, fish mince and temperature, screw speed on Hardness of extrudates

mince. Similar trend was observed by Park & Baik (2002) and Parvathy et al. (2017) in fish-fortified noodles. Texture properties of extrudates are highly influenced by expansion degree as reported by Anton et al. (2009). Hardness was found to increase with increase in content of Sorghum from 40% to 70%. Fish has more positive effect on hardness than Sorghum with an optimum value of 637.52 N. Effect of blend ratio on hardness showed an R^2 value of 97% which indicated quadratic model fitted into experimental data

Organoleptic characteristics of extruded snack: Commercial acceptability of product depends on sensory attributes like taste and flavour even if product is of high nutritional Significance (Alam et al., 2015). The optimised samples were subjected to organoleptic tests with respect to appearance, colour, odour texture, flavour, taste, and overall acceptability with average values 7.9±0.42, 7.6±.34, 7.8±.28, 7.7±.24, 7.4±.21, 7.6±0.28, 7.7±0.43 respectively. Based on scores obtained it was noted that by incorporating fish mince to a level of 15.13 % good sensory acceptability could be attained. Similar findings were observed by (Kamalakanth et al., 2015) who incorporated of fish mince to noodles and improved the sensory attributes.

The present study showed the possibility of use of Sorghum, a low-cost cereal along with corn and fresh water fish Tilapia as a protein source in product development with improved nutritional quality. Based on the desirability function score, the optimum combination of ingredient was Sorghum 44.87%, corn 40%, Tilapia mince 15.13%, at 130ºC and 343 rpm. The findings of the study with incorporation of underutilized Sorghum and fresh water fish Tilapia protein for formulating a value-added food product, opens up better utilization of the raw materials offering impetus to the growers of the cereal and the fish.

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References

Adem, M., Sadik, J. A., Worku, A. and Neela, S. (2019) Optimization of lupine (*Lupinus albus* L.) composition, feed moisture content and barrel temperatures for best quality maize based extruded snack food. Food Sci. Nutr. 50 (5): 853-869

Alam MS, Pathania S, Kumar S. and Sharma, A. (2015) Studies on storage stability of carrot pomace-chickpea incorporated rice based snacks. Agric. Res. J. 52(4): 73-79

Anton, A. A., Fulcher, R. G. and Arntfield, S. D. (2009) Physical and nutritional impact of fortification of corn starch-based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: Effects of bean addition and extrusion cooking. Food Chem. 113(4): 989-996

Asare, E. K., Sefa-dedeh, Samuel, Afoakwa, E. O., Sakyi-dawson, Esther. and Budu, A. S. (2012) Extrusion cooking of rice groundnut cowpea mixtures effects of extruder characteristics on nutritive value and physico functional properties of extrudates using response surface methodology. J. Food Process. Preserv. 36(5): 465-476

Baik, B. K., Powers, J. and Nguyen, L. T. (2004) Extrusion of regular and waxy barley flours for production of expanded cereals. Cereal Chem: 81(1): 94-99

Brennan, C., Brennan, M., Derbyshire, E. and Tiwari, B. K. (2011) Effects of extrusion on the polyphenols, vitamins and antioxidant activity of foods. Trends in Food Sci. and Tech. 22(10): 570-575

Chávez, D. W., Ascheri, J. L., Carvalho, C. W., Godoy, R. L. and Pacheco, S. (2017) Sorghum and roasted coffee blends as a novel extruded product: Bioactive compounds and antioxidant capacity. J. Functional Foods. 29: 93-103

Cortez Netto, J.P., Oliveira Filho, P.R.C., Lapa-Guimara˜es, J. and Viegas, E.M.M. (2014) Physicochemical and sensory characteristics of snack made with minced Nile tilapia. Food Sci. Technol. 34(3): 591-596

de Carvalho Teixeira, N., Queiroz, V. A. V., Rocha, M. C., Amorim, A. C. P., Soares, T. O., Monteiro, M. A. M. and Junqueira, R. G. (2016) Resistant starch content among several sorghum (*Sorghum bicolor*) genotypes and the effect of heat treatment on resistant starch retention in two genotypes. Food Chem. 197: 291-296

Dileep, A. O., Shamasundar, B. A., Binsi, P. K. and Howell, N. K. (2010) Composition and quality of rice flour–fish mince based extruded products with emphasis on thermal properties of rice flour. J. Texture Stud. 41(2): 190-207

Ding, Q. B., Ainsworth, P., Tucker, G., & Marson, H. (2005) The effect of extrusion conditions on the physico-chemical properties and sensory characteristics of rice-based expanded snacks. J. Food Eng. 66(3): 283-289

Dlamini, N. S., and Solomon, W. K. (2016) Effect of ingredients ratio on physicochemical and sensory properties of Sorghum, maize, and soya protein concentrate blend extrudates. Int. J. Food Sci. Nutr. Eng. 6(5): 112-120

Escobar-Puentes, A., Rincón, S., García-Gurrola, A., Zepeda, A., Calvo-López, A. D. and Martínez-Bustos, F. (2019) Development of a third-generation snack with type 4 resistant sorghum starch: Physicochemical and sensorial properties. Food Biosci. 32: 100474

Espinoza-Moreno, R. J., Reyes-Moreno, C., Milán-Carrillo, J., López-Valenzuela, J. A., Paredes-López, O., and Gutiérrez-Dorado, R. (2016) Healthy ready-to-eat expanded snack with high nutritional and antioxidant value produced from whole amaranth in transgenic maize and black common bean. Plant Foods for Human Nutrition. 71(2): 218-224

FAO (2015) The state of food insecurity in the world. http://wedocs.unep.org/handle/ 20.500.11822/979613

Fenster, C. (2003) White food Sorghum in the American diet. In: US Grains Council 43rd Board of Delegates Meeting July 2003, Minneapolis, USA

Ganorkar, P. M., Patel, J. M., Shah, V. and Rangrej, V. V. (2016) Defatted flax seed meal incorporated corn-rice flour blend based extruded product by response surface methodology. J. Food Sci. Technol. 53(4): 1867-1877

Gogoi, B. K., Choudhury, G. S., & Oswalt, A. J. (1996) Effects of location and spacing of reverse screw and kneading element combination during twin-screw extrusion of starchy and proteinaceous blends. Int. Food Res. J. 29(5-6): 505-512

Guy, R. (2001) Extrusion cooking: Technologies and application. Wood Head Publishing Ltd. Cambridge, UK: 75-89

Homchoudhury, M., Chakraborty, R., Sarkar, S. and Raychaudhuri U. (2011) Optimization of rice flour (*Oryza sativa*) and chapra (*Fenneropenaeus indicus*) extrusion by response surface methodology. Fish Technol. 48(2): 155-162

Hood-Niefer, S. D. and Tyler, R. T. (2010) Effect of protein, moisture content and barrel temperature on the physicochemical characteristics of pea flour extrudates. Int. Food Res. J. 43(2): 659-663

Hussain, S. Z., Ali, F., Jabeen, R. and Zargar I. (2017) Twin screw extrusion cooking of Lotus rhizome and broken rice flour blends: A response surface analysis. J. Sci. Ind. Res. 76: 485-493

Ilo, S., Liu, Y. and Berghofer, E. (1999) Extrusion cooking of rice flour and amaranth blends. LWT-Food Sci. and Technol. 32(2): 79-88

Jafari, M., Koocheki, A. and Milani, E. (2017) Effect of extrusion cooking on chemical structure, morphology, crystallinity and thermal properties of Sorghum flour extrudates. J. Cereal Sci. 75: 324-331

Jeyakumari, A., Rahul Das, M. S., Bindu, J., Joshy, C. G. and Zynudheen, A. A. (2016) Optimisation and comparative study on the addition of shrimp protein hydrolysate and shrimp powder on physicochemical properties of extruded snack. Int. J. Food Sci. and Technol. 51(7): 1578-1585

Jorge, M.C., Roberto, G.D., Karina, P.J.S., Oliva, C.R.E., Benjamin, R.W. and Cuauhte´mocc, R.M. (2006) The optimization of the extrusion process when using maize flour with a modified amino acid profile for making tortillas. Int. J. Food Sci. and Technol. 41: 727-736

Kamalakanth, C. K., Asees, C. A., Jose, L., Gopal, T. S., Ravishankar, C. N. and Joseph, A. C. (2007) Studies of the physical properties of the extruded fish products employing a single screw extruder. Fish. Technol. 44(2): 181-186

Kamalakanth, C. K., Gopal, T. S., Joshy, C. G., Ginson, J. J. and Ravishankar, C. N. (2015) Optimisation of physical properties of ready to cook fish incorporated noodles using response surface methodology.Fish. Technol. 52: 109-117

Khan, I., Yousif, A., Johnson, S. K. and Gamlath, S. (2013) Effect of Sorghum flour addition on resistant starch content, phenolic profile and antioxidant capacity of durum wheat pasta. Int. Food Res. J. 54(1): 578-586

Malik, H., Gulzar, A. and Dar, B. N. (2015) Optimisation of process for development of nutritionally enriched multigrain bread. J. Food Proc. Technol. 7(1): 1-6

Maluf, M. L. F., Weirich, C. E., Dallagnol, J. M., Simões, M. R., Feiden, A. and Boscolo, W. R. (2010) Elaboração de massa fresca de macarrãoenriquecida com pescadodefumado. Revista do Instituto Adolfo Lutz, 69(1): 84-90

Meng, X., Threinen, D., Hansen, M. and Driedger, D. (2010) Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack. Int. Food Res. J. 43(2): 650-658

Mkandawire, N. L., Weier, S. A., Weller, C. L., Jackson, D. S. and Rose, D. J. (2015) Composition, in vitro digestibility, and sensory evaluation of extruded whole grain Sorghum breakfast cereals. LWT-Food Sci. and Technol. 62(1): 662-667

Netto, J. D. P. C., Oliveira Filho, P. R. C. D., Lapa-Guimarães, J. and Viegas, E. M. M. (2014) Physico-chemical and sensory characteristics of snack made with minced Nile tilapia. Food Sc. and Technol 34(3): 591-596

Pardhi, S. D., Singh, B., Nayik, G. A. and Dar B. N. (2017) Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology. J. Sau. Soc. Agri. Sci. 17: 218-225

Park, C.S. and Baik, B.K. (2002) Flour characteristics related to optimum water adsorption of noodle dough for making white salted noodles. Cereal Chem. 79: 867-873

Parvathy, U., Bindu, J. and Joshy, C. G. (2017) Development and optimization of fish fortified instant noodles using response surface methodology. Int. J. of Food Sci. and Technol. 52 (3): 608-616

Peksa, A., Kita, A., Carbonell-Barrachina, A. A., Miedzianka, J., Kolniak-Ostek, J., Tajner-Czopek, A. and Drozdz, W. (2016) Sensory attributes and physicochemical features of corn snacks as affected by different flour types and extrusion conditions. LWT-Food Sci. and Technol. 72: 26-36

Pelembe, L. A. M., Erasmus, C. and Taylor, J. R. N. (2002) Development of a protein-rich composite Sorghum–cowpea instant porridge by extrusion cooking process. LWT-Food Sci. and Technol. 35(2): 120-127

Pontieri, P., Mamone, G., deCaro, S., Tuinstra, M.R., Roemer, E., Okot, J., de Vita, P., Ficco, D.B.M., Alifano, P., Pignone, D., Massardo, D.R. and Del Giudice, L. (2013) Sorghum, a healthy and gluten-free food for celiac patients as demonstrated by genome, biochemical, and immunochemical analyses. J. Agric. Food Chem. 61: 2565-2571

Prinyawiwatkul, W., McWatters, K. H., Beuchat, L.R., Phillips, R.D. and Uebersak, M. A. (1996) Cowpea flour: a potential ingredient in food products. Crit. Rev. Food Sci. Nutr. 36(5): 413-436

Rajesh, G.K., Thirupathi, V., Nambi, V. E. and Pandiselvam R. (2014) Optimization of extrusion cooking process for rice-fish extrudates with an underutilized fish mince based on physical, functional and textural properties. J. Agric. Eng. 2: 9-21

Ranganna, S. (2002) Handbook of analysis and quality control for fruit and vegetable products. Tata McGraw-Hill, New Delhi.

Reshi, M., Shafiq, F., Hussain, S. Z., Naseer, B. and Amin, T. (2020) Physicochemical properties of iron fortified low glycemic index (GI) barley based extruded ready to eat snacks developed using twin screw extruder. J. Food Process Preserv. 44(8): 14606

Rhee, K. S., Kim, E. S., Kim, B. K., Jung, B. M. and Rhee, K. C. (2004) Extrusion of minced catfish with corn and defatted soy flours for snack foods. J. Food process preserv. 28(4): 288-301

Seker, M. (2005) Selected properties of native or modified maize starch / soy protein mixtures extruded at varying screw speed. J. Sci. Food Agric. 85(7): 1161-1165

Seth, D. and Rajamanickam, G. (2012) Development of extruded snacks using soy, Sorghum, millet and rice blend – A response surface methodology approach. Int. J. Food Sci. and Technol. 47(7): 1526-1531

Singh, B. R., and Singh, D. P. (1995) Agronomic and physiological responses of Sorghum, maize and pearl millet to irrigation. Field Crops Res. 42(2-3): 57-67

Souza, M. L. R. (2006) Farinha de Carcaça de Peixe com ErvasAromáticas para Alimentação Humana (CD-ROM, No. 2590). Bento Gonçalves, Brazil: Aquabio

Taylor, J. R. N., Schober, T. and Bean, S. R. (2006) Non-traditional uses of Sorghum and pearl millet. J. Cereal Sci. 44: 252-71

Vanier, N. L., Vamadevan, V., Bruni, G. P., Ferreira, C. D., Pinto, V. Z., Seetharaman, K. and Berrios, J. D. J. (2016) Extrusion of rice, bean and corn starches: Extrudate structure and molecular changes in amylose and amylopectin. J. Food Sci. 81(12): 2932-2938

Wu, G., Ashton, J., Simic, A., Fang, Z. and Johnson, S. K. (2018) Mineral availability is modified by tannin and phytate content in Sorghum flaked breakfast cereals. Int. Food Res. J. 103: 509-514

Yang, L., Allred, K. F., Geera, B., Allred, C. D. and Awika, J. M. (2012) Sorghum phenolics demonstrate estrogenic action and induce apoptosis in non-malignant colonocytes Nutr. Cancer. 64(3): 419-427

