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RESEARCH PAPER

Development of Nutritious Convenience Extruded Snacks Using Composite Flour of Sorghum, Maize and Sweet Potato

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ABSTRACT

The present study was aimed at utilization of underutilized crops such as sorghum, maize and sweet potato in development of nutritious convenience foods. Home scale *atta chakki* was used to mill sorghum (PSC-4) and maize (PMH-1) to obtain whole flours. Method for obtaining flour from sweet potato (PSP-21) was standardized. Formulation for ready-to-eat extrudates (RTE) was optimized using response surface methodology (RSM). Feed moisture (FM) was the most significant ($p \leq 0.01$) independent variable that affected the expansion ratio, bulk density, hardness and overall acceptability of the RTE extrudates. The optimized formulation was 50.0 g SPF, 5.71 g SF per 100 g blend along with maize flour and 12.00 per cent (v/w basis) FM at 91.10 per cent desirability. The optimized extrudates were subjected analysis of physico-chemical and functional properties. Shelf-life studies revealed that the extruded snacks were acceptable for up to 90 days under ambient conditions. Overall, incorporation of SPF in extrudates increased the vitamin-C and potassium contents while incorporation of maize increased the beta carotene content.

Keywords: Sweet potato, sorghum, maize, nutritious, convenience, extrudates, formulations

Convenience foods include foods such as biscuits and snack foods which do not need any preparation (Iwegbue, 2012). Boer *et al.* (2004) defined convenience foods as products that have undergone secondary processing including ready meals, pizzas, confectionery products and other consumer ready products. Most of these foods have wheat as their major ingredient. Gluten intolerance has become a well-known disorder affecting almost 1 percent of the population (Catassiand Fasano, 2008). The only effective treatment for celiac disease is a strict adherence to a gluten-free diet throughout the patient's lifetime, which resulted in clinical and mucosal recovery. Individuals with celiac disease are intolerant to prolamin fraction of protein of grains such as wheat, rye, barley and oats (Gallagher *et al.* 2004). Excessive avoidance of these grains may limit intake of adequate nutrition and lead to malnutrition (Lamacchia, 2014). Avoidance of wheat may also pose technical challenges in making acceptable products as it contains gluten protein which is essential for good baking performance of the flour. Hence it is important to look at other food sources such as sorghum, maize and sweet potato to develop appropriate processing technology to convert them into acceptable convenience foods.

Sorghum (*Sorghum bicolour*) is a staple cereal of

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people in warm climates in Africa, Central America and South Asia. Sorghum is the fifth most produced grain globally. Sorghum acts as a principal source of energy, proteins, vitamins and minerals for millions of the poorest people living in Africa, Asia and the Semi-arid tropics worldwide (Mauder, 2006). Endosperm of sorghum grain is rich source of starch, protein, vitamin B-complex respectively. Bran of sorghum is excellent source of fiber, containing lesser amounts of ash and proteins. The consumption of sorghum may reduce risk of cancers such as those of colon and skin diseases. Phytochemicals as tannins anthocyanin's phenolic compounds phytosteroles etc. are important health maintaining contents of sorghum flour (Hahn *et al.* 1984). Sorghum is a gluten free cereal and can be used to prepare foods for those with celiac disease. With certain technological interventions, sorghum flour can be used as a wheat flour replacement in breads, pastas, and baked goods.

Maize (*Zea mays*) is a versatile crop as it has wide adaptability over variousagro-climatic conditions. Proximate composition of maize and maize products was in the range of 11.6- 20.0 percent (moisture), 1.10-2.95 percent (Ash), 4.50-9.87 percent (protein), 2.17-4.43 (fat), 2.10- 26.70 percent (fibre) and 44.60-69.60 percent (carbohydrate). According to Enyisiet al. (2014) mineral elements of the maize and maize products namely: phosphorus, magnesium and potassium were found to be high compared to other elements: zinc, calcium copper, sodium manganese and iron. Higher percentage of these minerals was concentrated in the maize bran. Although this crop finds wide application as a feed and in starch industry, its use as a food crop is still limited in India. However, it has great potential for food use. It is a gluten-free cereal and has high anti-oxidant activity.

Sweet potato (*Ipomoea batatas*) is a root crop and the world's seventh most important crop. It is an important staple food in many of the developing countries of the tropics and sub-tropics. Sweet potato flour can serve as a source of energy and carbohydrates, beta carotene, vitamins B and C, minerals (Ca, P, Fe and K) and dietary fibre (Vimala *et al.* 2011). It can add natural sweetness, colors and flavour to processed food products (Woolfe, 1992). Depending on the flesh color, sweet potatoes are rich in β -carotene, anthocyanins, total phenolics, dietary fiber, ascorbic acid, folic acid and minerals (Woolfe, 1992; Bovell-Benjamin, 2007). Therefore, sweet potato has an exciting potential for contributing to the human diets around the world.

Sweet potato has been used in the production of purees and these can be used as an ingredient in various products including baby food, casseroles, puddings, pies, cakes, bread, restructured fries, patties, soups and beverages (Walter *et al.* 2001). Increased production of sweet potatoes puts burdon on the industrial or village-level processing of the crop due to lack of commercialization technology at low levels. The major avenue left for preservation of sweet potato is processing into secondary products. Technologies such as extrusion processing is an alternative to development of convenience foods from sweet potato (Dhungana *et al.* 2014).

Milligan *et al.* (1981) defined composite flour as a mixture of flours, starches and other ingredients intended to replace wheat flour totally or partially in bakery and pastry products. Composite flour reduces the importation of wheat flour and encourages the use of locally grown crops as flour in developing countries (Hasmadi *et al.* 2014). Thus, several developing countries have encouraged the initiation of programmes to evaluate the feasibility of alternative locally available flours as a substitute for wheat flour (Abdelghafor *et al.* 2011).

Extrusion cooking is a high-temperature, short-time process that plasticizes and cooks moistened, expansive, starchy and/or protein-rich food materials in a tube by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions (Castells *et al.* 2005).

The aim of present investigation was to standardize the method for preparation extruded snacks from sorghum-sweet potato-maize blends and to evaluate the quality and shelf-life of the developed products from above underutilized crops in development of convenience foods.

MATERIALS AND METHODS

Location of study: The study was carried out in the Department of Food Science and Technology, College of Agriculture, PAU, Ludhiana.

Raw materials used in the study

Maize (PMH-1) and Sorghum (PSC-4) grains were procured from the Department of Plant Breeding and Genetics, PAU, Ludhiana. Sweet potato (PSP-21) tubers were procured from Department of Vegetable Science, PAU, Ludhiana.

Processing of maize, sorghum and sweet potato

Milling of maize and sorghum

Milling of maize and sorghum into flour were done using home scale *atta chakki* in the Milling Technology Laboratory, Department of Food Science and Technology, PAU, Ludhiana.

Preparation of flour from sweet potato

Flour from sweet potato was prepared as per Olapade and Ogunade (2014) with little modifications for standardization as shown in Fig. 1. The tubers were sorted out and washed with clean water. The clean tubers were peeled and sliced into about 5 mm thickness and then were treated with 2000 ppm potassium metabisulphite for 20 minutes, then dried at 50 ± 5°C for 8 hr in a cabinet drier (Mermmet, Germany) and dried sweet potato chips were milled in a laboratory using home scale *atta chakki* and screened through a sieve of 0.8 mm aperture to get the flours. The flours obtained were packaged in a low-density polyethylene bag and stored in a cool place until needed.

Milling yield

Milling yields of maize, sorghum grains and dried sweet potato chips were calculated using the following formula:

$$\text{Milling Yield (\%)} = \frac{\text{Weight of flour obtained}}{\text{Weight of initial material}} \times 100$$

Preparation and shelf-life assessment of convenience foods from sorghum, maize and sweet potato flour blends

Preparation of flour blends

Blends of sorghum, maize and sweet potato were prepared by mixing different ratios of particular flours. The flours were packed into polythene bags for further use in the preparation extruded snacks.

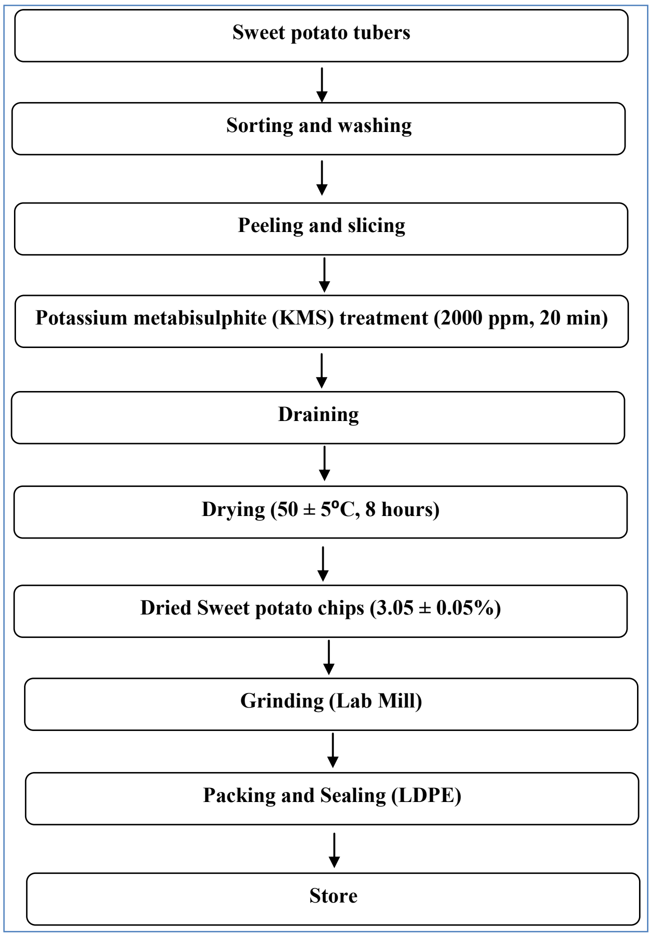


Fig. 1: Sweet potato tubers preparation

Preparation of convenience extruded snacks

Extruded snacks were prepared using a laboratory-scale co-rotating twin-screw extruder with intermeshing model BCH (Clextral, Firminy, France). The extruder had four barrel zones. Temperatures in barrel zones were maintained at 24.5-26.8°C, 57.3-58.4°C, 72.5-76.5°C, and 121.0-139.2°C in the first, second, third and fourth zones respectively throughout the extrusion process. The diameter of the die opening was 1.5 mm. The extruder was calibrated thoroughly with respect to the combination of feed rate and screw speed to be used. The moisture content of the feed was varied by injection of water into the extruder with a water pump. The twin-screw extruder conditions were kept to stabilize the set temperatures;feed rate of poured samples was adjusted according to the study parameters. The extrudates were collected at the die end and left to cool and then were packed in aluminium laminates and high density (HDPE) polythene bags for further analysis.

Experimental design for extrusion process

Response surface methodology (RSM) was applied to the experimental data using a commercial statistical software package (Design-Expert, version 10.0.0.3, Stat-Ease, Inc.). The same software was used for the generation of response surface plots, superimposition of contour plots, and optimization of process variables.)

RSM (response surface methodology) based on the CCRD (Central Composite Rotatable Design (CCRD), with three independent variables; namely, sweet potato flour (SPF), sorghum flour (SF) and feed moisture (FM); at five levels and eight replicates at center point (Cochran and Cox, 1964) was adapted to design the experiments. Preliminary trials were done to establish the upper and lower levels of the independent variables. The factors (independent variables) and their levels, in terms of coded and decoded forms are given in Table 1. A total of 30 runs were obtained in randomized order. It was assumed that for each response variable, there existed n-mathematical functions, $f_k(k = 1, 2\ldots.. n)$, Y_k in terms of m independent processing factors X_i (i = 1,2, ……………., m) (Eq. 1).

$$Y_k = f_k(X_1, X_2, \ldots, X_m) \qquad \ldots(1)$$

In this case, $n = 4$, $m = 3$

Full second-order equation (Eq. 2) was fitted in each response to describe it mathematically and to study the effect of variables. The equation was as follows:

$$Y_K = \beta_0 + \sum_{i=1}^{m} \beta_i X_i + \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \beta_j X_I X_j + \sum_{i=1}^{m} \beta_i X^2{}_i \qquad \ldots(2)$$

where, Y_k = response variable, β_0 is the value of the fitted response at the centre point of the design i.e. (0,0) and β_i, β_{ij}, β_{ii} are the linear, quadratic and interactive regression coefficients, respectively. X_i and X_j are the coded independent variables. The magnitude of the coefficients in second order polynomials showed the effect of concerned variable on responses.

The aim of extrusion process optimization was to determine the independent variables (i.e. feed moisture and sweet potato and sorghum flours proportions) levels that could produce maximum expansion ratio (ER), water absorption index (WAI), water solubility index (WSI), overall acceptability (OA), bulk density (BD) and hardness within the range. Numerical optimization was used to determine the best formulation (product sample) which was used for storage and shelf-life study.

Table 1: Central composite design arrangement with coded variables

Run	Coded value			Actual value		
	X_1	X_2	X_3	**SPF (g/100g blend)**	**SF (g/100g blend)**	**FM (%)**
1	+1	-1	+1	70	5	16
2	+1	+1	+1	70	10	16
3	0	+2	0	60	12.5	14
4	-2	0	0	40	7.5	14
5	-1	+1	+1	50	10	16
6	+1	+1	-1	70	10	12
7	0	0	0	60	7.5	14
8	0	0	-2	60	7.5	10
9	-1	-1	-1	50	5	12
10	0	0	0	60	7.5	14
11	+1	-1	+1	70	5	16

12	-1	-1	-1	50	5	12
13	-1	+1	+1	50	10	16
14	-1	+1	-1	50	10	12
15	+1	+1	+1	70	10	16
16	0	0	0	60	7.5	14
17	0	0	0	60	7.5	14
18	+1	+1	-1	70	10	12
19	0	-2	0	60	2.5	14
20	0	0	0	60	7.5	14
21	0	0	0	60	7.5	14
22	+1	-1	-1	70	5	12
23	+1	-1	-1	70	5	12
24	0	0	+2	60	7.5	18
25	-1	+1	-1	50	10	12
26	-1	-1	+1	50	5	16
27	0	0	0	60	7.5	14
28	0	0	0	60	7.5	14
29	+2	0	0	80	7.5	14
30	-1	-1	+1	50	5	16

SPF: sweet potato flour; SF: sorghum flour; FM: feed moisture.

Physical properties of convenience extruded snacks

The functional properties of extrudates are expansion ratio, bulk density, colour and hardness etc. Degree of puffing during extrusion is described by expansion ratio and bulk density. Colour is an important characteristic of extruded foods which can give information about the extent of browning reaction such as Millard reaction, degree of coking and pigment degradation (Altan *et al.* 2008). The functional properties of extrudate i.e. bulk density, expansion ratio, colour and hardness were calculated as per standard methods.

Expansion Ratio (ER)

Expansion ratio (ER) was determined according to the procedure described by Ding *et al.* (2005) Expansion ratio was calculated as:

ER = Diameter of extrudate/ Diameter of die

Water absorption index (WAI) and water solubility index (WSI)

Water absorption index (WAI) and water solubility index (WSI) were measured using the technique according to Anderson *et al.* (1969) with little modifications.

Hardness

TA–XT2 texture analyzer (Stable Micro Systems Ltd., Godalming, UK) was used to determine the textural properties of the extrudates with a 500 kg load cell. The highest first peak value was recorded as this value indicated the first rupture of snack at one point and this value of force was taken as a measurement for hardness (Stojceska *et al.* 2008).

Colour analysis

The color of the extrudates was measured in accordance with CIE L*, a*, b* color space system (Lab Scan XE Hunter Lab Instruments, Virginia, USA) based on the tri-stimulus value. The L*, a*, b* values were recorded (Kimura *et al.* 1993).

PROTEINSOLUBILITYANDDIGESTIBILITY

Protein solubility

Approximately 5 g of fine ground and sieved (60 mesh or 250 microns particle size) of extrudates were weighed. The samples were allowed to absorb water over night after adding 35 ml of deionized water. The suspension was centrifuged at 750 rpm for 15 minutes. A 10 ml of the filtrate obtained was analyzed for nitrogen using a Kjeldahl method. Nitrogen to protein conversion factor of 6.25 was used to derive the percentage soluble protein (McWatters *et al.* 2002).

Protein digestibility

Protein digestibility was estimated by enzymatic method of Akeson and Stahmann (1964) with little modifications. 0.5 g of dry samples were homogenized and suspended in 50 ml of pepsin solution and incubated at 37°C for 24 hours. The suspension was than neutralized with 30 ml of 0.2 N NaOH and treated with 50 ml of pancreatin solution in phosphate buffer (pH 8.0) and incubated for 24 hours at 37°C. After incubation, the sample was treated with few drops of Toluene and centrifuged at 3000 rpm for 20 minutes. Then the suspension was filtered through whatman paper and the residue left was analyzed for nitrogen content by Micro Kjeldahl method.

Proximate composition analysis: Extrudates were analyzed for moisture, crude protein, beta carotene, total fat, total ash, crude fibre and carbohydrates.

Moisture content: Standard AACC (AACC, 2000) procedure given under 44.15 A was followed to estimate the moisture content extruded product. Moisture content was calculated according to the following formula;

$$\text{Moisture content (\%)} = \frac{\text{Loss in weight (g)}}{\text{Weight of sample (g)}} \times 100$$

Crude Protein: Standard AACC (AACC, 2000) procedure given under 46-11 A was followed to estimate the crude protein content of extruded product. The factor 6.25 was used for extruded product. Protein content (%) = % N_2 × factor

Total fat: Three gram of moisture free samples of extruded product in duplicate for each was taken in thimbles. Round bottom flasks were weighed. Fat was extracted using petroleum ether in soxhlet apparatus for 16 hours. Ether was recollected and round bottom flasks were weighed after extraction of fat. The results were expressed as;

$$\text{Total fat (\%)} = \frac{\text{Weight of fat (g)}}{\text{Weight of sample (g)}} \times 100$$

Total Ash: Standard AACC (AACC, 2000) procedure given under 08-01 was followed to estimate the ash content of extruded product. Samples were cooled, wighed and ash content was expressed as percent ash.

$$\text{Ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample (g)}} \times 100$$

Crude fibre: Standard AACC (AACC, 2000) given under 32-10 was followed to estimate the crude fibre content of extruded product. The loss in weight represents crude fibre.

$$\text{Ash (\%)} = \frac{\text{Loss in weight noted}}{\text{Weight of sample}} \times 100$$

Carbohydrate content: Total carbohydrate was calculated by difference method;

Carbohydrate % = 100 – (CP% + CF% + TF% + MC %)

Where; CP = Crude Protein; CF = Crude Fibre; TF = Total Fat; MC = Moisture Content

Minerals: Minerals in extruded product were determined by thermo electron inductively coupled plasma atomic emission spectrometry (ICP-AES), model iCAP-630 (Arora and Bajwa, 1994). One gram of dry sample was taken and 10ml of di-acid was added and left overnight. Then the mixture was digested until white fumes were observed. Then the volume was made to 25 ml and the mixture was filtered twice using Whatman paper (number one). The filtrate was analyzed for minerals.

Vitamin-C: Vitamin-C of extruded product was determined using dye-titration method based on the official procedures (AOAC, 2005).

Beta carotene: Beta-carotene of extruded product was estimated by following approved AACC (14-50, 1995) method with little modifications. The β-carotene content was calculated from calibration curve from known amount of β-carotene.

Tannins: Tannins content in extruded product was estimated following the procedures described by Saxena *et al.* (2013). The reading for the absorbance was taken at 700 nm after 30 min.

Sensory evaluation

Sensory analysis was conducted for all the samples using hedonic scale (Larmond, 1970). Ten panelists were asked to assess the expanded snacks and allot score to sample as per Hedonic Rating Test (1 – Dislike extremely, 5 – Neither like nor dislike and 9 – Like extremely) in accordance with their opinion for taste, texture, color and overall acceptability.

Shelf-life study

Extruded snacks were evaluated periodically for moisture, water activity, free fatty acid content, peroxide value (AOAC, 2001) and overall acceptability. Prepared extruded snacks were packed in HDPE (200 gauge) and aluminium laminates and kept under ambient conditions. Shelf-life was evaluated by estimating moisture, water activity, free fatty acid content, peroxide value, sensory evaluation and textural quality at the regular intervals of one month over the period of three months.

STATISTICAL ANALYSIS

Data obtained were analyzed statistically using techniques of analysis of variance (Gomez and Gomez, 1984). The statistical procedures performed using SPSS (version 16.0) SPSS Inc. (Chicago, USA). A comparison of the means was ascertained by Tukey's test, to 5 per cent level of significance using analysis of the variance (ANOVA).

RESULTS AND DISCUSSION

Milling yields of sorghum, maize and dried sweet potato chips

Milling yields of sorghum, maize grains and dried sweet potato chips are shown in Table 2. Maize grains showed higher milling yield than sorghum grains and sweet potato chips.

Table 2: Milling yields of sorghum, maize and dried sweet potato chips

Sample	Initial Weight (kg)	Final weight (kg)	Milling yield (%) (IW/FW* 100)
Maize grains	1	0.98	98.00
Sorghum grains	1	0.95	95.00
Sweet potato chips	1	0.96	96.00

Optimization of extrusion parameters for extruded products

Optimization means the processing conditions that give the optimum (maximum or minimum) value of a function of certain decided variables subject to constraints that are imposed. The values of the processing variables that produce the desired optimum value are called optimum conditions (Myers and Montgomery, 2002).

Numerical optimization was used to determine the optimum combination of SPF, sorghum flour and MF. Preliminary trials were done to establish the upper and lower levels of the independent variables. These were 50-70 g/100g blend, 5-10 g/100g blend and 12-16 per cent for SPF, SF and FM, respectively. Maize flour was mixed with SPF and SF as per the experimental design to obtain 100 g blend. Expansion ratio, bulk density, hardness and overall acceptability were taken as dependent variables for each run to optimize the development of ready-to-eat (RTE) extrudates. The goal was to obtain maximum expansion ratio, bulk density in range, minimum hardness and maximum overall acceptability. Among the solutions obtained, the solution with the maximum desirability was selected. Physical characteristics of snacks, such as expansion, hardness and density, are important parameters that affect functional characteristics and acceptability of the final products (Seth and Rajamanickam, 2012; Devi *et al.* 2013). The predicted responses are presented in Table 3. The optimized values (per 100 g blend) were 50.0 g, 5.71 g and 12.0 ml, SPF, SF and FM, respectively with 91.10 per cent desirability. The obtained formulation was used to develop the extrudates and the actual response values obtained as an average of three replications are given in Table 3 (Plate 1&2). The actual response values were quite comparable to the predicted values and had an overall acceptability of 7.75 ± 0.15. This re-confirmed the adequacy of the models.

Diagnostic checking of fitted models

The estimated regression coefficients of the fitted quadratic equation as well as the correlation coefficients for each model are given in Table 2. The adequacy of the models was tested using F-ratio and coefficient of determination (R^2). The R^2values for the responses i.e. expansion ratio, bulk density, hardness and overall acceptability were 80.50per cent, 87.99per cent, 73.61 per cent and 88.36per

Table 3: Central Composite Design arrangement of coded variables and experimental results for each run

Std.	Run	SPF (g/100g blend)	SF (g/100g blend)	FM (%)	Overall Acceptability	Expansion Ratio	Hardness (g)	Bulk Density (g/ml)
14	1	70	5	16	6.95	3.52	14380.20	0.24
16	2	70	10	16	7.13	4.55	15031.50	0.26
20	3	60	12.5	14	7.33	3.88	3496.12	0.14
17	4	40	7.5	14	7.48	4.75	2946.48	0.14
15	5	50	10	16	4.54	3.08	4771.61	0.26
4	6	70	10	12	7.50	4.44	3172.10	0.08
24	7	60	7.5	14	8.04	4.14	4664.92	0.12
21	8	60	7.5	10	6.25	4.31	5945.27	0.06
1	9	50	5	12	7.83	5.22	3018.52	0.08
28	10	60	7.5	14	7.38	3.95	4152.02	0.12
6	11	70	5	16	6.25	3.23	6368.58	0.22
9	12	50	5	12	7.25	4.45	4374.54	0.06
7	13	50	10	16	4.66	3.25	16870.70	0.28
11	14	50	10	12	7.71	5.11	4238.73	0.08
8	15	70	10	16	6.06	3.42	14454.70	0.24
27	16	60	7.5	14	8.01	4.14	4660.00	0.12
25	17	60	7.5	14	7.93	4.10	5595.20	0.11
12	18	70	10	12	7.21	4.75	5466.77	0.06
19	19	60	2.5	14	7.64	3.87	4104.58	0.12
26	20	60	7.5	14	7.95	3.87	4150.00	0.11
23	21	60	7.5	14	7.95	3.80	4155.28	0.12
10	22	70	5	12	7.85	4.27	5890.76	0.08
2	23	70	5	12	7.81	4.36	3901.91	0.08
22	24	60	7.5	18	4.41	2.63	19700.50	0.30
3	25	50	10	12	7.88	4.58	5552.39	0.12
5	26	50	5	16	6.13	2.85	15849.80	0.26
30	27	60	7.5	14	7.88	3.87	5590.25	0.11
29	28	60	7.5	14	7.83	3.80	5545.20	0.12
18	29	80	7.5	14	7.69	3.87	5588.68	0.12
13	30	50	5	16	7.58	3.41	9598.18	0.10

SPF: sweet potato flour; SF: sorghum flour; FM: feed moisture.

Plate 1: Extruded snacks from different combinations of sorghum, maize and sweet potato flours

Plate 2: Optimized extruded snacks from combinations of sorghum, maize and sweet potato flours (SF 5.7: MF 44.3: SPF 50)

cent, respectively (Table 4). Granato *et al.* (2010a, b) established that R^2> 70 per cent was considered good for sensory, colorimetric and physico-chemical results. For the models that present a regression coefficient below 70 per cent, it must be considered that there is a failure of the models to represent the data in the experimental domain (Myers and Montgomery, 2002). Moreover, lack of fit was found not significant for all the parameters. The proposed models approximated the response surfaces and could be used suitably for prediction at any values of the parameters within experimental range. All four responses were considered adequate to describe the effect of variables on the quality of RTE extrudates.

Effect of variables on overall acceptability

Overall acceptability is an important parameter from the point of view of consumers. Overall acceptability varied from 4.41 to 8.01 within the combination of variables studied. Level of SF and FM had a highly significant ($p \le 0.01$) negative effect on overall acceptability of the extrudates at the linear level as shown in Table 4. A significantly ($p \le 0.05$) negative interactive effect of SF and FM on overall acceptability was also observed. Further, SF and FM also had a highly significant ($p \le 0.01$) negative quadratic effect on overall acceptability of the extrudates. Fig. 2 (a, b and c) also depicted the effect of variables on the overall acceptability of the extrudates.

Fig. 2(c) shows that with increase in FM, there is a dip in the curve towards lower value of overall acceptability. Higher FM resulted in lesser expansion, higher bulk density and more hardness. This might be the cause of significantly low overall acceptability. Dhungana *et al.* (2014) obtained similar results for sweet potato-tomato pomace extruded product. With F-value of 16.87 and an insignificant lack of fit, the model may be considered adequate to represent the response (Table 5).

Effect of variables on expansion ratio

Expansion ratio describes the degree of puffing a sample undergoes as it exits from the extruder. A higher expansion ratio is desirable in the production of extruded snacks. Feed moisture has been found to be the most significant factor affecting expansion ratio (Ding *et al.* 2005).

High expansion ratio is a desirable quality attribute for expanded products. Expansion occurs as a result of rapid release of pressure as the food emerges from the die. This is accompanied by release of steam and gas from the material (Fellows, 2000). The negative coefficient of FM had highly ($p \le 0.01$) significant effect on expansion ratio. However, the interactive effect of SPF and FM affected the expansion ratio positively. Response surface plots (Fig. 3 b and c) show a clear increase in the expansion ratio with decrease in FM. Further, Fig. 3(b) also shows that at constant moisture, increase in SPF would result in increased expansion ratio. SPF had negative effect on

Table 4: Estimated coefficients of the fitted quadratic equation for different responses

Factors	Expansion ratio	Bulk density	Hardness	Overall acceptability
β_0	+3.98**	+0.12**	+5172.70**	+7.80**
β_1	-0.049	-8.333E-004	+403.19	0.13
β_2	+0.079	+0.012	+206.63	-0.44**
β_3	-0.55**	+0.071**	+3717.50**	-0.63**
β_{12}	+0.11	-0.014	+561.95	+0.16
β_{13}	+0.23*	+6.250E-003	+118.59	+0.14
β_{23}	+0.044	+0.011	+230.47	-0.24*
β_{11}	+0.11	+5.893E-003	+132.31	-0.077
β_{22}	-2.768E-003	+5.893E-003	+15.50	-0.27**
β_{33}	-0.10	+0.018**	+2271.13**	-0.64**
R^2, %	80.50	87.99	73.61	88.36

**Significant at $p \le 0.01$, *Significant at $p \le 0.05$.

Table 5: Analysis of variance for different models

Response	Source of variation	d.f.	Sum of squares	Mean square	F-value
Overall acceptability	Model	9	28.90	3.21	16.87**
	Residual	20	3.81	0.19	
	Cor. Total	29	32.71		
	Lack of fit	5	1.79	0.36	2.66
Expansion ratio	Model	9	9.26	1.03	9.17**
	Residual	20	2.24	0.11	
	Cor. Total	29	11.50		
	Lack of fit	5	0.75	0.15	1.51
Hardness	Model	20	4.896E+008	5.440E+007	6.20**
	Residual	10	1.756E+008	8.778E+006	
	Cor. Total	29	6.652E+008		
	Lack of fit	5	4.106E+007	8.213E+006	0.92
Bulk density	Model	9	0.14	0.016	16.28**
	Residual	20	0.019	9.552E-004	
	Cor. Total	29	0.16		
	Lack of fit	5	4.317E-003	8.635E-004	0.88

[a]*Overall acceptability,* ***Significant at* $p \leq 0.01$, **Significant at* $p \leq 0.05$.

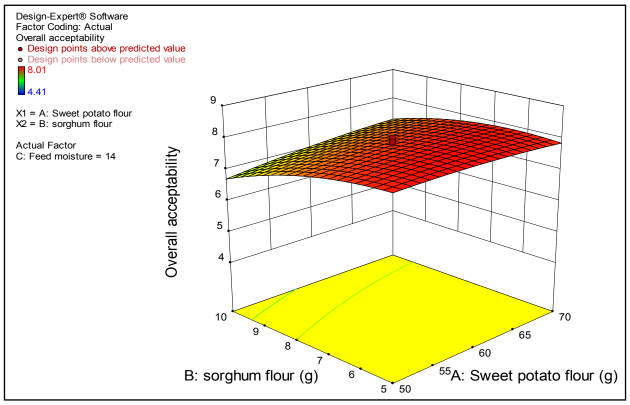


Fig. 2(a)

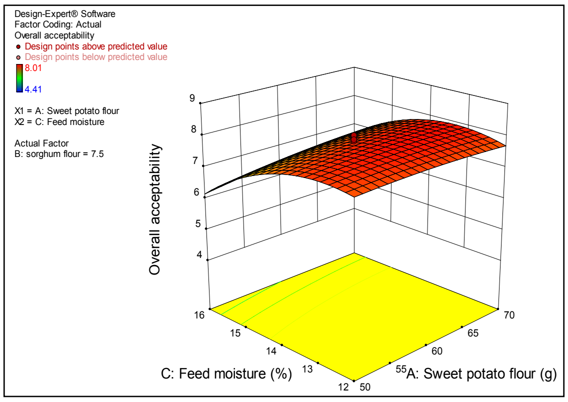


Fig. 2(b)

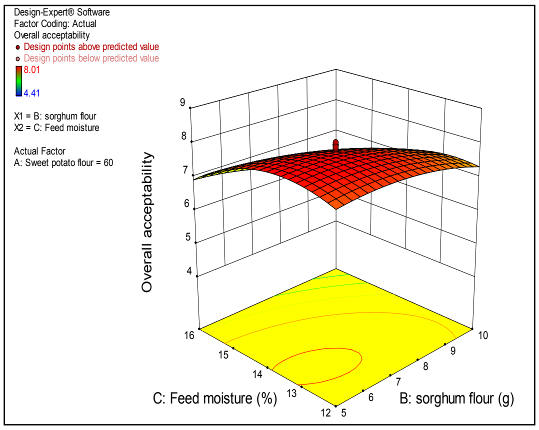
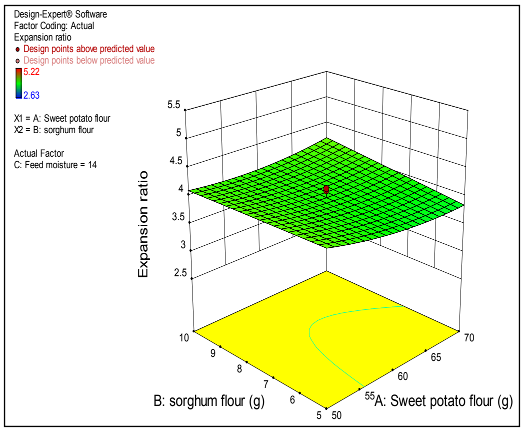


Fig. 2(c)



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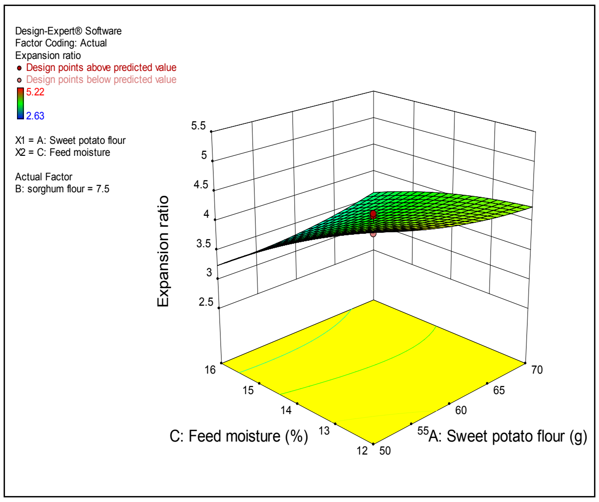

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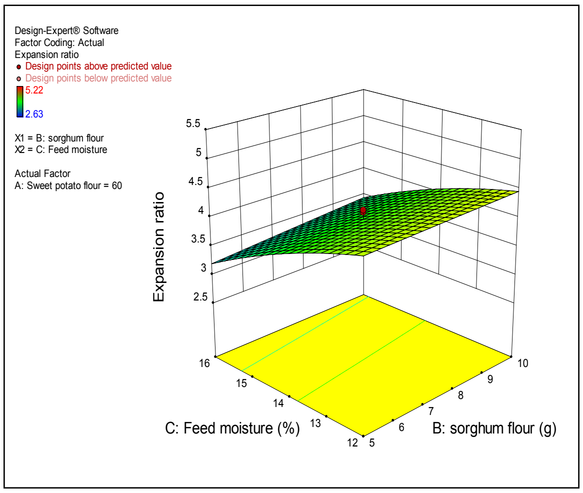

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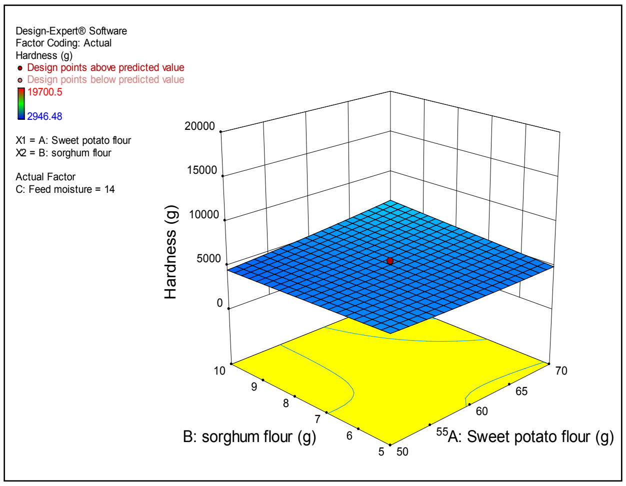
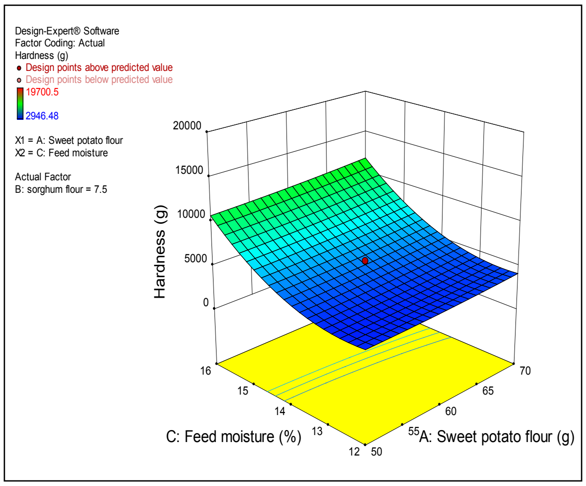


Fig. 4(a)



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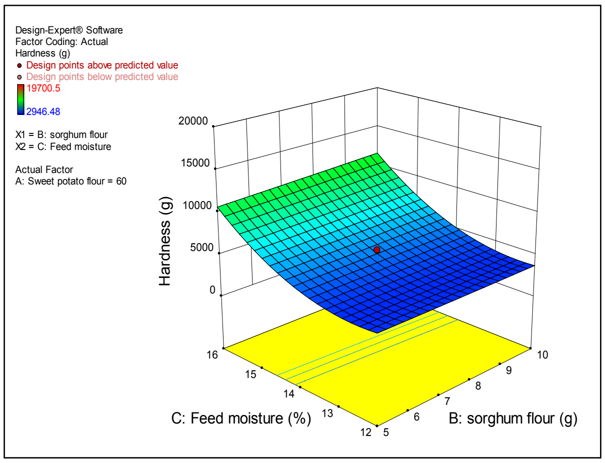

Fig. 4(c)

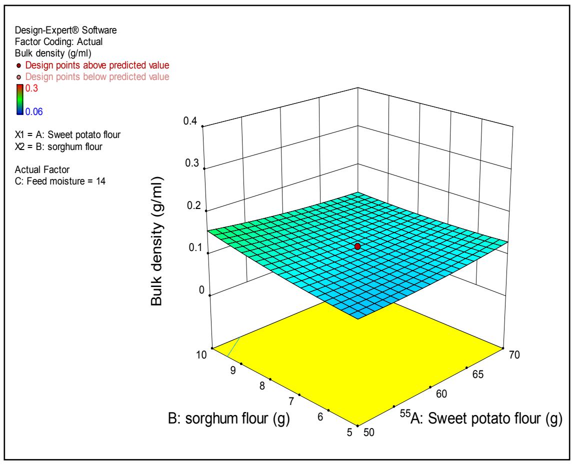

Fig. 5(a)

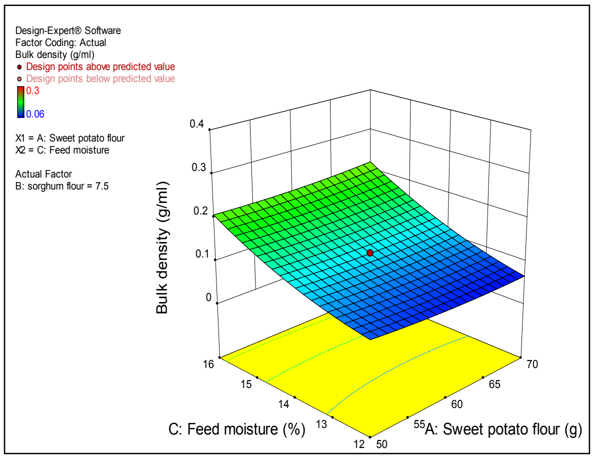

Fig. 5(b)

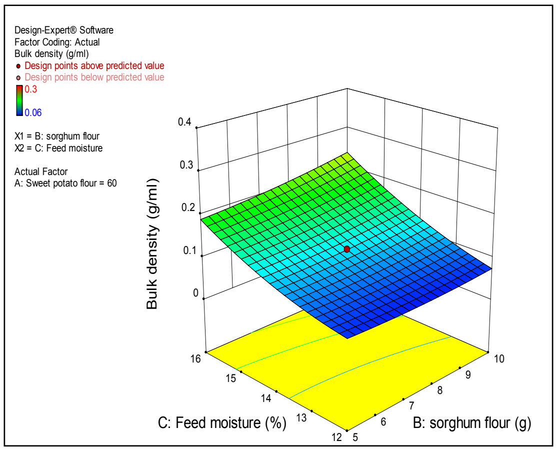

Fig. 5(c)

expansion ratio but was insignificant. SF had positive effect on expansion ratio but was insignificant. SPF is an excellent source of starch, which is the major component affecting expansion. Similar increase in expansion characteristics with decrease in moisture have been reported by several workers (Dhungana *et al.* 2014; Yadav *et al.* 2016). Moisture plays a key role in preparation of extruded products. The expansion ratio increases with decrease in feed moisture content and increase in screw speed and barrel temperature. Increased feed moisture leads to a sharp decrease in the expansion of extrudate (Pathania *et al.* 2013). However, increased FM leads to decrease in amylopectin structure of the material and results in reduced melt density. Higher content of amylose content also causes an increase in expansion ratio (Chinnaswamy and Hanna, 1988) However; higher FM causes a decrease in viscosity of the material in the barrel of the extruder. Devi *et al.* (2013) in development of a protein-rich sorghum expanded snack reported an increase in expansion ratio with increase in corn flour and a decrease with the addition of protein source. The structure of extruded products determinessarch gelatinization on starch gelatinization. Increasing the ratio of starch to protein leads to formation of a continuous starch matrix that enables water vapour to expand because starch melt viscosity is lower than protein melt viscosity (Devi *et al.*, 2013). As a result, the smaller pressure difference leads to less expansion on extrusion (Dhungana *et al.* 2014). F-value of 9.17 implied that the model was highly significant (p≤0.01) (Table 5). Lack of fit was found insignificant. This confirmed the validity of the model and could be used to represent the response.

Effect of variables on hardness

Hardness, an indicator of strength of the lamellae of pores inside the extrudates, was measured using texture analyzer. It was measured in terms of peak force needed by the probe to compress the sample. FM had a highly significant positive ($p \leq 0.01$) influence on hardness both at the linear and quadratic levels (Table 4). Fig. 4(a, b and c) show the RSM plot for the effect of FM, SPF and SF on extrudate hardness. SPF and SF also had positive effect on FM, although it was insignificant. Hardness of the extrudate may be a result of lower expansion ratio and high bulk density at high FM. Hardness has also been related to reduced porosity and pore distribution of the extruded product (Yadav *et al.* 2016). Table 4 shows that the model was highly significant (p≤0.01) with an F-value of 6.20 (Table 5). Lack of fit was insignificant and the model was considered adequate to represent the response.

Effect of variables on bulk density

Bulk density is an important parameter to determine the packaging and storage space requirement of a product. The values of estimated coefficients of

Table 6: Constraints, criteria for optimization, solution along with predicted and actual response values

Name	Goal	Lower limit	Upper limit	Predicted values	Actual response values*
Sweet potato flour (g/100 g blend)	Is in range	50	70	50.0	—
Sorghum flour (g/100 g blend)	Is in range	5	10	5.71	—
Feed moisture (%)	Is in range	12	16	12.0	—
Expansion ratio	Maximize	2.63	5.22	4.863	4.582±0.32
Hardness (g)	Minimize	2946.48	19700.5	3991.35	3996.5±0.23
Bulk density (g/ml)	Is in range	0.06	0.3	0.072	0.07±0.02
Overall acceptability	Maximize	4.41	8.01	7.844	7.75±0.15

**Means (±SD) of seven replications.*

the bulk density in the quadratic equation given in Table 4 indicate that positive coefficient of FM had a significantly ($p \leq 0.01$) positive influence on bulk density of the product both at the linear and quadratic level.

SPF and SF did not have any significant effect on bulk density (Fig. 5a). Fig. 5 (b and c) shows a decrease in bulk density with the decrease in moisture from 16 to 12 per cent. Increased FM has earlier been associated with increased bulk density (Stojceska *et al.* 2008; Jadhav and Annapure, 2013). Low expansion due to high moisture is also the cause of higher bulk density. A highly significant ANOVA ($p \leq 0.01$) for the model and an insignificant lack of fit confirmed the validity to represent the response (Table 5).

Physico-chemical analysis extruded snacks

The developed extruded snacks had 3.82 ± 0.07 per cent moisture content and had 5.39 ± 0.17 per centprotein, 0.72 ± 0.16 per cent fat, 3.88 ± 0.05 per cent total ash content, 2.05 ± 0.05 per cent crude fibre and 86.19 ± 0.44 per cent carbohydrates on dry basis. The extrudates had high amount of potassium and sodium minerals and low amount of copper and zinc minerals (Table 7). The developed snacks showed that there was a decrease of mineral content compared the raw material (flours) mineral contents; this may be due to processing effects. The extrudates also had 502.50 ± 15.50 µg/100g β-carotene and 16.78 ± 2.11 mg/100g of vitamin C. The amount of tannins for the developed snacks was 860.00 ± 33.00 µg/100g and this indicates that the tannins content decreased after processing.

Table 7: Physico-chemical analysis of extruded snacks

Constituents	Sample
Moisture (%)	3.82±0.07
Protein (%)	5.39±0.17
Fat (%)	0.72±0.16
Ash (%)	3.88±0.05
Crude Fibre (%)	2.05±0.05
Carbohydrate (%)	86.19±0.44
Calcium (mg/kg)	24.10±0.30
Copper (mg/kg)	0.08±0.01
Iron (mg/kg)	0.22±0.01
Potassium (mg/kg)	325.50±0.05
Magnesium (mg/kg)	18.05±0.10
Manganese (mg/kg)	18.20±0.15
Sodium (mg/kg)	183.85±0.15
Zinc (mg/kg)	0.11±0.00
Vitamin C (mg/100g)	16.78±2.11
β-Carotene (µg/100g)	502.50±15.50
Tannins (µg/100g	860.00±33.00
Colour	
L	60.73±1.46
a	4.47±0.06
b	21.85±1.85

**Means (±SD) of seven replications; **Sample (MF: SF: SPF 44.3:5.7:50)*

Colour is an important quality factor directly related to the acceptability of food products, and is an important physical property to report for extrudate products. Colour is an important characteristic of extruded foods which can give information about the extent of browning reaction such as millard reaction, degree of coking and pigment degradation (Altan *et al.* 2008).

Degree of lightness or darkness of the samples was represented by "L*" value, redness to greenness by "a*" value and yellowness to blueness by "b*" value on hunter scale. The colour analysis of extrudates indicated L*, a* and b* values as 60.73 ± 1.46, 4.47 ± 0.06 and 21.85 ± 1.85 respectively.

Functional properties of extruded snacks

Extrusion cooking is a high-temperature, short-time (HTST) technology that has become a popular process for preparing snack foods and ready-to-eat breakfast cereals, using starch-based raw materials (Colonna *et al.* 1989). Being superior to conventional cooking, extrusion cooking not only improves digestibility of food (Singh *et al.* 2010) but also bioavailability of nutrients (Gu *et al.* 2008), thus providing health benefits of the ingredients incorporated and decreasing the anti-nutritional factors (Alonso *et al.* 2000).

The extruded snacks had higher protein digestibility as shown in Table 8. The benefits of extrusion include increased protein and starch digestibility in protein-enriched cereal snack products, therefore the high digestibility of developed snacks was due to extrusion processing. *In vitro* protein digestibility is an important criterion for evaluation of protein quality as well as an indicator for protein availability in foods (Chinma *et al.* 2011).

Cereals and tuber starches undergo several physico-chemical changes during extrusion cooking (Mercier and Feillet, 1975). In cereal-based products, the degree of starch processing is all important for major quality aspects such as taste, digestibility, texture and appearance. Their functional properties such as bulk

Table 8: Functional properties of extruded snacks

Sample	% Protein Solubility	% Protein Digestibility	Water Absorption Index	Water Solubility Index %	Bulk Density (g/ml)	Expansion Ratio
Snacks	0.43±0.00	95.17±0.07	4.91±0.01	29.14±0.27	0.06±0.01	4.16±0.06

**Means (±SD) of seven replications; **Sample (MF: SF: SPF 44.3:5.7:50).*

Table 9: Effect of packaging materials and duration of storage on the shelf life of extruded snacks

Duration of storage (days)	Packaging material	Moisture (%)	Water activity	Free Fatty Acids (%)	Peroxide Value (meq/kg)	Hardness (g)
0	Al laminate	3.82±0.07^{a}	0.25±0.01^{b}	0.09±0.04^{a}	0.60±0.00^{b}	3683.70±1001.10^{b}
	HDPE	3.82±0.07^{a}	0.25±0.01^{b}	0.09±0.04^{a}	0.60±0.00^{a}	3683.70±1001.10^{a}
30	Al laminate	3.62±0.03^{a}	0.17±0.01^{c}	0.06±0.01^{a}	0.31±0.01^{c}	6287.80±107.80^{a}
	HDPE	4.12±0.02^{a}	0.21±0.00^{c}	0.07±0.02^{a}	0.30±0.00^{b}	5022.00±78.30^{a}
60	Al laminate	1.12±0.62^{c}	0.29±0.01^{a}	0.05±0.01^{a}	0.70±0.00^{a}	3954.80±671.55^{b}
	HDPE	2.12±0.08^{c}	0.32±0.01^{a}	0.05±0.00^{a}	0.30±0.01^{b}	4197.40±361.70^{a}
90	Al laminate	2.07±0.02^{b}	0.30±0.01^{a}	0.05±0.00^{a}	0.60±0.00^{b}	3246.30±183.92^{b}
	HDPE	2.65±0.25^{b}	0.32±0.01^{a}	0.05±0.00^{a}	0.10±0.02^{c}	4202.45±256.85^{a}

**Means (±SD) of seven replications; **Means followed by the same letter within a column do not differ significantly (P≤0.05); ***Sample (MF: SF: SPF 44.3:5.7:50).*

density and expansion ratio were within the range as predicted during optimization of the extrudates processing. Bulk density of extrudates is important parameter in the production of expanded food products and also in relation to their ability to float or sink when poured into water and their packaging requirement.

Protein solubility was found to be 0.43 per cent in extruded snacks. Extrusion processing of sorghum flour improves sorghum protein solubility and functionality (Llopart *et al.* 2014).

Shelf-Life study of extruded snacks

Effect of packaging materials and duration of storage on the shelf-life of extruded snacks

The extruded snacks were packaged into two different packaging materials (aluminium laminate and high-density polyethylene) and stored under ambient conditions (27 ± 4°C, R_H 65 ± 5 per cent) away from sunlight for 90 days (Plates 3 and 4). Packed samples were tested for moisture, water activity, free fatty acids, and peroxide value and hardness (Table 9). Moisture content of flour is very important for its shelf-life, lower the flour moisture, the better its storage stability. An increase in moisture content might have affected the puffing of the extruded snack (Lee *et al.* 2000). The mold spoilage in the food is controlled by water activity. The foods with high water content undergo rapid deterioration due to biological and chemical changes (Abdullaha *et al.* 2000). In most of the hazard analysis and critical control points (HACCP) programs, water activity is used as a critical control point (CCP). Development of rancidity during storage is measured in terms of peroxide value. Texture is an important factor of comparing the cookies as it greatly affects consumer acceptance of the product (Eisa, 2006), the gluten free cookies when consumed should give a cookie eating feeling to consumer than only the product will be acceptable.

There was a decrease of moisture content for the snacks stored in aluminium laminates (Al) bags and an increase in moisture for the snacks stored in high density polyethylene (HDPE) bags after 30 days of storage though the difference was not significant at P≤0.05. There was a decrease of moisture contents for the snacks in both packaging materials but the

Plate 3: Optimized extruded snacks from combinations of sorghum, maize and sweet potato flours in high density polyethylene (HDPE) packaging material

Plate 4: Optimized extruded snack from combinations of sorghum, maize and sweet potato flours in aluminium laminates packaging material

difference was not significant at P≤0.05. There was significant difference in moisture contents for the snacks in both packaging materials between 30 days interval of storage period at P≤0.05.

There was a decrease of water activity for the snacks stored in both packaging materials after 30 days of storage though the difference was not significant at P≤0.05. Water activity increased after 60 days and remained slightly constant after 90 days for snacks in both packaging materials. There was significant difference in water activity for the snacks in both packaging materials between 30 days interval of storage period at P≤0.05.

There was a decrease of free fatty acids (FFA) in the extruded snacks after 30-90 days, but it remained constant after 60-90 days. Though there was a decrease in FFA in snacks in both packaging materials but the difference was significant at P≤0.05.

Peroxide value was decreased after 30 days of storage in snacks in both packaging materials and increased after 60 days for the snacks packed in aluminium laminate and remained constant for the snacks in HDPE. There was a decrease of peroxide value for snacks in both packaging materials after 90 days of storage. There was significant difference in peroxide values for snacks in both packaging materials between 30 days interval of storage period at P≤0.05 but there was non-significant difference for snacks in aluminium laminate between 0 day and after 90 days. Hardness decreased after 90 days of storage in snacks in both packaging materials, though remained slightly constant for the snacks packed in HDPE after 60 and 90 days. There was significant difference in hardness for the snacks in aluminium laminates between 30 days interval of storage period at P≤0.05 and there was no significant difference for snacks packed in HDPE between day 0 and after 90 days.

Effect of packaging materials and duration of storage on the sensory evaluation of extruded snacks

The extruded snacks were packaged into two different packaging materials (aluminium laminate and high-density polyethylene) and stored under ambient conditions (27 ± 4°C, R_H 65 ± 5per cent) away from sunlight for 90 days. Packed samples were evaluated for sensory attributes (Table 10).

Snack foods are less perishable, more durable and more appealing than natural foods. The acceptance of snacks is critical because of the specific quality attributes that attract people. The various sensory qualities attributes of snack foods are appearance, texture, taste, colour and flavour. Among them, texture is one of the most important one and it is particularly true for snack foods (Bourne, 2002).

There was non-significant difference for the snacks packed in both packaging materials for their

Table 10: Effect of packaging materials and duration of storage on the sensory evaluation of extruded snacks

Duration of storage (days)	Packaging Material	Appearance / Colour	Crispness	Mouth feel	Flavour	Overall Acceptability
0	Al laminate	7.58±0.73^{a}	8.13±0.98^{a}	8.17±1.17^{a}	7.58±1.29^{a}	7.69±1.15^{a}
	HDPE	7.58±0.73^{a}	8.13±0.98^{a}	8.17±1.17^{a}	7.58±1.29^{a}	7.69±1.15^{a}
30	Al laminate	6.70±1.25^{a}	7.70±0.71^{a}	7.45±0.98^{a}	6.55±1.30^{a}	6.79±1.33^{a}
	HDPE	6.60±1.26^{a}	7.65±0.78^{a}	7.20±0.82^{a}	6.45±1.38^{a}	6.65±1.43^{a}
60	Al laminate	7.25±1.06^{a}	7.90±1.07^{a}	7.90±0.74^{a}	7.30±0.98^{a}	7.55±0.75^{a}
	HDPE	7.25±1.06^{a}	8.15±1.00^{a}	7.55±0.90^{a}	7.10±1.02^{a}	7.45±0.81^{a}
90	Al laminate	7.40±0.81^{a}	7.75±0.72^{a}	7.30±0.71^{a}	6.90±0.74^{a}	7.51±0.55^{a}
	HDPE	7.20±0.82^{a}	8.13±0.98^{a}	7.25±0.82^{a}	7.05±0.69^{a}	7.54±0.57^{a}

**Means followed by the same letter within a column do not differ significantly (P≤0.05); **Sample (MF: SF: SPF 44.3:5.7:50); *Means (±SD) of ten replications.*

appearance, crispness, mouth feel, flavour and overall acceptability attributes at $P \leq 0.05$ after 90 days. The snacks stored in aluminum laminates had higher overall acceptability than snacks in HDPE after 30 and 60 days while snacks in HDPE were more acceptable after 90 days of storage. Stored snacks were acceptable up to 90 days under ambient conditions (27 ± 4°C, R_H 65 ± 5 per cent).

CONCLUSION

Sweet potato flour had higher amount of carbohydrates, lower fat and was rich in potassium and vitamin C than maize and sorghum flours. Sorghum flour was found to be rich in protein and minerals such as magnesium but had higher content of tannins. Maize flour contained higher beta carotene than sorghum and sweet potato flours. Formulation for ready-to-eat extrudates was optimized using sweet potato flour (SPF) and sorghum flour (SF) along with maize flours. The optimized formulation was 50.0 g SPF, 5.71 g SF per 100 g blend along with maize flour and 12.0 % feed moisture (FM) at 91.10% desirability. FM was the most significant independent variable that significantly ($p \leq 0.01$) affected the expansion ratio, bulk density, hardness and overall acceptability of the RTE extrudates.

The developed extruded snacks had 3.82 ± 0.07 per cent moisture content and had 5.39 ± 0.17 per cent protein, 0.72 ± 0.16 per cent fat, 3.88 ± 0.05 per cent total ash content, 2.05 ± 0.05 per cent crude fibre and 86.19±0.44 per cent carbohydrates on dry basis. The extrudates had high amount of potassium and sodium minerals and low amount of copper and zinc minerals.The extrudates also had 502.50 ± 15.50 μg/100g β-carotene and 16.78 ± 2.11 mg/100g of vitamin C. The extruded snacks packed in aluminium laminates were more acceptable than extruded snacks packed in HDPE after 90 days of storage under ambient conditions (27 ± 4°C, R_H 65 ± 5 per cent). Extrudates had high protein digestibility and shelf life of 90 days under ambient conditions. The RTE extrudates prepared using lesser utilized crops of Indian subcontinent such as sweet potato and sorghum would help in value addition of these crops as well as create a healthy alternative to the existing snack foods.

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