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Optimization of extrusion process parameters for the development of foxtail millet based extruded snacks

Extrusion cooking is a versatile food processing technique classified as a high temperature-short time process to produce fiber rich product. The twin screw extrusion of raw materials to produce corn snacks and ready-to-eat cereals has increased significantly owing to favorable economics and product quality. Extrusion technology is very useful from standpoint of nutritional value as nutrient losses are lower than other thermal processing methods.

Foxtail millet (*Sateria italica* (L.) P. Beauv.) can be easily incorporated with major cereals like wheat and rice and most of the pulse based recipe *viz.,* snacks, fermented foods, ready to eat foods, varieties of sweets and health beverages/foods. Rice bran, a by-product obtained from outer rice layers, is a good source of vitamin B-complex, dietary fibre and high antioxidant activity and it can also be used in extrusion cooking to produce nutritional extruded product (Liu *et al.,* 2011). Chickpea is known for its nutritional and health-promoting properties, since it is an excellent source of protein, fibre, carbohydrates, and for its role in decreasing the risk of certain cancers, managing obesity, lowering cholesterol and type-2 diabetes (Jukanti *et al.,* 2012). Keeping the parameters and benefits in terms of functional and nutraceutical to the consumers, the product with a suitable combination of foxtail millet, broken rice, chickpea and rice bran was selected to prepare extruded product with the objective to optimize the process parameters for development of foxtail millet based extruded product prepared under different extrusion conditions.

The foxtail millet (Variety RS-118) was obtained from Haveri (Karnataka, India), broken rice and chickpea were procured from local market in Raichur (Karnataka, India). Rice bran of fresh unparboiled sona masoori rice (Variety BPT 5204) was obtained from Laxmi Venkateshwara industry, Raichur, (Karnataka, India) and chickpea was procured from local shop Shekhar Paradise, Raichur (Karnataka, India). The composition of raw material was chosen according to preliminary trial tests without jamming of extruder and for acceptable physical, textural and sensory characteristics as well as better nutritive value in the final extruded product. The composition (g/100 g) of raw flour used in this study was foxtail millet (45 g/100 g), broken rice (45 g/100 g), chickpea (5 g/100 g) and rice bran (5 g/100 g).

Extrusion experiment (Plate 1) was performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd. Kolkata, India) with L: D ratio of 8:1. The gravity feeder was attached with extruded and feed rate was kept 4 kg/h. The die of 3 mm and speed of cutter was fixed 150 rpm. During extrusion process barrel temperature and screw speed varied according to experimental design. Mass flow rate and screw torque was recorded during process.

A Box-behnken RSM design was used to optimize process variables. A three factor experimental set up was used with barrel temperature (X_1 *i.e.,* 100, 110 and 120°C), screw speed (X_2 *i.e.,* 12.5, 15.0 and 17.5 %) and moisture levels (X_3 *i.e.,* 300, 350 and 400 rpm) as the independent factors at three levels each (Omohimi *et al.,* 2013).

The expansion ratio, bulk density (g/cm^3) of extruded product, mass flow rate (g/s), water absorption index (WAI), water soluble index (WSI), specific mass energy (SME) and hardness (Texture analyzer, TA.XT Plus/TA.HD Plus) were measured with the following equations.

$$\text{Expansion ratio} = \frac{\text{Diameter of exrudate (mm)}}{\text{Die diameter (mm)}}$$

$$\text{Bulk density} = \frac{4m}{\eth d\ L}$$

$$\text{Mass flow rate (g/s)} = \frac{\text{Weight (g)}}{\text{Time (s)}}$$

$$\text{WAI (\%)} = \frac{\text{Weight of dry solid in supernatant (g)}}{\text{Dry weight of extruded (g)}} \times 100$$

$$\text{WSI (g/g)} = \frac{\text{Weight gain by gel (g)}}{\text{Dry weight of extruded (g)}}$$

$$\text{SME (kJ/kg)} = \frac{\text{Screw speed (rpm)} \times \text{Torque (Nm)}}{\text{Die diameter (mm)} \times \text{Mass flow rate (kg/h)}}$$

Proximate compositions of crude protein (950.36), crude fat (922.06), ash (923.03) and total dietary fiber (962.09E) were determined (AOAC, 2005). The nitrogen conversion factor 6.25 was used for crude protein calculation. Total phenol content was determined using the Folin–Ciocalteau Reagent (FCR)

Plate 1. Twin screw extruder used for preparation of nutri-rich extruded product

Table 1. Physical properties and proximate composition of foxtail millet based extruded product

Temperature (°C)	Feed moisture (%)	Screw speed (rpm)	ER	BD (g/cc)	MFR (g/s)	WAI (g)	WSI (g/g)	SME (kJ/kg)	Hardness (g)	Protein (%)	Carbohydrate (%)	Ash (%)	Phenolic compound (mg/100g)	Dietary Fibre (%)	Fat (%)
100	12.5	300	2.54	0.22	3.25	2.52	0.11	35.17	689.99	7.71	70.67	1.03	2.45	8.13	2.55
100	15.0	350	2.71	0.21	3.80	2.60	0.13	34.21	659.87	7.61	70.41	1.07	2.44	8.13	2.53
100	15.0	400	2.87	0.20	3.54	2.64	0.12	33.03	643.66	7.58	70.36	1.10	2.43	7.91	2.52
100	15.0	350	3.01	0.20	3.73	2.67	0.14	32.26	634.16	7.50	70.34	1.13	2.43	7.97	2.49
110	12.5	300	3.05	0.18	3.32	2.68	0.13	31.86	619.78	7.48	70.32	1.17	2.42	8.06	2.46
110	17.5	300	3.07	0.17	3.78	2.68	0.13	31.32	596.67	7.38	70.01	1.20	2.42	7.93	2.44
110	15.0	350	3.16	0.16	3.58	2.68	0.13	30.88	588.34	7.28	70.01	1.23	2.41	7.93	2.42
110	15.0	350	3.18	0.16	3.58	2.69	0.13	30.82	587.91	7.27	70.01	1.23	2.41	7.93	2.42
110	15.0	350	3.18	0.16	3.58	2.69	0.13	30.82	587.81	7.27	69.93	1.23	2.40	7.93	2.42
110	15.0	350	3.18	0.16	3.58	2.69	0.13	30.82	587.80	7.27	69.89	1.23	2.37	7.93	2.42
110	15.0	350	3.18	0.16	3.57	2.69	0.13	30.82	587.61	7.27	69.89	1.23	2.33	7.93	2.42
110	15.0	350	3.18	0.16	3.58	2.70	0.13	30.81	587.51	7.27	69.72	1.23	2.32	7.93	2.42
110	12.5	400	3.19	0.15	3.41	2.70	0.13	30.74	568.43	7.27	69.56	1.27	2.26	7.74	2.41
110	17.5	400	3.24	0.14	3.59	2.72	0.13	30.68	550.26	7.12	69.53	1.30	2.21	7.73	2.40
120	12.5	350	3.33	0.14	3.61	2.75	0.14	30.54	533.39	7.01	69.24	1.33	2.20	7.60	2.39
120	15.0	300	3.37	0.13	3.45	2.75	0.14	30.44	533.13	6.83	69.02	1.37	2.15	7.69	2.38
120	15.0	350	3.47	0.12	3.66	2.77	0.14	29.90	521.79	6.39	68.95	1.40	2.10	7.51	2.37
120	15.0	400	3.52	0.12	3.87	2.82	0.15	29.54	509.93	6.38	68.93	1.43	1.97	7.44	2.36
		Average	3.14	0.16	3.58	2.69	0.13	31.37	588.17	7.22	69.82	1.23	2.32	7.86	2.43

ER- Expansion ratio, BD- Bulk density, MFR- Mass flow rate, WAI- Water absorption index, WSI- Water solubility index, WHC- Water holding capacity, SME- Specific mechanical energy

assay. The sensory properties of extruded product were rated on a nine-point Hedonic scale by sensory panel consisting of 15 members. Design expert 7.7.0 was used for numerical and graphical optimization process (Yagci and Gogus, 2008).

The physical properties of extruded product *viz.,* expansion ratio (2.54 to 3.52), bulk density (0.12 to 0.22), mass flow rate (3.25 to 3.87), WAI (2.59 to 2.82), WSI (0.12 to 0.15), SME (29.54 to 35.17) and hardness (509.93 to 689.99) are given in Table 1.

The higher temperature results in the larger extent of starch gelatinization, whereas the increased moisture content in feed increases the mass flow rate and reducing viscosity (Deshpande and Poshadri, 2011). The increase in temperature leads to depolymerization of amylase and amylopectin and resulted into the water absorption capacity of the product.

The proximate composition of developed foxtail millet based extruded product *viz.,* protein (6.38 to 7.71), carbohydrate (60.83 to 70.67), ash (1.03 to 1.43), phenolic compound (1.97 to 2.45), dietary fibre (8.13 to 7.44) and fat (2.36 to 2.55) are given in Table 1.

The higher the residence time (low screw speed), the more thermal energy absorbed by the feed which will cause a subsequent decrease of protein content, carbohydrate, dietary fiber and fat content. Higher extrusion temperature might have increased ash content. Ash content increased due to increase in moisture content and screw speed. The quality parameters judged by the consumer panel are given in Table 2.

The extruded product prepared at 120°C temperature, 15 per cent feed moisture and 400 screw rpm was accepted by sensory panel with maximum score of colour (7.73), flavor (7.82), taste (7.45), hardness (7.69), stickiness (7.85) and overall acceptability (7.82) (Table 2).

The uncoded optimum operating conditions for development of foxtail millet based extrudate were 118.23°C of barrel temperature, 400 rpm of screw speed, and 15.88 per cent of feed moisture. The responses predicted by the Design-Expert 7.7.0 software for these optimum process conditions resulted as follows with desirability 0.689.

The physical properties and proximate composition was significantly affected by barrel temperature and moisture level and to a lesser extent by screw speed. However, the optimization results based on desirability concept indicated that a barrel temperature of 118.23°C and 400 rpm of screw speed and 15.88 per cent of feed moisture would produce extrudates with preferable physical textural and sensory properties. The physical properties shows that the higher value of expansion ratio (3.52), mass flow rate (3.87 g/s), water absorption index (2.82 g/g), water solubility index (0.15 g/g), and overall acceptability (7.82) was found at the 120°C,

Table 2. Sensory evaluation of foxtail millet based extruded product

Temperature (°C)	Feed moisture (%)	Screw speed (rpm)	Sensory attributes					Overall acceptability
			Colour	Flavour	Taste	Hardness	Stickiness	
100	12.5	300	6.36	4.82	5.27	5.55	5.73	6.23
100	15.0	350	6.55	5.55	5.55	5.64	5.91	6.45
100	15.0	400	6.64	5.55	6.00	6.18	6.18	6.55
100	15.0	350	6.64	5.73	6.18	6.18	6.27	6.55
110	12.5	300	6.73	6.09	6.27	6.27	6.36	6.55
110	17.5	300	6.73	6.18	6.36	6.45	6.45	6.82
110	15.0	350	7.18	6.18	6.82	6.55	6.64	6.91
110	15.0	350	7.27	6.27	6.91	6.64	6.64	7.00
110	15.0	350	7.27	6.45	6.91	6.64	6.82	7.09
110	15.0	350	7.27	6.45	7.09	6.82	6.82	7.27
110	15.0	350	7.36	6.45	7.09	6.82	7.09	7.36
110	15.0	350	7.45	6.45	7.18	6.82	7.09	7.36
110	12.5	400	7.55	6.55	7.18	6.91	7.09	7.36
110	17.5	400	7.64	6.64	7.36	7.09	7.09	7.45
120	12.5	350	7.64	6.73	7.45	7.27	7.18	7.49
120	15.0	300	7.64	6.91	7.45	7.27	7.36	7.64
120	15.0	350	7.73	7.09	7.45	7.36	7.45	7.65
120	15.0	400	7.73	7.82	7.45	7.69	7.85	7.82
	S.Em.±		0.14	0.14	0.14	0.14	0.14	0.14
	C.D. (1%)		0.57	0.57	0.57	0.57	0.57	0.57

15 per cent moisture content and 400 screw rpm and the minimum values for bulk density (0.12 g/cc), specific mechanical energy (29.54), hardness (530.54) was recorded for optimised process parameters. The product developed with optimized parameter contains 7.50 per cent protein, 69.75 per cent carbohydrates, 3.39 per cent fat, dietary fibre 7.51 per cent, phenolic compound 2.19 per cent and ash content 1.37 per cent.

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