Effect of feed composition, moisture content and extrusion temperature on extrudate characteristics of yam-corn-rice based snack food

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Abstract Blends of yam, rice and corn flour were processed in a twin-screw extruder. Effects of yam flour (10–40 %), feed moisture content (12–24 %) and extruder barrel temperature (100–140 °C) on the characteristics of the dried extrudates was investigated using a statistical technique response surface methodology (RSM). Radial expansion ratio differed significantly ($p \leq 0.05$) with change in all the independent variables. Highest expansion (3.97) was found at lowest moisture content (12 %) and highest barrel temperature (140 °C). Increased yam flour level decreased the expansion ratio significantly. Water absorption index (WAI) increased significantly with increase of all variables. However, water solubility index (WSI) did not change with change in yam flour percent. Hardness of extrudates that varied from 3.86 to 6.94 N was positively correlated with yam flour level and feed moisture content, however it decreased significantly ($p \leq 0.001$) with increase of barrel temperature. Yam percent of 15.75 with feed moisture and barrel temperature at 12.00 % and 140 °C respectively gave an optimized product of high desirability (> 0.90) with optimum responses of 3.29 expansion ratio, 5.64 g/g dry solid water absorption index, 30.39 % water solubility index and 3.86 N hardness. The predicted values registered non-significant ($p < 0.10$) differences from the experimental results. Further study would include the sensory properties enhancement of extruded snacks and little emphasis on the chemistry of interaction between different components.

Keywords Yam · Extruded snack · Box-Behnken design · RSM · WSI · WAI

Introduction

Yam (*Dioscorea* species of family *Dioscoreaceae*) is a multi-species tuber crop cultivated in Africa, Asia, parts of South America, as well as the Caribbean and the South Pacific islands (Asiedu and Sartie 2010). Yams are excellent source of dietary energy for most people in the developing countries (Krishnan et al. 2010). They are rich in minerals like phosphorous, potassium, manganese and vitamins (Moorthy 1994). Yam tubers are consumed like the way potatoes are consumed. They are steamed, boiled or baked and consumed (Wanasundera and Ravidran 1992). In West and Central Africa, yams are processed into dry yam tubers/slices and flour (Otegbayo et al. 2006; Sobukola et al. 2010). The main application claimed for yam flour has been in bread products and snacks (Sebio and Chang 2000). Some species of yam are also exploited for pharmaceutical use (Asiedu and Sartie 2010).

Study on yam flour making with standardized methods of drying like sun drying (Oyelade et al. 2008), hot air oven drying (Alves et al. 2002), cabinet and foam mat drying (Falade and Onyeoziri 2012) have been carried out extensively, which is utilized for making extruded snacks. One potential problem in processed flour is the discoloration and the darkening of the product, which may be undesirable to many people (Onayemi 1986; Sobukola et al. 2008). This has been attributed to browning reactions as a result of the presence of water-soluble phenolic substances (Mathew and Parpia 1971).

Cereal and snack food industries have successfully adopted extrusion technology which is considered as one of the most economic process (Harper and Clark 1979). Extruded foods are composed mainly of cereals, starches, and/or vegetable proteins. The major functions of these ingredients are to give

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texture, structure, mouth feel, bulk, and many other characteristics desired for specific finished products (Launay and Lisch 1983). These characteristics are quantified by functional properties like bulk density, expansion index, water absorption and solubility indices and viscosity of the product (Singh et al. 2007; Oikonomou and Krokida 2011). The effects of extrusion conditions and feed compositions on functional properties of various cereal and pulse based products have been studied extensively (Balasubramanian et al. 2012; Seth and Rajamanickam 2012). Several studies found that increasing feed moisture content increases the bulk density, water solubility index, water absorption index and hardness and decreases the expansion ratio (Chiu et al. 2012; Kirjoranta et al. 2012; Oke et al. 2012). Higher barrel temperature increases the expansion and reduces the hardness of the extrudates (Sebio and Chang 2000). High fiber ingredient is associated with low expansion of extrudates (Pai et al. 2009).

Though cereal ingredients are mainly used in extrusion processes from the inception of the technology, the use of tubers in product formulation was seen at a later stage (Sebio and Chang 2000; Hashimoto and Grossmann 2003; Chiu et al. 2012). The tubers contribute more fiber to the extruded products with added health benefits. Sebio and Chang (2000) used yam species *Dioscorea rotundata* to develop extruded food product. Since, single ingredient was used in the study, extrudates gave hard texture with little expansion, attributed to the high fiber content of the tuber. This problem was rectified by Chiu et al. (2012) using cereal ingredients in conjunction with yam (*Dioscorea alata* L.) flour to make a good textured product. However, there is a dearth of information on the effect of barrel temperature on the extrudate quality which uses *D. alata* species along with the cereal ingredients. *D. alata* is characterized by higher dry matter, starch and amylase content, high amylose/amylopectin ratio. Amylose/amylopectin ratio has been reported to impart definite characteristics and functionality to starches by determining the basic texture and nature of their products (Moorthy 1994; Scott 1996). There are established researches on rice and corn based extrudates with good textural and sensory attributes (Jin et al. 1995; Hanwu et al. 2005). Hence, rice and corn flours were taken with yam for feed formulation and see the effects of feed composition, moisture content, and extruder barrel temperature on the product qualities.

Materials and methods

Raw materials Wholesome, mature, dormant tubers of water yam (*Dioscorea alata* L.) were obtained from a local market of Coimbatore, India and used for this investigation. De-husked polished rice and edible corn grits were purchased locally.

Preparation of flours and blending Yam tubers (*D. alata*) were washed and steam blanched at 90 °C for 20 min for easy peeling of the outer thick skin thereafter. Peeled yam tubers were cut into slices (2 cm thick) and mashed to paste before drying to moisture content of less than 5 % (w.b.). Dried yam flakes were ground to powder in a Hammer mill (Alfa Instruments, Delhi, India) and sieved through a 40 mesh screen to obtain yam flour. Rice and corn grits were cleaned and dried before milling in Hammer mill. The analysis of chemical compositions like crude protein, crude fat, crude fiber, ash and moisture content of dried yam flour, rice and corn flours were carried out by standard methods (AOAC 2000). The percents of carbohydrates were found by deduction method. The blends of feed ingredients were obtained according to the experimental design at three level combinations. The ratios of yam, rice and corn flours were 10:40:40, 25:37.5:37.5 and 40:30:30. All the flours were mixed in a Laboratory mixer (Neoplast Engineering Pvt. Ltd., India). The blend moisture content was determined by standard method (AOAC 2000). Before being processed, the blend was rehydrated to each required moisture content level (Table 1) by calculated amount of water sprayed on to the feed. The blend was then kept in sealed polyethylene bags for 24 h for uniform distribution of moisture.

Extrusion cooking process The prepared homogenous blend of yam, rice and corn flours were extruded in a co-rotating twin screw extruder (M/s Basic Technology Pvt. Ltd. Kolkata, India). Experiments were performed at a screw speed of 300 rpm and feed screw speed of 175 rpm. The barrel temperature was varied according to the experimental design at three levels viz. 100, 120 and 140 °C. The configurations of extruder are same as discussed by Seth and Rajamanickam (2012).

Response surface analysis Response surface methodology (RSM) is a multivariate equation solving technique, which uses experimental data to fit mathematically in a theoretical design through a response function (Santelli et al. 2006). This technique is applied to describe the individual and interactive effects of the independent variables on the response. The RSM helps in optimizing a set of operational variables of the process (Myers and Montgomery 2002). The RSM approach has widely been applied in extruded food product development (Yagci and Gogus 2009; Oke et al. 2012; Seth and Rajamanickam 2012). Among the factorial design Central Composite Design (CCD) and Box-Behnken Design (BBD) are the most common designs adopted in food product development to estimate response surface and subsequent optimization of the process variables. They help to reduce the number of trials and thus the time and cost of research with more realistic output. BBD is a spherical, revolving design, consists of middle points of the edges of the circle, circumscribed on the sphere. BBD gives the matrix of relatively few trials for determining the complex response function and the trials with variable combinations of

Table 1 Box-behnken experimental design with process variables (both coded and uncoded) and experimental results of yam-cereal based extruded snack

Trial no.	Yam flour (%)		Moisture content (% wb)		Barrel temperature (°C)		Expansion ratio (ER)	Water absorption index (WAI) (g/g dry matter)	Water solubility index (WSI) (%)	Hardness (N)
	Coded	Uncoded	Coded	Uncoded	Coded	Uncoded				
1	1	40	1	24	0	120	1.99	6.16	25.19	5.74
2	1	40	0	18	1	140	2.47	6.34	24.98	5.16
3	1	40	0	18	−1	100	2.11	6.05	22.17	5.97
4	1	40	−1	12	0	120	2.54	5.96	25.52	5.61
5	0	25	1	24	1	140	2.92	5.82	23.16	5.09
6	0	25	−1	12	−1	100	2.59	5.37	18.13	6.94
7	0	25	1	24	−1	100	2.47	5.69	24.83	6.75
8	0	25	−1	12	1	140	3.97	5.78	30.39	4.64
9	−1	10	1	24	0	120	2.10	5.36	25.14	5.81
10	−1	10	0	18	1	140	2.99	5.67	24.76	3.86
11	−1	10	−1	12	0	120	2.60	5.23	26.35	4.32
12	−1	10	0	18	−1	100	1.99	5.39	21.25	5.87
13	0	25	0	18	0	120	2.27	5.65	23.17	5.68
14	0	25	0	18	0	120	2.14	5.53	22.97	5.30
15	0	25	0	18	0	120	2.39	5.49	24.03	5.61
16	0	25	0	18	0	120	2.16	5.51	22.96	5.52
17	0	25	0	18	0	120	2.25	5.58	23.74	5.66

The values are Mean of three replicates

highest or lowest levels simultaneously are avoided. So, it is useful in avoiding experiments performed under extreme conditions, for which unsatisfactory results might occur (Ferreira et al. 2007). The number of experimental runs required in BBD is $N = 2K(K-1) + C_0$, where K is the number of variables and C_0 is the number of central points. Thus, for a three factorial design, a total of 17 experimental runs with 5 central points were performed in this study. The levels of each independent variable were fixed according to preliminary trials and related literature data. The coded (± 1 and 0) and natural value of the independent variables with design matrix is given in Table 1. A second order polynomial model was employed for three factor design which is given as

$$Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{j=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=1}^3 \beta_{ij} X_i X_j + \varepsilon$$

where Y is the predicted response, β_0 the constant coefficient, β_i the linear coefficient, represent, β_{ii} the quadratic coefficients, β_{ij} the interaction coefficients and X_i , X_j the coded values of the process variables and ε the residual error (Diamante et al. 2012). In the current study β_1 , β_2 and β_3 are the coefficients of yam flour level, feed moisture content and barrel temperature respectively. The responses studied were expansion ratio (ER), water absorption index (WAI), water solubility index (WSI) and hardness. The goodness of the fit and the significance of linear, quadratic and interaction effects of each factor on the responses were examined by performing analysis of variance (ANOVA) (Table 3). The estimated regression coefficients of the coded values are presented in Table 4. The generation of response surface plots and statistical analysis was carried out using statistical software Design-expert, version-6 (Stat-ease Inc, Minneapolis,

Table 2 Proximate compositions of yam, rice and corn flours (percent on dry basis)

	Moisture (%)	Carbohydrate (%)	Crude protein (%)	Crude fat (%)	Crude Fiber (%)	Ash (%)
Yam flour	4.85±0.12	78.04±0.28	12.14±0.13	0.34±0.07	1.52±0.94	4.08±0.08
Rice flour	12.29±0.15	79.42±0.26	5.96±0.08	0.45±0.03	0.21±0.02	0.06±0.02
Corn flour	11.29±0.06	79.57±0.14	11.18±0.09	1.50±0.09	4.65±0.11	0.91±0.00

Values are mean of three replicates with standard deviations

Table 3 Analysis of variance showing the linear, quadratic, interaction and lack of fit of the response variables

Source of variation	df	Response variables							
		Expansion ratio (ER)		Water absorption index (WAI) (g/g dry solids)		Water solubility index (WSI) (%)		Hardness (N)	
		Sequential sum of square	F	Sequential sum of square	F	Sequential sum of square	F	Sequential sum of square	F
Regression	9	3.71	38.02***	1.47	52.78***	98.74	20.17***	8.88	13.99**
Linear	3	1.93	4.50*	1.24	20.71***	36.30	2.37 ^{ns}	7.05	13.11***
Square	3	0.32	0.69 ^{ns}	0.021	0.29	48.83	9.34**	0.92	2.19 ^{ns}
Interaction	3	1.46	44.95***	0.22	23.23***	13.62	8.34*	0.91	4.31 ^{ns}
Residual error	7	0.076		0.022		3.81		0.49	
Lack of fit	3	0.036	1.20 ^{ns}	0.005	0.42 ^{ns}	2.87	4.07 ^{ns}	0.40	5.33 ^{ns}
Pure error	4	0.04		0.016		0.94		0.096	
Corr Total	16	3.79		1.49		102.55		9.38	
R^2		98.00 %		98.55 %		96.29 %		94.73 %	
Adjusted R^2		95.42 %		96.68 %		91.51 %		87.97 %	

* Significant at $P \leq 0.05$ ** Significant at $P \leq 0.01$ *** Significant at $P \leq 0.001$ ^{ns} not significant

USA). The correlation coefficients (R^2) of the generated models of all the response variables were more than 0.90 and the lack of fit were non-significant at 95 % probability level ($p \leq 0.05$).

Extrudate characteristics Expansion ratio (ER) of extrudate was measured laterally with caliper (Mitutoyo Inc, Japan) and expressed as the ratio of cross sectional area of the extrudate to that of the die (Chakraborty et al. 2009). ER was obtained from a mean of 15 random samples. WAI and WSI were obtained from 2.5 g sample according to the method of Anderson (1982). WAI (g/g dry solid) was expressed as the ratio of the weight of the gel after removal of supernatant to the dry weight of the sample. The weight of dry solid in supernatant expressed as a percentage of the original weight of the sample is the WSI. Hardness of samples was measured using Stable Microsystems TA-HD Texture Analyzer (Texture Technologies Corp, Scarsdale, NY, USA) fitted with a 5 kg load cell. The force (N) required for a circular probe of 35 mm diameter to penetrate 20 % into the bar was measured (Chiu et al. 2012).

Results and discussion

The proximate compositions of yam flour, rice and corn grits are presented in Table 2. The reported values are mean of triplicate samples with standard deviations.

Expansion Ratio (ER) It was observed from the regression coefficients (Table 3) that the feed moisture content had a negative linear and positive quadratic effect, whereas the barrel temperature had a positive effect in both linear and quadratic terms ($p \leq 0.001$). Figure 1a shows the effect of moisture content and barrel temperature on the ER of extruded snack. The highest value of ER was at 12 % (wb) moisture content and 140 °C barrel temperature, whereas the lowest value was found at 18 % moisture content and 100 °C barrel temperature. Sun and Muthukumarappan (2002) extruded soy and corn flour and reported that ER increased with increase in feed moisture from 13 to 18 % and then decreased. Similar trend was observed in this study. Oke et al. (2012) studied the effect of moisture content on ER and concluded that decreased moisture content increases the drag force and therefore exerts more pressure at the die resulting in greater expansion of extrudate at the exit. The expansion at higher barrel temperature can be attributed to the starch gelatinization and strengthening of structure (Ali et al. 1996; Ainsworth et al. 2007). Many researchers reciprocated similar findings while developing yam based extruded products (Kpodo and Plahar 1990; Sobukola et al. 2012).

Increasing yam flour level decreased ER significantly ($p \leq 0.01$) in quadratic term. The decrease in ER could be due to the increased percentage of protein and fiber in the feed and their interaction, which form complexes and render the expansion of extrudate at the die (Rampersad et al. 2003). Higher percentages of protein and fiber in corn might have hindered the expansion of extrudates. Figure 1b shows the

Fig. 1 Response surface diagrams illustrating the effects of yam flour, feed moisture and barrel temperature on (a & b) expansion ratio and (c & d) water absorption index of extruded snack

effect of yam flour on ER. Chiu et al. (2012) developed yam based snack and observed similar effect of yam flour level on ER.

Water absorption index (WAI) WAI, an index of starch gelatinization (Anderson 1982; Singh et al. 2007) was in the range of 5.23 to 6.34 g/g dry solid. The coefficient estimates of WAI model (Table 4) showed that all the three variables had significant positive effect in the linear and quadratic terms. The effect of yam flour level on WAI is shown in Fig. 1c, d and it was interpreted that increased yam flour level increases the WAI significantly ($p \leq 0.001$). This could be due to increased availability of fiber in the yam flour which has the higher water absorption capacity. Hashimoto and Grossmann (2003)

observed similar relationships between WAI and fiber while developing cassava bran and cassava starch extrudates. Chiu et al. (2012) found increased effect of yam flour level from 10 to 30 % on WAI; however, the effect was not significant at $p \leq 0.05$. Many researchers (Anderson 1982; Chakraborty et al. 2011; Sobukola et al. 2012) demonstrated strong relationship of barrel temperature on WAI. In the present study, an increase in WAI was observed with increased temperature and moisture content (Fig. 1c, d). At higher temperature, starch granule is disrupted and more water is bound to the starch molecule resulting in increased WAI. Kumar et al. (2010) examined the increased effect of WAI with increased temperature which is in support of our current findings. WAI has been reported to increase with increase in moisture content of feed (Ding et al.

Table 4 Estimated regression coefficients of the fitted second order polynomial for response variables (coded)

Coefficients	Estimated coefficients			
	Expansion ratio (ER)	Water absorption index (WAI)	Water solubility index (WSI)	Hardness
β_0	2.24	5.55	23.37	5.55
β_1	-0.07	0.36***	0.045	0.33*
β_2	-0.28***	0.086**	-0.26	0.24*
β_3	0.40***	0.14***	2.11***	-0.85***
β_{11}	-0.27**	0.16***	0.67	-0.41*
β_{22}	0.33***	0.036	1.51**	0.23
β_{33}	0.41***	0.15***	-0.75	0.073
β_{12}	-0.013	0.017	0.22	-0.34*
β_{13}	-0.16*	0.002	-0.18	0.30
β_{23}	-0.23**	-0.07*	-3.48***	0.16

* Significant at $P \leq 0.05$ ** Significant at $P \leq 0.01$ *** Significant at $P \leq 0.001$

ns not significant

2005; Singh et al. 2007; Chakraborty et al. 2011). Lawton and Handerson (1972) explained that, at higher moisture content, viscosity of starch would be low, allowing the starch molecules to move freely and thereby enhancing the penetration of heat as a result greater gelatinization. However, Sobukola et al. (2012) interpreted that lower moisture content imparts more shearing action in the barrel causing more mechanical damage to starch, thus low WAI.

Water solubility index (WSI) The extrudates exhibited WSI in the range of 18.13 to 30.39 %. Barrel temperature was the single most important factor that affected the WSI significantly ($p \leq 0.001$) (Table 4). This could be due to starch degradation at higher temperature exposure to product inside the barrel and greater shearing action of the blend. According to Anderson et al. (1970), it is the amount of free polysaccharides released from the starch granules after addition of excess water. Sobukola et al. (2012) reported that, increased barrel temperature increases WSI, due to increased solubility of starch molecules. This was also in consistent with the results of Ding et al. (2005). Feed moisture content had a quadratic effect on the WSI ($p \leq 0.01$). From the Fig. 2a, it can be seen that, the WSI decreased with increase in feed moisture from 12 to 18 %. Lower moisture content again could have increased the drag force at the die making the starch to gelatinize. Higher moisture content above 18 % might have helped the polysaccharides to dissolve easily to the food matrix, as a result increased WSI. Ding et al. (2005) discussed the higher lateral expansion is attributed to higher WSI at initial increase of moisture content, but further increase in

moisture content decreased lateral expansion due to plasticization of melt. Regression coefficients (Table 4) show that yam flour level did not have significant effect on WSI, though a slight increase was observed (Fig. 2a). The WSI value is an indication of state of protein in proteinaceous blends. Since, in our blend, the proportion of protein is high, the increase might be due to partial protein denaturation at higher temperature (Oikonomou and Krokida 2011). Kumar et al. (2010) indicated that WSI increases with increase in fibrous content in the feed formulation, which supports our findings (Fig. 2b).

Hardness The effects of process variables on the hardness of yam extrudates are presented in Fig. 2c, d and exhibited that increasing yam flour level and feed moisture content increased the hardness of extrudate, whereas barrel temperature decreased the hardness. Fiber in the yam flour could have imparted structural integrity to the extrudate due to protein-fiber interaction, as a result higher value of hardness (Chiu et al. 2012). The effect of premature gas cell rupture which reduces the expansion due to fiber, was explained by Lue et al. (1991). Further, Jin et al. (1995) interpreted in their findings that, thickness of cell wall and smaller air cell increased breaking strength, thus hardness. Increased moisture content increased hardness significantly at $p \leq 0.05$ (Table 4), which might be due to reduced expansion of the extrudate and lower rate of starch degradation at higher moisture content. Relationship between hardness and moisture content has widely been investigated by researchers (Sebio and Chang 2000; Kumar et al. 2010; Chiu et al. 2012). Variation of hardness with the barrel temperature was prominent ($p \leq 0.001$). Many researchers (Kpodo and Plahar 1990; Sebio and Chang 2000; Kumar et al. 2010) found similar effects of temperature on hardness. The decrease in hardness with increase of temperature might be due to higher expansion at elevated temperatures.

Optimization and model verification The independent variables were optimized numerically using statistical software Design Expert, version- 6.0.11 (Stat-Ease Inc.). The variables were kept in range during optimization. The goals were assigned to each response parameters. The WAI and WSI were kept in range; hardness and ER were at minimum and maximum respectively. From the numerical analysis, it was observed that 15.75 % yam flour, 12.06 % feed moisture and 140 °C barrel temperature gave an optimized product of 0.987 desirability. The corresponding optimized response values found were ER 3.29, WAI 5.64 g/g dry solid, WSI 30.39 % and hardness 3.86 N. Extrusion cooking was carried out using optimum processing conditions with optimized blend and the responses were recorded. The response values mentioned in Table 5 are the mean of five replicates with standard deviation. To check the variability of predicted responses, two-tailed, one sample *t*-test was carried out. The

Fig. 2 Response surface diagrams illustrating the effects of yam flour, feed moisture and extrusion temperature on (a & b) water solubility index and (c–d) hardness of extruded snack

results of the *t*-test demonstrated no significant difference between the values of recorded responses and the predicted

responses. Thus, suitability of the models to predict various responses was ascertained.

Table 5 Results of the *t*-test conducted to compare the predicted and actual experimental response values

	Responses			
	ER	WAI	WSI	Hardness
Predicted value	3.29	5.64	30.39	3.86
Actual value ^a	3.286±0.009	5.584±0.152	30.582±0.7681	4.150±0.59
Standard error	0.005	0.068	0.343	0.266
% variation	0.12	1.00	0.63	6.98
Mean difference	0.004	0.056	0.192	0.29
Significance (two-tailed)	0.477	0.456	0.606	1.090

$H_0: \mu_0 = \mu_1$, $t_{cal} < t_{table}$ at $p < 0.10$, ' H_0 ' was accepted

^a Mean of 5 replications

Conclusion

Designed experiments using Box-Behnken successfully exhibited the effect of independent variables (yam flour level, barrel temperature and feed moisture content) on the response variables (ER, WAI, WSI and Hardness) of extrudates developed from yam-rice-corn flour blend formulation. The developed models found to be statistically valid and demonstrated adequate information regarding the behavior of extrudate characteristics upon variation of process variables. The optimized combinations of independent variables found were yam flour (15.75 %), feed moisture content (12.06 %) and barrel temperature (140 °C). The one sample, 2-tailed *t*-test demonstrated no significant differences between the predicted and original values ($p < 0.10$).

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