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Optimisation of extrusion cooking conditions and characterization of rice (*Oryza sativa*)—Sweet potato (*Ipomoea batatas*) and rice-yam (*Dioscorea alata*) based RTE products

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ABSTRACT

Extrusion cooking has been extensively used to produce variety of foods like ready to eat breakfast cereals, baby foods, snack foods, etc. Taking rice flour as the base ingredient, two locally available tuberous root vegetables, greater yam (*Dioscorea alata*) and sweet potato (*Ipomoea batatas*) were used in this study for the development of ready-to-eat breakfast products in a single screw extruder. During extrusion cooking, the screw speeds ranged from 132 to 468 rpm and the barrel temperatures ranged from 103˚C to 137˚C. The extrudates were then analyzed for various physical and physicochemical properties. Optimization was done following Response Surface Methodology (RSM) using Central Composite Design. Using screw speed, barrel temperature and feed composition as the three independent variables, the three responses taken were bulk density, expansion index and breaking strength. The optimized conditions were used for developing 3 new products one of which also contained tomato pulp powder. The products were analyzed for their physical, proximate, sensory and antioxidant properties. There was significant colour change in all the three samples as indicated by total colour change (∆E). Texture analysis of the extrudate samples showed hardness values ranging from 28.68 N to 47.57 N. Amylose content was found to be 15.3% in rice-sweet potato extrudate, 14.7% in rice-yam extrudate and 18.2% in rice-sweet potato-tomato extrudate. The antioxidant profile of the extrudates studied through DPPH (2,2-diphenyl-picryhydrazyl) scavenging activity and FRAP (ferric reducing antioxidant property) showed that the antioxidant capacity in all the 3 extrudates was very low. Rice flour incorporated with sweet potato was judged the best on sensory evaluation. The study has shown that both sweet potato and greater yam tubers can be commercially exploited for the development of ready-to-eat (RTE) products.

Keywords: Extrusion; RSM; RTE; Physicochemical Properties

1. INTRODUCTION

Consumers want snacks that taste good, smell good, feel good, look good and in addition, are nutritionally superior and healthy. Extrusion cooking is one of the most important food processing technologies which have been used since the mid 1930s for the production of breakfast cereals, ready to eat snacks, and other textured foods. In the past decade, extrusion cooking has been studied extensively to produce variety of specialty foods including pasta products and ready to eat breakfast cereals, baby foods, snack foods, texturised vegetable protein, pet foods, dried soups and dry beverage mixes, as it not only improves digestibility (Singh, Dartois, & Kaur, 2010) but also improves the nutrients bioavailability (Gu, Hous Rooney, & Prior, 2008) compared to conventional cooking. The quality of the product depends on the process conditions, such as the extruder type, the feed moisture, the temperature profile in the barrel sections, the screw speed and the feed rate (Thymi, Krokida, Pappa & Maroulis, 2005).

Owing to the popularity and high nutritive value of vegetables, their utilization has increased either in raw form or processed form. Greater yam (*Dioscorea alata*) and sweet potato (*Ipomoea batatas*) are two species of large underground tuberous root vegetables seasonally available and are gaining importance as processed food sources. Work on extrusion cooking of sweet potato - soybean blend (Iwe *et al.*, 1998) and sweet potato-whole wheat bran (Dansby *et al.*, 2003) has been reported. Oke *et al.* (2012) and Chiu *et al.* (2013) have worked on extrusion cooking of yam (*Dioscorea alata*). However, extrusion cooking of sweet potato and grater yam with rice has not been reported. In this study sweet potato and grater yam powders were blended with rice to obtain a ready to eat breakfast product. The products were analyzed for their physical, physicochemical, nutritional and sensory properties.

2. MATERIALS AND METHODS

2.1. Materials

The tubers of *Dioscorea alata* (greater yam) and *Ipomoea batatas* (sweet potato) and tomatoes (*Solanum lycopersicum*) were obtained from the market place near Tezpur University campus. The chemicals were obtained from Merck, Hi-Media and Rankem, and the glasswares used were from Borosil and Rankem. The extruder machine (G.L. Extrusion System Pvt. Ltd, New Delhi) used in the current study is a single-screw one, driven by 5 H.P. induction motor (DC).

2.2. Sample Preparation for Extrusion

The water yam and sweet potato tubers were washed, peeled and cut into thin slices using Slicer (Alpha Instruments, Delhi) while yam tubers were dipped in 0.5% sodium metabisulphite solution to reduce browning. All samples were dried in a tray drier at 55˚C. The dried chips were subsequently milled into flour in a pulverizer (Alpha Instruments, Delhi) to pass through a 1.00 mm mesh screen. The flour samples were put in sealed pouches and kept in covered plastic containers until used for extrusion processes and analyses. Blends were prepared from sweet potato flour and rice flour in definite ratios for carrying out 18 different runs in the extruder. The moisture contents of the blended samples for extruder feed were adjusted at around 12% by adding calculated amounts of water into each blend and then mixing them properly. The blended mix in different ratios were kept overnight in a tightly covered vessel for moisture equilibration. The extrusion processes were performed on a single screw extruder. Raw materials were fed into the extruder barrel and at the end of extrusion cooking was discharged from the end of the barrel as the extrudates.

2.3. Sample Preparation for Analysis of Extrudates

The samples were ground in a mixer grinder into powder and kept in sealing pouches for their analysis.

2.4. Pasting Properties

Pasting properties of extrudate powders were determined using a Rapid Visco Analyser (RVA) model 2-D (Newport Scientific Instrument) with Thermocline software (3.0 version) by ICC Standard Method No. 162 (1995). Briefly, sample suspension was prepared by placing 3.5 g extrudate powder, in an aluminum canister containing 25 mL distilled water. A programmed heating and cooling cycle was used. Each sample was stirred at 960 rpm for 10 s while heating at 50˚C, and then constant shear rate (160 rpm) was maintained for the rest of the process. Temperature was held at 50˚C for 1 min. Then the samples were heated from 50˚C to 95˚C within 3 min 42 s and held at 95˚C for 2 min 30 s. Subsequently samples were cooled down from 95˚C to 50˚C within 3 min 48 s and then held at 50˚C for 2 min. The RVA plot of viscosity (cP) versus time (s) was used to determine peak viscosity (PV) and final viscosity (FV).

2.5. Expansion Index (EI)

Expansion of extrudates was measured using a vernier caliper (Mitutoyo, Japan) according to the method of Ding *et al.* (2005). Measurements were taken on ten randomly selected pieces of extrudates. The die diameter of the extruder used in the study is 2 mm.

2.6. Bulk Density (BD)

Bulk density (BD) of extrudates was determined following the method of Bhatnagar *et al*. (1995).

2.7. Color

The colour values of the rice extrudates incorporated with sweet potato powder in terms of *L*, *a*, *b* values was measured using colour measurement spectrophotometer (Hunter Lab, Ultra-scan VIS).

2.8. Texture Profile Analysis (TPA)

Texture evaluation of the extrudates was performed with texture analyzer (TA-HD-plus, Stable Micro Systems, UK) with a 5 kg load cell. Hardness (HRD), puncture force (PF) and breaking strength (BS) of extrudates were determined as the maximum force offered by extrudates during compression and three point cutter test, respectively.

Breaking Strength (N/mm^2) = Peak breaking force/Cross sectional area

2.9. Water Absorption Index (WAI) and Water Solubility Index (WSI)

WAI and WSI were determined following the procedure of Anderson *et al*. (1969).

2.10. Determination of Amylose

Amylose content was measured according to Sowbahagya & Bhattacharya (1979).

2.11. Sensory Properties

The extruded products were sensorily evaluated by ten panelists. The samples were provided along with milk (for soaking) and sugar (for taste). Based on a 9-point Hedonic scale (0 - 9), the panel members were asked to give their scores on 6 different attributes, namely, appearance, colour, taste, texture, mouthfeel and overall acceptability.

2.12. Determination of Proximate Content

The moisture, crude fat, crude protein, crude fiber and ash were determined as per AOAC (1999). The total carbohydrate in the samples was calculated by the method of difference on wet basis.

2.13. Determination of DPPH Activity

The radical scavenging activity of the extrudates was measured by determining the inhibition rate of DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical (Brand-Williams, 1995).

2.14. Determination of Ferric Reducing Antioxidant Property (FRAP)

FRAP activity of the samples were measured by the method of Benzie and Strain (1999), after preparing extracts in the same way as for DPPH analysis.

2.15. Statistical Analysis

All the readings are average of minimum two readings. Analyses of all parameters are reported with standard deviation error bar.

3. RESULTS AND DISCUSSION

3.1. Experimental Design and Statistical Analysis

Response Surface Methodology (RSM), which explores the relationship between several explanatory variables and one or more response variables, was applied to the experimental data using the package, Design expert version 7.1.1, (STATE-EASE Inc, Minneapolis, USA. Trial version). The same software was used for generation of response surface plots, superimposition of counter plots and optimization of process variables (Altan *et al*., 2008; Yagci & Gogus, 2008; Ding *et al*., 2005). The results are reported as means of three replicates. A four variable (five level of each variable) central composite design (CCD) was employed (Montgomery, 2001; Yagci & Gogus, 2008). The parameters and their levels were chosen based on literature available on rice based extrudates (Yagci and Gogus, 2008; Ding *et al*., 2005; Upadhyaya, 2008). The ingredients used for the extrudates were: rice flour, sweet potato powder, yam powder and tomato pulp powder. The independent variables included screw speed (SS), barrel temperature (BT) and feed composition (FCM). Response variables were expansion index (EI), bulk density (BD) and breaking strength (BS). The five levels of the process variables were coded as −1.682, −1, 0, 1, 1.682 (Montgomery, 2001) and the design in coded (x) form is given in **Table 1**. A quadratic polynomial equation was fitted to the data to obtain a regression equation. The statistical significance of the terms in the regression equation was examined by analysis of variance (ANOVA) for each response. The extrusion processing parameters were optimized by using a conventional graphical method of RSM in order to obtain extrudates with acceptable properties. All the processing variables were kept within range while the responses were either maximized (for expansion index) or kept less than a specific value (bulk density, breaking strength). The ANOVA results are shown in **Table 2**. The Optimized parameters thus obtained from the above model are shown in **Table 3**.

Finally, the optimized solution that was obtained with the values of predicted responses are shown in **Table 4**. The desirability level was 0.84. The Coefficients of variables in the predictive model for response variables (coded units) are:

$$\begin{aligned}\mathrm{EI} = &+4.79 + 0.16x_1 + 0.44x_2 - 0.032\,x_3 + 0.048\,x_1^2 \\ &+ 0.25x_2^2 + 0.090x_3^2 + 0.19x_1 \cdot x_2 - 0.11\,x_1 \cdot x_3 \\ &- 0.021\,x_2 \cdot x_3\end{aligned} \tag{1}$$

$$\begin{aligned}&\mathrm{BD} \\ &= +0.17 - 7.705 \times 10^{-3} x_1 - 0.026\,x_2 + 9.181 \times 10^{-3} x_3 \\ &\quad - 0.010\,x_1^2 - 0.015\,x_2^2 + 4.405 \times 10^{-3} x_3^2 + 3.150 \\ &\quad \times 10^{-3} x_1 \cdot x_2 - 3.150 \times 10^{-3} x_1 \cdot x_3 + 1.050 \times 10^{-3} x_2 \cdot x_3\end{aligned} \tag{2}$$

$$\begin{aligned}&\mathrm{BS} \\ &= +0.29 - 0.025x_1 - 0.098\,x_2 + 8.446 \times 10^{-3} x_3 - 7.975 \\ &\quad \times 10^{-3} x_1^2 - 0.021x_2^2 - 0.021\,x_3^2 - 0.011\,x_1 \cdot x_2 \\ &\quad + 0.017\,x_1 \cdot x_3 - 0.013\,x_2 \cdot x_3\end{aligned} \tag{3}$$

For EI, $R^2 = 0.761$
For BD, $R^2 = 0.742$
For BS, $R^2 = 0.706$

3.2. Properties of the Extrudates of Rice and Sweet Potato Powder

Various parameters of the 20 extrudates of rice and sweet potato were studied. Their colour profile is given

Table 1. Experimental design for extrusion experiment with coded and actual variable levels.

Sample codes	Coded			Un coded		
	x_1	x_2	x_3	X_1	X_2	X_3
RS(92:8)A	−1	1	−1	200	130	80
RS(80:20)A	−1	1	1	200	130	200
RS(86:14)A	1.682	0	0	468	120	140
RS(80:20)B	1	1	1	400	130	200
RS(86:14)B	0	0	0	300	120	140
RS(86:14)C	0	0	0	300	120	140
RS(80:20)C	1	−1	1	400	110	200
RS(86:14)D	0	0	0	300	120	140
RS(86:14)E	0	0	0	300	120	140
RS(92:8)B	1	1	−1	400	130	80
RS(86:14)F	0	0	0	300	120	140
RS(76:24)	0	0	1.682	300	120	240
RS(86:14)G	0	0	0	300	120	140
RS(86:14)H	0	1.682	0	300	137	140
RS(92:8)C	−1	−1	−1	200	110	80
RS(86:14)I	−1.682	0	0	132	120	140
RS(92:8)D	1	−1	−1	400	110	80
RS(80:20)D	−1	−1	1	200	110	200
RS(96:4)	0	0	−1.682	300	120	40
RS(86:14)J	0	−1.682	0	300	103	140

x_1 and X_1, screw Speed (rpm); x_2 and X_2, extrusion temperature (˚C); x_3 and X_3, concentration of sweet potato powder ($\text{g}\cdot\text{kg}^{-1}$); R denotes rice flour; S denotes sweet potato.

Table 2. Analysis of variance results for fitted models of product properties.

Response	Source	df	Sum of square	Mean squares	F-value	P-value
EI	Regression	9	4.30	0.48	3.54	0.0307^{*}
	Lack of Fit	5	0.40	0.080	0.42	0.8159
	Pure error	5	0.95	0.19		
	Residual	10	1.35	0.13		
	Total	19				
BD	Regression	9	0.017	1.842×10^{-3}	3.19	0.0426^{*}
	Lack of Fit	5	2.519×10^{-3}	5.039×10^{-4}	0.77	0.6078
	Pure error	5	3.259×10^{-3}	6.519×10^{-4}		
	Residual	10	5.779×10^{-3}	5.779×10^{-4}		
	Total	19				
BS	Regression	9	0.16	0.017	2.67	0.0708
	Lack of Fit	5	0.028	5.564×10^{-3}	0.75	0.6203
	Pure error	5	0.037	7.424×10^{-3}		
	Residual	10	0.065	6.494×10^{-3}		
	Total	19				

*Significant at $P < 0.05$; df: degree of freedom.

Table 3. Optimized parameters in the response optimizer.

Response	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
EI	Maximum	4.388	6.22	1	1	3
BD	Minimum	0.101	0.22	1	1	3
BS	Minimum	0.085	0.46	1	1	3

Table 4. Optimized solution obtained using the response optimizer.

Optimal solution			Predicted responses			Desirability
X_1 (rpm)	X_2 (˚C)	X_3 (g/kg)	EI	BS, N/mm^2	BD, g/cm^3	
400	130	150	5.84	0.13	0.12	0.84

in **Table 5** and physical properties are given in **Table 6**. The 3-D graphical representations of the 3 responses (expansion index, bulk density and breaking strength) against different screw speeds (SS), barrel temperatures (BT) and feed composition (FCM) are given in **Figure1**. The water absorption index (WAI) and water solubility index (WSI) of the 20 samples are given in **Table 7**.

3.3. Selection of Best-5 Extrudates Based on Their Appearances

Based on the appearence of the 20 samples, a score ranging from 1 to 9 was given to each sample as given in **Table 7**. The 5 samples that got the highest scores of 9 were selected for sensory evaluation and RVA studies. For convenience of terms, the product codes of the 5 samples with the highest score of 9 are changed as given in **Table 8**.

3.4. Pasting Profile of the Extrudates

The RVA study of the extrudates showing their peak, hold and final viscosities along with their breakdown and setback values are given in **Table 8**. The Table shows

Table 5. Color profile of the 20 extrudate samples developed from rice flour and sweet potato.

Sample	*Pre extrusion*			*Post extrusion*			Δ*E*
	L_0	a_0	b_0	*L*	*a*	*b*	
RS(92:8)A	76.64	0.05	8.15	65.18	2.09	10.75	11.93
RS(80:20)A	78.75	0.50	9.42	69.05	2.04	11.56	10.05
RS(86:14)A	76.58	0.26	8.93	65.65	2.91	12.17	11.70
RS(80:20)B	77.45	0.54	9.14	65.85	2.10	11.10	11.87
RS(86:14)B	75.97	0.40	8.76	67.34	0.94	9.33	8.67
RS(86:14)C	75.61	0.55	9.07	66.58	1.61	10.19	9.16
RS(80:20)C	78.23	0.75	9.42	66.35	2.32	11.41	12.15
RS(86:14)D	76.33	1.09	10.24	64.45	1.95	10.45	11.91
RS(86:14)E	75.70	0.41	8.36	65.34	1.89	10.72	10.73
RS(92:8)B	76.03	0.51	9.00	67.81	2.93	12.67	9.32
RS(86:14)F	75.27	0.95	9.12	68.40	2.56	11.54	7.46
RS(76:24)	75.68	0.62	9.51	66.35	2.92	12.60	10.09
RS(86:14)G	75.97	0.40	8.76	67.34	0.94	9.33	8.67
RS(86:14)H	73.91	0.41	7.78	68.03	3.01	11.95	7.66
RS(92:8)C	75.76	0.39	8.91	67.41	1.07	9.59	8.41
RS(86:14)I	75.61	0.55	9.07	66.58	1.61	10.19	9.16
RS(92:8)D	75.89	0.55	8.05	67.76	2.13	10.94	8.77
RS(80:20)D	76.67	0.59	9.16	67.39	1.55	10.46	9.42
RS(96:4)	75.90	0.50	7.53	64.43	1.07	8.93	11.57
RS(86:14)J	77.45	0.55	8.59	65.58	1.14	8.5	11.88

Table 6. Physical properties of the 20 extrudate samples made from rice flour and sweet potato.

Sample	*Hardness* (*N*)	*BS* (*N*/*mm*^{2})	*EI* (*mm*)	*BD* (*g*/*cm*^{3})
RS(92:8)A	12.15 ± 0.11	0.21 ± 0.03	4.90 ± 0.48	0.14 ± 0.02
RS(80:20)A	20.34 ± 0.22	0.34 ± 0.01	4.94 ± 0.22	0.12 ± 0.01
RS(86:14)A	20.42 ± 0.09	0.34 ± 0.04	5.00 ± 0.24	0.12 ± 0.0
RS(80:20)B	14.17 ± 0.01	0.26 ± 0.02	4.60 ± 0.43	0.11 ± 0.01
RS(86:14)B	24.35 ± 0.16	0.37 ± 0.02	5.55 ± 0.33	0.14 ± 0.01
RS(86:14)C	22.36 ± 0.09	0.37 ± 0.05	5.00 ± 0.35	0.13 ± 0.01
RS(80:20)C	12.95 ± 0.16	0.22 ± 0.01	4.89 ± 0.44	0.12 ± 0.0
RS(86:14)D	24.35 ± 0.16	0.37 ± 0.02	5.55 ± 0.33	0.14 ± 0.01
RS(86:14)E	22.36 ± 0.09	0.37 ± 0.05	5.00 ± 0.35	0.13 ± 0.01
RS(92:8)B	15.66 ± 0.25	0.26 ± 0.03	5.08 ± 0.04	0.11 ± 0.0
RS(86:14)F	14.11 ± 0.03	0.22 ± 0.01	5.39 ± 0.36	0.13 ± 0.0
RS(76:24)	14.42 ± 0.21	0.24 ± 0.01	5.04 ± 0.37	0.13 ± 0.0
RS(86:14)G	31.21 ± 0.18	0.37 ± 0.02	4.51 ± 0.35	0.16 ± 0.01
RS(86:14)H	19.33 ± 0.14	0.31 ± 0.05	5.22 ± 0.28	0.12 ± 0.0
RS(92:8)C	11.97 ± 0.11	0.21 ± 0.03	4.77 ± 0.38	0.12 ± 0.01
RS(86:14)I	23.46 ± 0.52	0.37 ± 0.01	5.12 ± 0.18	0.17 ± 0.01
RS(92:8)D	13.32 ± 0.27	0.21 ± 0.01	5.17 ± 0.55	0.13 ± 0.01
RS(80:20)D	14.54 ± 0.16	0.23 ± 0.02	5.34 ± 0.45	0.17 ± 0.01
RS(96:4)	19.24 ± 0.14	0.33 ± 0.04	4.82 ± 0.27	0.20 ± 0.01
RS(86:14)J	19.06 ± 0.28	0.32 ± 0.04	5.04 ± 0.42	0.19 ± 0.0

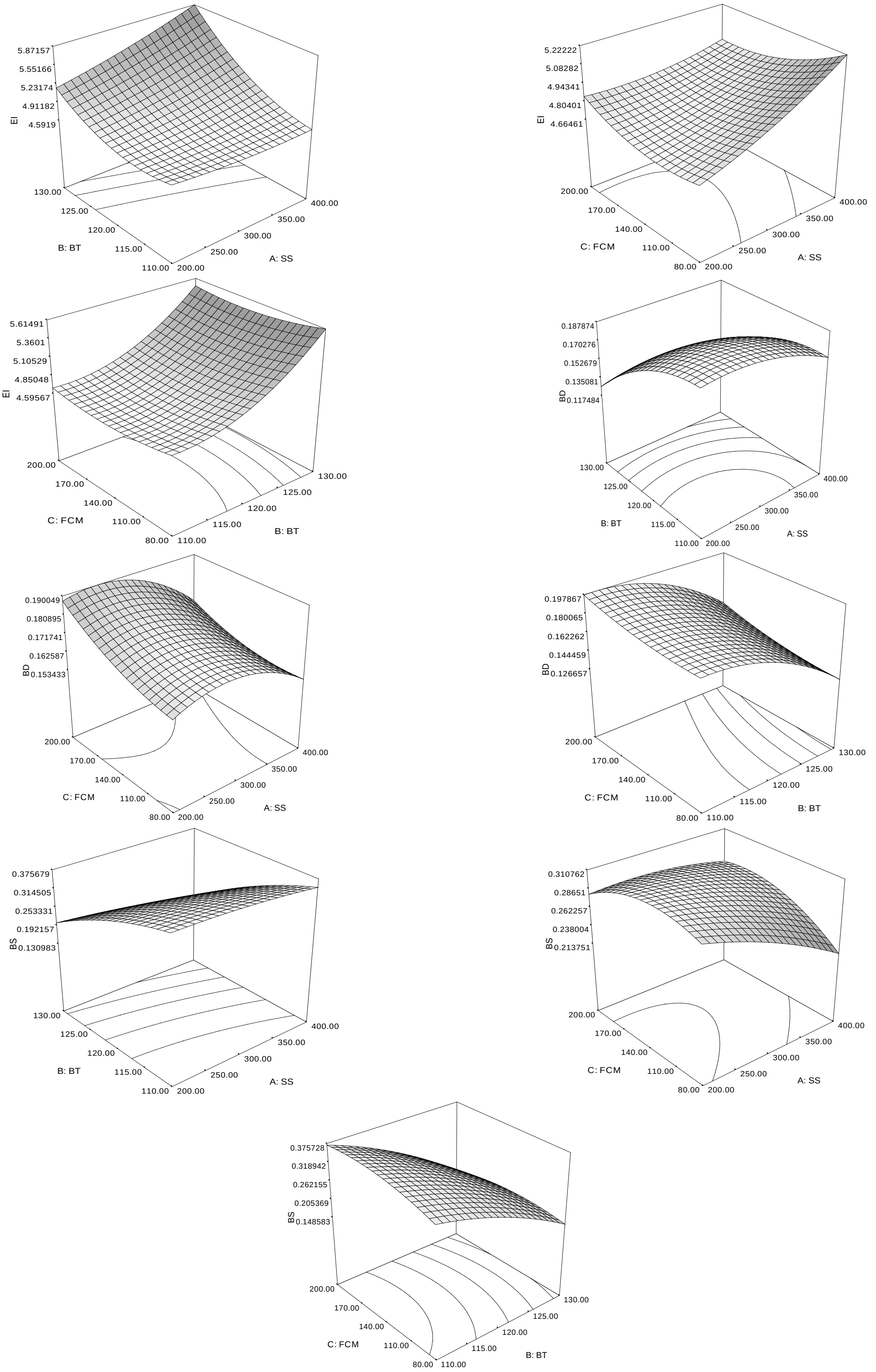

Figure 1. The nine 3-D graphs showing changes in EI, BD and BS with respect to changes in screw speeds (SS), barrel temperatures (BT) and feed composition (FCM).

Table 7. Water absorption and solubility indices of the 20 extrudate samples made from rice flour and sweet potato.

Sample	*WAI(g gel/g)*	*WSI* (%)	*Score on Appearance*
RS(92:8)A	7.67 ± 0.69	11.93 ± 0.71	7
RS(80:20)A	7.83 ± 0.71	9.23 ± 0.81	8
RS(86:14)A	7.84 ± 0.31	12.68 ± 0.66	9
RS(80:20)B	7.52 ± 0.51	10.86 ± 0.43	9
RS(86:14)B	6.62 ± 0.43	10.00 ± 0.36	6
RS(86:14)C	8.16 ± 0.37	8.00 ± 0.32	6
RS(80:20)C	8.27 ± 0.93	11.28 ± 0.19	6
RS(86:14)D	8.17 ± 0.23	8.09 ± 0.61	8
RS(86:14)E	6.62 ± 0.44	10.15 ± 0.31	7
RS(92:8)B	6.84 ± 0.75	13.20 ± 0.32	9
RS(86:14)F	7.06 ± 0.73	13.36 ± 0.31	8
RS(76:24)	7.02 ± 0.49	11.53 ± 0.11	8
RS(86:14)G	7.04 ± 0.40	5.29 ± 0.15	7
RS(86:14)H	7.25 ± 0.15	10.54 ± 0.73	9
RS(92:8)C	7.15 ± 0.83	9.86 ± 0.41	7
RS(86:14)I	7.02 ± 0.21	9.42 ± 0.19	6
RS(92:8)D	7.48 ± 0.35	12.04 ± 0.10	9
RS(80:20)D	7.37 ± 0.92	9.10 ± 0.47	7
RS(96:4)	7.29 ± 0.57	6.39 ± 0.27	8
RS(86:14)J	6.89 ± 0.52	6.74 ± 0.38	7

Table 8. Change of sample codes and RVA profile of the rice-sweet potato extrudates.

Former sample code	*New sample code*	*Peak viscosity* (*cP*)	*Hold Viscosity* (*cP*)	*Final Viscosity* (*cP*)	*Breakdown* (*cP*)	*Setback* (*cP*)
RS(86:14)A	RS-1	1693	153	251	1540	98
RS(80:20)B	RS-2	1749	187	300	1562	113
RS(92:8)B	RS-3	1534	158	247	1376	89
RS(86:14)H	RS-4	3437	321	528	3116	207
RS(92:8)D	RS-5	1738	177	286	1561	109

that sample RS-4 has the highest peak viscosity of 3437 cP. It reaches its final viscosity of 528 cP, which is also the highest among all the other samples. The sample RS-3 has the lowest peak viscosity of 1534 cP and also the lowest final viscosity of 247 cP. It was observed that sample RS-4 that was extruded at a barrel temperature of 137˚C had the highest peak viscosity of 3437 cP while the other extrudates that were processed at barrel temperature less than 137˚C had lower peak viscosities. This may be attributed to the higher degree of gelatinised starch in the extudate that allowed it to absorb large quantities of water. According to Liu *et al*. (2006), starch content in the flour, other components in the starch-water system and processing of flours are very critical to pasting properties. The interaction of other components and the degree of starch damage during extrusion could affect the peak viscosity of extruded flours. Screw speed and feed composition did not have any effect as the other samples showed similar RVA profiles.

3.5. Sensory Profile

The extrudates were subjected to sensory analysis for the attributes of appearance, color, taste, mouthfeel, texture and overall acceptability by a panel of 10 semi trained panellists. The graphical representation of the same is given in **Figure 2**. The graph of sensory evaluation revealed that RS-3 had the highest ranking scores in all the 6 attributes-appearance, colour, taste, texture, mouthfeel and overall acceptability. The sample with the lowest score in all the attributes was RS-5. It is clearly seen that mouthfeel was the attribute with the most significant difference followed by texture and overall acceptability. There was least difference among the samples for appearance. The attributes of colour and taste also showed evident differences, but with their ranges much smaller than that of mouthfeel.

3.6. Development of Rice Extrudates under Optimized Conditions

The optimized conditions obtained from RSM were:
Screw speed: 400 rpm
Barrel temperature: 130˚C
Concentration of sweet potato: 150 g/kg

The optimized conditions for making rice-sweet potato extrudate were followed to make rice-greater yam extrudate, rice-sweet potato extrudate and rice-sweet potato-tomato-chilli extrudate. The feed compostion of the blends used for processing into extrudates is given in **Table 9**. The photographs of the extrudates are given in **Figures 3(a)-(c)**.

3.7. Properties of Rice Extrudates Prepared under Optimized Conditions

Physical Properties

The changes in *L*, *a* and *b* values and the total color change in RS, RY and RST are shown in **Table 10**. The color profile showed that there was a significant decrease in the *L* value *i.e*. lightness of the samples post-extrusion. Also, as indicated by the results, extrusion resulted in an increase in *a* value *i.e*. redness of the samples. *a* was stronger in RST having tomato. The yellowness (b value) increased in RST, but in RY and RS, there was a slight decrease probably due to destruction of pigments. The total difference in color values (ΔE) of RST showed a much significant colour change compared to RY and RS. Shih *et al*. (2009) found that air-dried sweet potato slices had a ΔE values of 7.80. High temperature of extrusion cooking (130˚C) might have a higher effect on the colour of the extrudates.

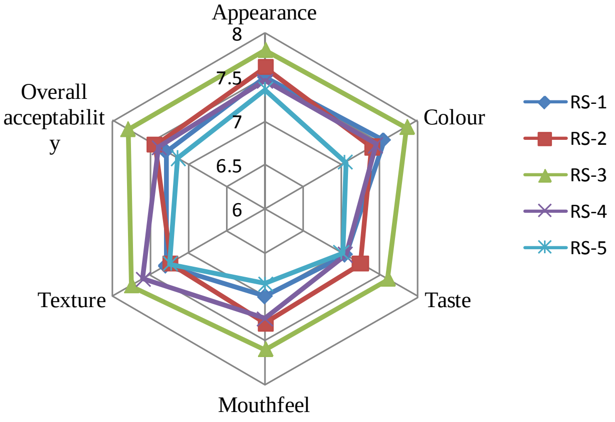

Figure 2. Sensory profile of the extrudates.

The texture profile of RS, RY, and RST are shown in **Table 10**. Product hardness is the average force required for a probe to penetrate the sample. The results of texture analysis showed that RST has the highest hardness with a value of 47.57 N, while RS had the lowest with 28.68 N. Springiness was also found to be the highest in RST, but RY and RS had equal springiness value of 0.51 mm. The higher degree of tomato incorporated extrudate may be because of the effect of tomato pulp. It has got a good amount of fibre in it that could have added to the increased hardness of RST.

Physico-chemical properties Pasting Properties

The pasting properties of the 3 extrudates-RS, RY and RST are shown in **Table 11**. All the samples had an equal pasting temperature between 50.1˚C and 50.2˚C. From

Table 9. Feed composition for extrusion under optimized conditions.

Sl.No.	*Composition*	*Product Code*
1	Rice flour(85%) + sweet potato powder(15%) + 3% water	RS
2	Rice flour(85%) + yam powder(15%) + 3% water	RY
3	Rice flour(80%) + sweet potato powder (15%) + Tomato pulp powder(5%) + 3% Chilli powder	RST

Numbers in the brackets indicate percentage level of incorporation.

(a) (b) (c)

Figure 3. (a) RS extrudates; (b) RY extrudates; (c) RST extrudates.

Table 10. Changes in colour values and texture profile of RS, RY and RST.

Sample	*Pre extrusion*			*Post extrusion*			ΔE	*Texture*	
	L_0	a_0	b_0	*L*	*a*	*b*		*Hardness* (*N*)	*Springiness* (*mm*)
RS	76.28	3.90	12.31	73.11	4.16	11.53	3.33	28.68	0.51
RY	62.58	3.09	9.30	60.10	3.80	8.17	2.82	34.53	0.51
RST	71.10	6.39	11.98	68.22	11.8	18.63	9.09	47.57	0.95

Table 11. RVA profile, Water Absorption Index (WAI) and Water Solubility Index (WSI) of RS, RY and RST.

Sample	*Pasting properties*						*WAI* (*g gel/g*)	*WSI*(%)
	PT(˚C)	*PV*(*cP*)	*HV*(*cP*)	*FV*(*cP*)	*BD*(*cP*)	*TSB*(*cP*)		
RS	50.2	704	220.5	337.5	483.5	117.0	8.16 ± 0.35	3.22 ± 0.04
RY	50.1	661	187.0	295.0	474.0	108.0	8.59 ± 0.75	3.41 ± 0.14
RST	50.1	644	159.0	254.5	481.0	95.5	8.16 ± 0.73	4.25 ± 0.25

the viscosity profile, it can be seen that extrudate having sweet potato had the highest peak viscosity, hold viscosity and final viscosity. Setback and breakdown were also therefore the highest in rice-sweet potato extrudates. RST sample that had tomato pulp powder had diluted the starch and therefore its viscosity was lower than RS. The higher viscosity of rice-sweet potato extrudate than rice-yam extrudate indicates the susceptibility of the sweet potato starch to extensive gelatinisation and the higher water absorption of the gelatinised starch. According to El-Dash *et al*. (1984), the intensity and extent of the breakdown of a starch granule will depend on the type of starch, mechanical shear, and temperature present during the gelatinization of the starch.

The water absorption index (WAI) and water solubility index (WSI) of RS, RY and RST are shown in **Table 11**. Water absorption index (WAI) was found to be the highest in RY (8.59). However RST and RS had an equal WAI value of 8.16. However, Water solubility index was highest in RST (4.25%) and lowest in RS (3.22%). The WAI measures the amount of water absorbed by starch and is related to the degree of starch gelatinization. Thus, higher value of WAI can be attributed to higher degree of gelatinized starch in extrudates. According to Anderson *et al*. (1969), WSI is related to the amount of low molecular weight products of starch degradation, which are easily soluble because of reduced entanglement. Likimani *et al*. (1991) accounted the higher value of WSI a result of starch damage during extrusion due to high temperature.

Amylose content

The amylose content in RS, RY, RST, yam powder, sweet potato powder and rice powder are shown in **Table 12**. Amylose content was found to be highest in the rice flour (24.8%). The raw yam powder had slightly higher amylose content than the sweet potato powder. On blending, the amylose composition of rice-sweet potato and rice-yam extrudate were reduced. The amylose content in the sample containing yam powder (RY) reduced slightly more (14.7%) than that of the sample containing sweet potato powder, RS (15.2%). Among the extrudates, sample RST had the highest amylose content (18.2%). Aprianita *et al*. (2009) reported that the amylose content of yam flour to be 14.60%, while that of sweet potato flour to be around 18.12%. Chinnaswamy *et al*. (1988) found that the expansion ratio of extruded corn starches increased from 8 to 16.4 as amylose content increased from 0% to 50%. The bulk density of the extrudates decreased with increased amylose content. In contrast, shear strength of starch extrudates increased with increasing amylose content. Similar results were reported by Guha *et al*. (2006) on the effect of amylose content on product. The low-amylose extrudates gave the higher expansion ratio, followed by intermediate-amylose and high-amylose content extrudates. Extrudate products with a higher expansion ratio are preferred.

Table 12. Amylose content for various samples.

Sample	*Amylose* (%)
Rice Powder (RP)	24.83 ± 0.77
Sweet Potato Powder (SPP)	20.06 ± 0.78
Yam Powder (YP)	21.94 ± 0.94
RS	15.29 ± 0.15
RY	14.74 ± 0.16
RST	18.23 ± 0.24

Proximate profile

The proximate composition of RS, RY and RST are shown in **Table 13**. The proximate profile of the extrudate samples showed mixed results. The moisture content of all samples was almost uniform around 9%. However, differences were observed in ash, protein and crude fiber contents. Ash, fat, protein and crude fiber percentages were 2.4%, 0.29%, 6.3% and 1.35%, respectively in sample RST. RY had the lowest ash, fat and crude fibre content among all; 0.83%, 0.19% and 0.5%, respectively. Protein content was found to be equal in both RY and RS being 5.6%. By difference method, total carbohydrate content was found to be highest in RY with 83.04% and lowest in that of RST with 79.98%. Iwe *et al*. (2001) found that in extruded soy flour and sweet potato blends, fat content was 0.5%, ash 3% and carbohydrate around 79%. Aprianita *et al*. (2009) found that the total carbohydrate content of yam flour was higher than that of sweet potato flour.

Sensory profile

The extrudates were subjected to sensory analysis for the attributes of appearance, color, taste, mouthfeel, texture and overall acceptability by a panel of 10 semi trained panelists. The sensory profile of RS, RY and RST are graphically given in **Figure 4**. Among the 3 samples, the graph suggests that the sample with the best sensory score in all the attributes is RS, while the sample with the least favourable attribute is RY, for its colour.

The attribute having the most prominent difference

Table 13. Proximate composition of RS, RY and RST.

Composition (*w.b.*)	*Sample*		
	RS	*RY*	*RST*
Moisture %	9.82 ± 0.02	9.84 ± 0.02	9.66 ± 0.07
Ash %	1.81 ± 0.34	0.83 ± 0.19	2.45 ± 0.18
Fat %	0.22 ± 0.01	0.19 ± 0.08	0.26 ± 0.01
Protein %	5.60 ± 0.0	5.60 ± 0.0	6.30 ± 0.0
Crude fiber %	0.99 ± 0.27	0.5 ± 0.14	1.35 ± 0.06
Total carbohydrate % (by difference)	81.56 ± 0.58	83.04 ± 0.22	79.98 ± 0.81
Energy (kcal/100 g)	350.62	356.27	347.46

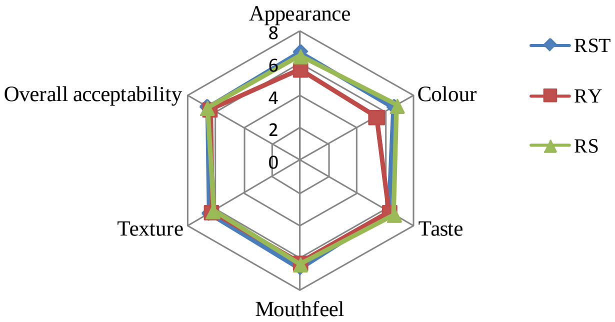

Figure 4. Graphical representation of the sensory profile of the extrudates RS, RY and RST.

among the samples is colour, followed by appearance. However, as it is evident, there are no significant differences in the scores of the 3 samples in the other 4 attributes namely-taste, mouthfeel, texture and overall acceptability. RS had the best taste among all. RST was the one getting the least score in taste, but had the highest score in appearance.

Antioxidant Profile

The results of antioxidant properties of RS, RY and RST are given in **Table 14**. By carrying out the radical scavenging activity test, DPPH and the FRAP test for the presence of antioxidants, the antioxidant content in the extrudates were found to be very low. Both the tests showed a similar result for all the 3 extrudates where it was observed that the radical scavenging activity was highest in RST than the other two being 3.6%. RY had a higher radical scavenging activity at 3.22% than RS at 1.36%. Similarly the Ferric reducing antioxidant power was found to be higher in RST being 218 µM of Fe/100 g than the other two. RY and RS had a closer FRAP values being 148 and 118 µM of Fe/100 g. The higher antioxidant activity in RST is due to the presence of tomato pulp powder in its composition that naturally has a good amount of antioxidants in it. The low antioxidant content in the extrudates is due to the fact that the molecules acting as antioxidants that were present in the raw samples are generally destroyed during the high temperature used in extrusion cooking. According to Shih *et al.* (2009), temperatures greater than 60˚C is regarded as unfavourable, due to the possibility of inducing oxidative condensation or decomposition of thermolabile compounds, such as catechin. A similar decrease in reducing power has been reported by other authors like Xu *et al.* (2008) upon thermal processing in different cereals.

Table 14. Antioxidant profile for RS, RY and RST.

Sample	*DPPH* (*% radical scavenging activity*)	*FRAP* (*µM of Fe/100g sample*)
RS	1.36 ± 0.08	118 ± 0.12
RY	3.22 ± 0.16	148 ± 0.11
RST	3.60 ± 0.15	218 ± 0.14

4. CONCLUSION

The studies have shown that both sweet potato (*Ipomoea batatas*) and greater yam tubers (*Dioscorea alata*) can be utilized for development of ready to eat (RTE) products. Both the extruded products of rice incorporated with sweet potato powder and yam powder have shown to possess good functional properties and desirable nutritive value. RTE breakfast cereal products available in the market are generally expensive, so if such products are developed that are incorporated with locally available vegetables, not only those products can be made affordable enough, but it will also help the local farmers and traders in improving their economy and vegetation. Levels of fat, carbohydrate, protein and kilocalories of energy that these products were carrying, were found to be comparable with that of a popular RTE breakfast product available in the market. So it can be concluded from this study that nutritionally enhanced breakfast cereals can be made from rice-sweet potato extrudates and rice-yam extrudates with addition of minerals and vitamins.

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