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Optimization of extrusion process varibles for preparation of vitamin C enriched ready–to–eat product from maize–rice–aonla using response surface methodology

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SUMMARY :

Response surface methodology (8.0.7.1) was employed to study the optimization of process variables of extrusion technology *i.e.* die temperature, Screw speed and feed moisture content. A ready to eat extruded food was developed by using a twin screw extruder. A nutritious ready to eat expanded product based on maize grits, rice flours and aonla was developed for school going children (6-16 years). Feed moisture content was found to have maximum influence on bulk density whereas the screw speed and die temperature had maximum influence on colour and expansion ratio of the product, respectively. Blends of maize grits, rice flours and aonla (80 : 10 : 10) were used as the ingredients for extrusion that would provide the vitamin C requirement of the targeted population with a minimum cost. Based on organoleptically evaluation, product extruded at processing conditions of 125°C die temperature, 310 screw rpm and 22 per cent (d.b) feed moisture content was found to be most acceptable quality extruded product.

KEY WORDS : Bulk density, Moisture content, Expansion ratio, Hardness, Colour, Extrusion

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Extrusion cooking is an important and popular food processing technique classified as a high temperature/short time process to produce fibre-rich products (Gaosong and Vasanthan, 2000 and Vasanthan *et al.*, 2002). In the extruder, the food mix is thermo mechanically cooked to high temperature, pressure and shear stress which are generated in the screw-barrel assembly. The cooked melt is then texturized and shaped in the die (Arhaliass *et al.*, 2003). Cereal grains are generally used as the major raw materials in extruded snack foods due to have a poor biological value due to their limited essential amino acid content (Meng *et al.*, 2009 and Ibanoglu *et al.*, 2006). Nutritious snack foods can be produced by incorporation of legumes, vegetables and fruits in to formulations (Ibanoglu *et al*., 2006).

Ascorbic acid (vitamin C) is used extensively in the food industry, not only for its nutritional value but for its many functional contributions to product quality. Acting as an antioxidant, vitamin C can improve the colour and palatability of many kinds of food products. Vitamin C is a co-factor in at least eight reactions enzymatic, including several collagen synthesis reactions that, when dysfunctional, cause the most severe symptoms of scurvy. Scurvy is an vitaminosis resulting from lack of vitamin C, since without this vitamin, the synthesised collagen is too unstable to perform its function. Scurvy leads to the formation of brown spots on the skin, spongy gums, and bleeding from all mucous membranes. The spots are most abundant on the thighs and legs, and a person with the ailment looks pale, feels depressed, and is partially immobilized. It is reported to have high therapeutic value in traditional Indian medicine and is used in treating haemorrhage, diarrhea, dysentery, anemia and jaundice (Kirtikar and Basu, 1993).

The Indian gooseberry (*Emblica officinlis* L.) also called as amla or aonla is one of the tropical fruits reported to contain highest ascorbic content (Gopalan *et al*., 1996). The ascorbic acid content in the gooseberry fruit was reported to be 160 times of that of apple (Barthakur and Arnold, 1991). It is also a rich source of ployphenols, which imparts characteristic acidic and astringent taste to the fruit.

Maize is the third largest grain crop of the world next to wheat and paddy. Maize and millets are mainly used for food purposes in the underdeveloped and developing countries (Roonedy and Serna, 1987). Cooking extrusion of starchy materials has become a very used technique to obtain a wide range of products such as snacks and breakfast cereals (Fast, 1990 and Bouzaza *et al*., 1996). Since maize grits are widely used to widely used to elaborate expanded products, there is a need to improve the nutrional value of this kind of foods.

Rice (*Oryza sativa*) is a staple food crop for a large part of the world's population, making it the second most consumed cereal grain. Rice provides more than one fifth of the calories consumed worldwide by humans. Rice contains approximately 7.37 per cent protein, 2.2 per cent fat, 64.3 per cent carbohydrate available, 0.8 per cent fibre, and 1.4 per cent ash content (Zhoul *et al*., 2002). Rice flour has become an attractive ingredient in the extrusion industry due to its bland taste, attractive white colour, hypoallergenicity and ease of digestion (Kadan *et al*., 2003).

Therefore, an attempt was made to develop an extruded product with maize, Rice and Aonla powder. The objective of this study was to school going children (6–16 yrs) based on linear programming model. The extruded products sensory and physical properties were determined in terms of colour, texture, bulk density and hardness for overall acceptability of the product.

EXPERIMENTAL METHODS

Materials :

Freshly harvested fruits Aonla (variety: Chakiya) were procure from fruit orchard of Division of fruits and Horticultural Technology, Indian Agricultural Research Institute, New Delhi. Care was taken to select firm and uniformly matured aonla for experimentation. Aonla were washed in tap water and the washed aonla were grated in the grating machine into 20-30 mm length and dried in tray drier at 60 °C up to moisture of 8 per cent d.b. maize (variety: HQPM1) was procured from Directorate of Maize Research, Indian Agricultural Research Institute, New Delhi. The rice was procured from local market. Both rice and maize were made into flour by using mixer and then sieved to remove the unwanted trashes in the flour.

Methods :

Samples of maize, rice and aonla flours were analyzed for vitamin C and total phenol according to AOAC (1984). Minerals content were analyzed using atomic absorption spectrophotometer and vitamins content by using titration method (Ranganna).

Sample preparation :

Formulation :

The objective was to make a formulation which has a low cost and contain at least the minimum quantity of vitamin C content *i.e.* 41 μg (6-16 yrs children, NNI, Hyderabad).

Selection of flour blend composition :

Flour blend composition consisting of maize, rice and aonla was first decided. To do this, the factors like the nutritional requirements of children of age group of 6-16 years, low cost of the blend as well as the colour of the blend was kept in mind. According to ICMR (2010) guidelines the RDA for vitamin C requirement of the above age group is approximately 41mg per day. It has also been suggested that supplementary food should fulfil 1/3 RDA (ISI, 1989) requirement.

Hence, the blend compositions were so adjusted as to have approximately 14 mg/ 100 g of vitamin C content. So the blend compositions of ≥70 per cent of maize, ≥10 per cent of rice and ≥5 per cent of aonla were selected based on minimum cost and their nutritional values were determined. Considering the prevailing cost of maize, rice and aonla in the local market as Rs. 12, 25 and 45 per kg, respectively the cost of the blend composition was calculated. To calculate the nutritional compositions and the cost of different combination of flour blend a linear programming model of optimization was used. It is clear from the Table A that the blend composition (maize 80 %, rice 10 % and aonla 10 %) fulfilled the desired nutrional requirement of the targeted population at the lowest cost and hence, was selected for extrusion processing for snacks preparation. Response surface methodology was used.

Linear programme optimization solution :

Variables :

X_1 = Amount of maize grits in 100 g of mixture.

X_2 = Amount of rice flour in 100 g of mixture.

X_3 = Amount of Aonla in 100 g of mixture.

where, $X_1 \geq 70$, $X_2 \geq 10$ and $X_3 \geq 4$.

Constraints :

Nutrients constraints :

$$\mathbf{0.068\ X_1 + 0\ X_2 + 5.5\ X_3 \geq 60}$$

Table A : Standardization of formulation

Sr. No.	Maize (%)	Rice (%)	Aonla (%)	Vitamin-C (mg)	Cost (Rs./ 100 g)
1.	80	10	10	60	1.36
2.	70	20	10	58	1.44
3.	75	15	10	60	1.40
4.	75	10	15	32	1.32
5.	79	13	8	44	1.36
6.	82	11	7	44	1.34

Table B : Response surface design of the extrudate

	Coded values			Actual values		
Run No.	A	B	C	Barrel (temp.)	Screw speed (rpm)	MC (% db)
1.	1	0	1	130.00	350	22.00
2.	0	0	0	120.00	350.00	20.00
3.	0	0	0	120.00	350.00	20.00
4.	0	0	0	120.00	350.00	20.00
5.	1	1	0	130.00	400.00	20.00
6.	0	0	0	120.00	350.00	20.00
7.	0	0	0	120.00	350.00	20.00
8.	-1	-1	0	110.00	300.00	20.00
9.	0	-1	-1	120.00	300.00	18.00
10.	0	1	-1	120.00	400.00	18.00
11.	1	0	-1	130.00	350.00	18.00
12.	1	-1	0	130.00	300.00	20.00
13.	-1	0	-1	110.00	350.00	18.00
14.	0	-1	1	120.00	300.00	22.00
15.	0	1	1	120.00	400.00	22.00
16.	-1	1	0	110.00	400.00	20.00
17.	-1	0	1	110.00	350.00	22.00

Balancing constraint :

$$1X_1 + 1X_2 + 1X_3 = 100$$

Objective :

Presumably to minimize cost, *i.e.* Minimize $Z = 0.12 X_1 + 0.025 X_2 + 0.04 X_3$.

Extrusion process :

The samples were extruded in a twin screw extruder (380V-3phase, Basic Technology Private Limited, Calcutta). The machine was kept on for 30 minutes to stabilize the set temperature. The temperature, screw speed, feeder speed and cutter speed were maintained at 110-130°C, 300-400 rpm, 40rpm and 275rpm, respectively. The moisture content of feed was then adjusted to 18-22 per cent dry basis by adding calculated amount of potable water and mixed continuously in a mixer. These were then passed through the 2 mm screen for breaking the lumps. To ensure uniform mixing and to minimize variability in the feed material, the samples were put in the polythene covers and stored overnight at 8°C for conditioning. Prior to the extrusion the samples were equilibrated for 2 hours at room temperature.

The samples were poured in the feed hopper slowly and continuously in order to avoid the choking. The extrudate samples were collected and dried at 60°C for 5 hours in a tray drier to a maximum moisture content of up to 6 per cent d.b. Dried samples were stored in polythene bags at room temperature and used for further analysis.

Methodology used for estimating product responses :

Bulk density :

Bulk density of the extrudates was calculated by measuring the actual dimensions of the extrudates. The diameter and length of 50 pieces of randomly selected extrudate samples were measured by Vernier caliper. The weight of these extrudate pieces were determined by electronic weighing balance having an accuracy of 0.001 g. The bulk density was then calculated using the following formula, assuming a cylindrical shape of extrudate.

$$\rho b = \frac{4W}{\pi d2l} \quad ....(1)$$

where, ρb is bulk density, g/cm^3; w is weight, g; d is diameter, cm; and l is the length of the extrudate, cm.

Hardness :

The peak force as an indication of hardness was measured with Texture Pro CT V1.3 Build Texture Analyzer (Model: TA + Di, Stable Micro Systems, U.K.) interfaced with a PC computer that was fitted with a 5 kg load cell attached and a 3 mm diameter stainless steel cylinder probe. The sample was then placed in the texture analyzer at a cross head speed of 1 mm/s until the probe had sunk into the specimen to a depth of 75 per cent of the radius. Ten randomly selected samples were measured for each extrusion condition. The maximum peak force (N) was recorded as the hardness of the extrudate.

Colour :

Colour (L*, a*, b* values) of the samples were determined by using Hunter Colour Flex Meter. L* is known as the lightness and extends from 0 (black) to 100 (white). The other two co-ordinates a* and b* represent redness (+ a) to greenness (- a) and yellowness (+ b) to blueness (-b), respectively were recorded. Three measurements were taken for each sample and their means were reported.

Expansion ratio :

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Fan *et al.*, 1996). The diameter of extrudate was determined as to express the expansion of extrudate (Fan *et al.*, 1996). The diameter of extrudate was determined as the mean of 10 random measurements made with a Vernier caliper. The extrudate expansion ratio was calculated as :

$$ER = \frac{\text{diameter of extrudate}}{\text{die diameter}} \quad ...(2)$$

Vitamin C :

Vitamin-C content of the extruded product was analyzed by using AOAC (1999) titration method. The vitamin-C content would then calculate using the following formula :

$$\text{Vit. C} = \frac{\frac{\text{Titre values} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Aliquat of extract taken for extraction} \times \text{wt of sample}} \text{mg}}{100\text{ g}} \quad .(3)$$

Sensory analysis :

Sensory evaluation was done by a panel of 15 members which included students and faculty from the Division of Post Harvest Technology, IARI, New Delhi who evaluated the extruded snacks for appearance, taste, colour, and overall acceptability on a 9-point hedonic scale.

Data analysis :

Extrusion process parameters were optimized using a conventional overlay plot method in design expert version of Response surface methodology (8.0.7.10).

EXPERIMENTAL FINDINGS AND ANALYSIS

Physical characteristics *viz.*, expansion ratio, bulk density, texture and colour (L*, a*, b*) were determined.

Bulk density :

Low bulk density is a desirable character in the extruded products. Bulk density also describes the degree of expansion undergone by the melt as, it exits the extruder. The sectional expansion ratio considers only in the direction perpendicular to extrudate flow, while bulk density considers expansion in all directions (Meng *et al*., 2009; Altan *et al*., 2008 and Ilo and Berghofer, 1999). Response surface of bulk density are shown in Fig. 3 and 4. Bulk density of the extruded products varied between 82 to 126.8 kg/m^3 (Table 2). The regression analysis of the variables resulted in following after

Table 1 : Proximate composition of feed mixture

	Maize	Rice	Aonla
Moisture (% d.b)	14.9	13.7	81.8
Protein (%)	11.1	7.1	0.5
Iron (%)	0.52	4.3	1.2
Vitamin C (%)	6.8	0	550
Calcium (%)	10	10	50
Carbohydrates (%)	66.2	78.2	13.7

Table 2 : Regression co-efficients of eq. for process and product response

Response	Intercept	A	B	C	AB	AC	BC	A^2	B^2	C^2
BD	101.542	16.15	3.735	1.585	-1.95	1.05	0.52	0.369	-1.561	3.889
P=		< 0.0001	0.0058	0.1407	0.1917	0.4620	0.7115	0.7872	0.2741	0.0212
Hardness	18.638	-10.165	-2.9775	-1.015	0.3475	-0.0825	-0.0425	0.31475	0.03475	-0.15525
P=		<0.0001	< 0.0001	< 0.0001	0.0284	0.5343	0.7462	0.0377	0.7858	0.2474
Colour	38.15	5.305	0.985	0.145	1.175	0.195	0.34	2.035	0.17	0.37
P=		<0.0001	0.0006	0.4108	0.0015	0.4330	0.1903	< 0.0001	0.4811	0.1494
ER	3.126	0.3725	0.12625	0.03875	0.095	0.045	0.0275	0.07325	0.05575	0.06575
P=		<0.0001	0.0036	0.2298	0.0566	0.3159	0.5303	0.1142	0.2121	0.1494
Vit-C	193.96	-11.1	-1.825	0.275	-1.25	-0.15	-0.05	0.395	0.695	0.295
P=		<0.0001	0.0035	0.5352	0.0743	0.8087	0.9395	0.5187	0.2708	0.6275
	p <.01	.01<= p <.05	.05<= p <.10	p >=.10						

A:Temperature, B=Screw Speed and C=Moisture Content

Table 3 : Analysis of variance (ANOVA) for regression of 2nd order polynomial for the responses A: Die temperature, B: Screw speed and C: Feed MC % (d.b)

Source	Sum of square	Df	Mean square	F-value	P-value	Responses
Regression	2311.48	9	256.83	35.25	<0.0001	BD
Residual	51.0	7	7.29	-	-	
Regression	906.81	9	100.76	1580.74	<0.0001	Hardness
Residual	0.45	7	0.064	-	-	
Regression	258.0	9	28.67	130.39	<0.0001	Colour
Residual	1.54	7	0.22	-	-	
Regression	1.36	9	0.15	21.72	<0.0003	ER
Residual	0.049	7	6.942	-	-	

Regression 1022.64 9 113.63 79.84; <0.0001 Vit-C;
Residual 9.96 7 1.42

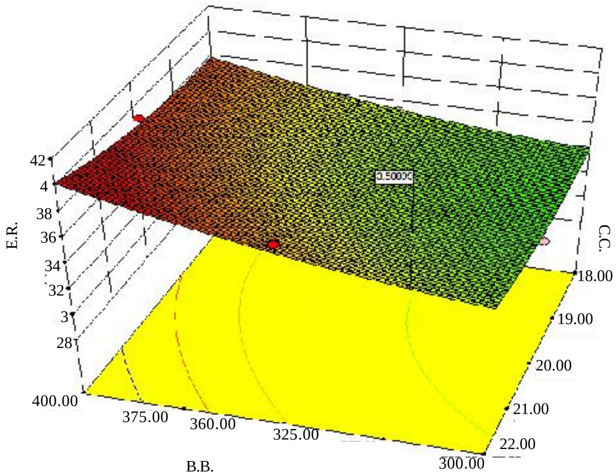

Fig. 1 : Effect of moisture content and screw speed on expansion ratio of the extruded product

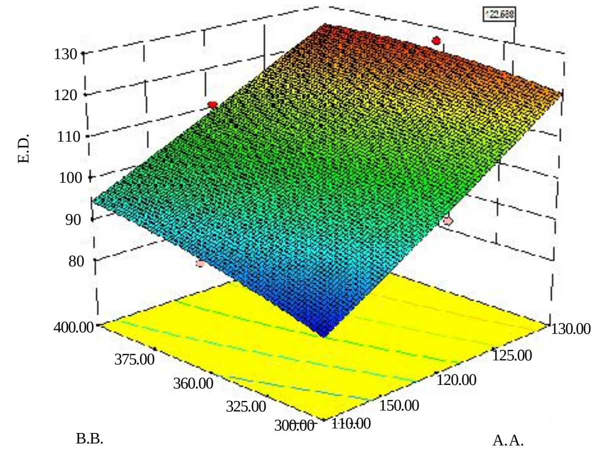

Fig. 4 : Effect of temperature and screw speed on bulk density of the extruded product

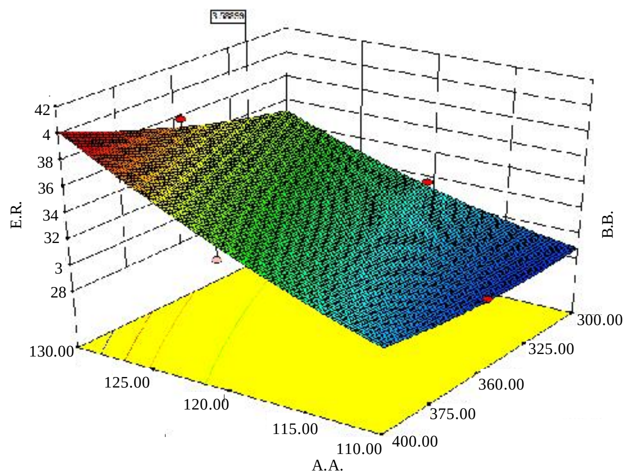

Fig. 2 : Effect of temperature and screw speed on expansion ratio of the extruded product

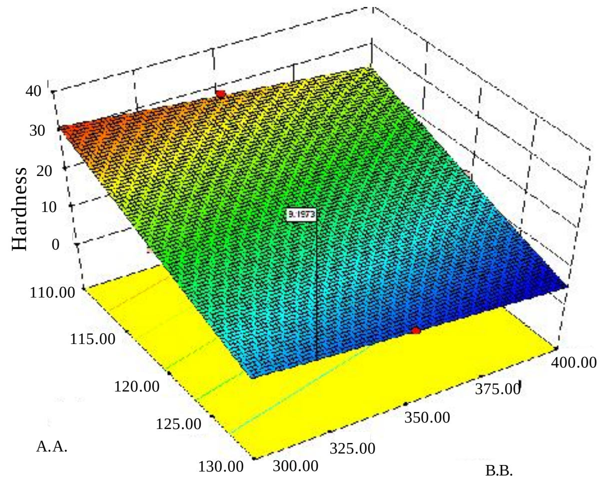

Fig. 5 : Effect of temperature and screw speed on hardness of the extruded product

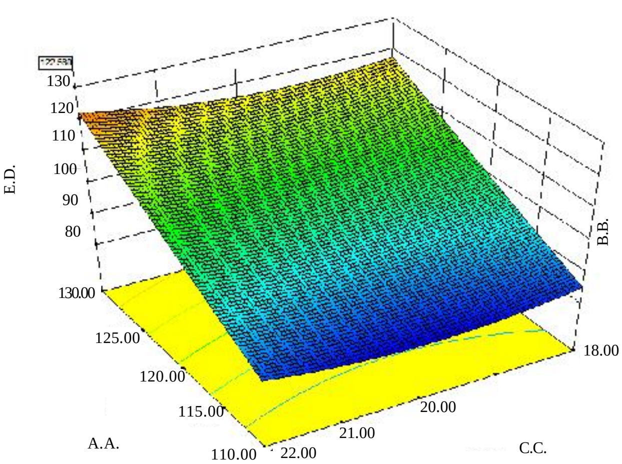

Fig. 3 : Effect of temperature and moisture content on bulk density of the extruded product

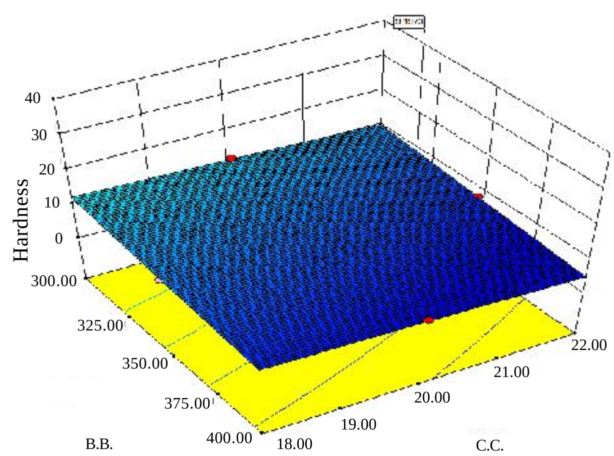

Fig. 6 : Effect of moisture content and screw speed on hardness of the extruded product

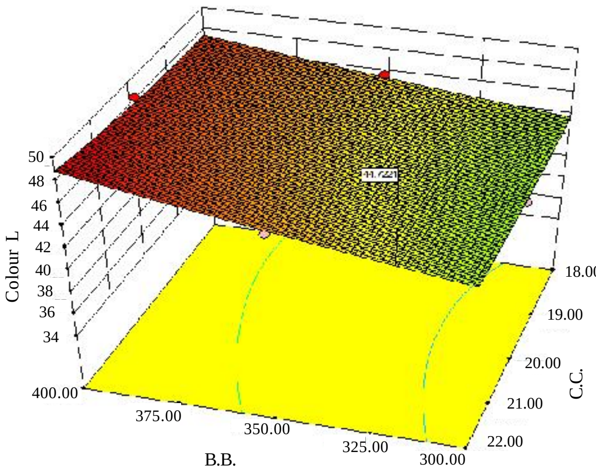

Fig. 7 : Effect of moisture content and screw speed on colour of the extruded product

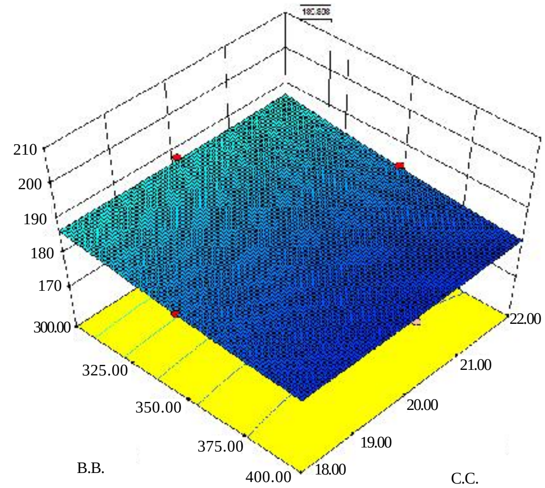

Fig. 10 : Effect of moisture content and screw speed on vitamin-C content of the extruded product

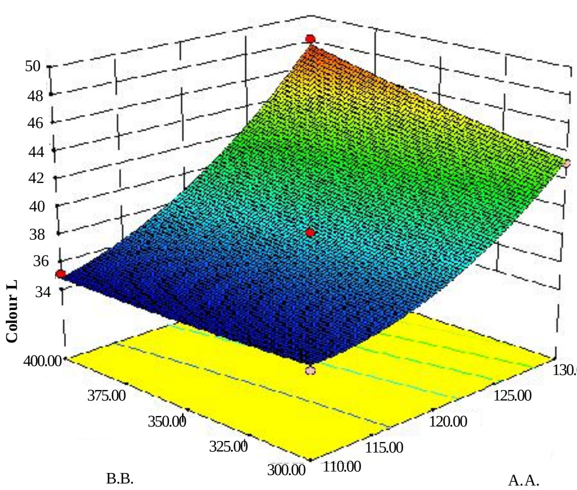

Fig. 8 : Effect of temperature and screw speed on colour of the extruded product

Fig. 11 : Temp. : 125, Screw speed : 310, MC = 22 %

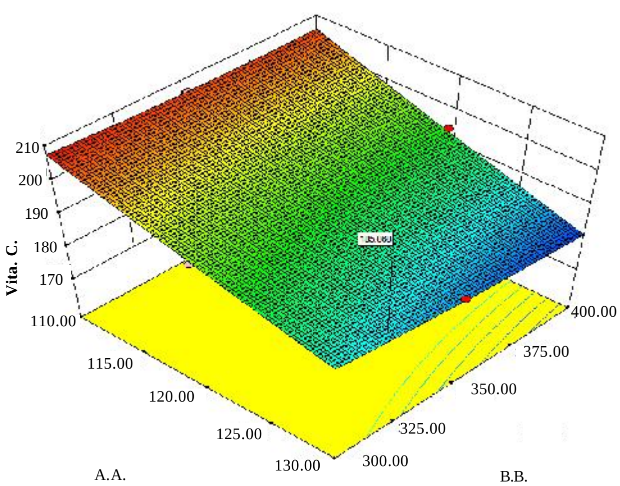

Fig. 9 : Effect of temperature and screw speed on vitamin C content of the extruded product

Fig. 12 : Temp. : 125, Screw speed : 310, MC = 20 %

Fig. 13 : Temp. : 129, Screw speed : 310, MC = 20 %

Fig. 14 : Temp. : 130, Screw speed : 350, MC = 22 %

eliminating non-significant terms.

Using coded variables :

BD =+101.54+16.15* A+3.74* B+1.59* C-1.9* A* B+1.05*A* C+0.52* B* C+0.37* A_2-1.56* B_2 + 3.89* C_2... (R^2 =0.9784) ....(5)

The results indicate that the linear term effects of temperature and feed moisture content as well as quadratic term effects of die temperature and moisture content were significant (eqation 5). It was observed from Table 3 and equation 4 that F values for temperature (A), screw speed (B) and moisture content (C) was 35.25 and in Table 2 p values 0.0001, 0.0058 and 0.1407 ($P < 0.05$), respectively, indicating that the A, B and C are the significant terms. But P values for square term of temperature (A^2) was 0.7872 ($P < 0.01$), showing that the square term for Temperature is most significant (Table 2).

The hardness of expanded extrudate is a perception of the human being and is associated with expansion and cell structure of the product (Meng *et al*., 2009). Response surface for hardness have been presented in Fig. 5 and 6. Hardness was found to vary from 6.32 to 32.35N (Table 2). The regression analysis of the variables yielded following polynomial after removing non-significant terms.

Using coded variables :

Hardness=+18.64-10.17* A-2.98 * B-1.02 * C+0.35* A* B-0.083* A* C-0.043* B* C+0.31* A^2+0.035* B^2-0.16* C^2... (R^2 =0.9995) ..(6)

The results indicate that the linear term effects of temperature, screw speed and feed moisture content as well as quadratic term effects of die temperature and screw speed were significant (eqation 6). It was observed from Table 3 and equation 4 that F values for temperature (A), screw speed (B) and moisture content (C) was 1580.74 and in Table 2 p values 0.0001, 0.0001 and 0.0001 ($P < 0.05$), respectively, indicating that the A, B and C are the significant terms. But P values for square term of screw speed (B^2) was 0.7858 ($P < 0.01$), showing that the square term for screw speed is most significant (Table 2).

Colour :

Colour is an important appealing factor for the consumer to accept the product. Colour changes can give information about the extent of browning reactions such as caramelization, maillard reaction, degree of cooking and pigment degradation during the extrusion process (Ilo and Berghofer, 1999). Response surface for hardness have been presented in Fig. 7 and 8. The lightness (L*) is an indication of the brightness. The lightness value of the products ranges from 34.85 to 48.21 (Table 2). The regression analysis of the variables resulted in following after eliminating non-significant terms.

Using coded variables :

Colour L=+38.15+5.31* A+0.99* B+0.14* C+1.17* A* B+0.20* A* C+0.34* B*C+2.03* A^2+0.17* B^2+0.37* C^2... (R^2=0.9941) ...(7)

The results indicate that the linear term effects of temperature, screw speed and feed moisture content as well as quadratic term effects of die temperature and screw speed were significant (eqation 7). It was observed from Table 3 and equation 4 that F values for temperature (A), screw speed (B) and moisture content (C) was 130.9 and in Table 2 p values 0.0001, 0.0006 and 0.4108 ($P < 0.05$), respectively, indicating that the A, B and C are the significant terms. But P values for square term of screw speed (B^2) was 0.4811 ($P < 0.01$), showing that the square term for screw speed is most significant (Table 2).

Expansion rate :

Expansion characteristics of extruded foods have an important role in the acceptability of the final product (Ibanoglu *et al.*, 2006). Addition of aonla powder decreased the expansion ratio (ER) of the extrudate, which may be due to the high fibre content, that competes for the free water found in the matrix, lowering its expansion capabilities. Fig. 1 and 2 show the responses surfaces for expansion ratio of extrudate. Expansion ratio was found to vary in the range 2.81 to 3.89 (Table 2).

The regression analysis of the variables yielded following polynomial after removing non-significant terms.

Using coded variables :

$$ER = +3.13+0.37*A+0.13*B+0.039*C+0.095*A*B+0.045*A*C+0.027*B*C+0.073*A^2+0.056*B^2+0.06*C^2 ... (R^2 = 0.9674) \quad ..(4)$$

The results indicate that the linear term effects of die temperature, screw speed and feed moisture content as well as quadratic terms effect of die temperature and moisture content were significant (eqation 4). It was observed from Table 3 and equation 4 that F values for temerature (A), screw speed (B) and moisture content (C) was 21.72 and in Table 2 p values 0.0001, 0.0036 and 0.2298 ($P < 0.05$), respectively, indicating that the A, B and C are the significant terms. P values for square term of screw speed (C^2) was 0.2121 ($P < 0.01$), showing that the square term for screw speed is most significant (Fig. 11, 12, 13 and 14).

Vitamin C :

Vitamin C is an important nutrional factor for the consumer to accept the product. As vitamins differ greatly in chemical structure and composition, their stability during extrusion is also variable. The extent of degradation depends on various parameters during food processing and storage, e.g. moisture, temperature, light, oxygen, time and pH. This subject is addressed in reviews on nutritional changes during extrusion (Bjorck and Asp, 1983; Camire *et al.*, 1990; Camire, 1998) and in a review of vitamin retention by Killeit (1994). Minimising temperature and shear within the extruder protects most vitamins. Response surface for vitamin-C have been presented in Fig. 9 and 10. The vitamin C value of the products ranges from 179 to 208 mg/100 g (Table 2). The regression analysis of the variables resulted in following after eliminating non-significant terms.

$$\text{Vita C} = +193.96-11.10*A-1.82*B+0.28*C-1.25*A*B-0.15*A*C-0.050*B*C+0.39*A^2+0.69*B^2+0.3*C^2 ... (R^2=0.9994) \quad ....(8)$$

The results indicate that the linear term effects of temperature, screw speed and feed moisture content as well as quadratic term effects of die temperature and feed moisture content were significant (equation 8). It was observed from Table 3 and equation 8 that F values for temperature (A), screw speed (B) and moisture content (C) was 79.84 and in Table 2 p values 0.0001, 0.0035 and 0.5352 ($P < 0.05$), respectively, indicating that the A, B and C are the significant terms. But P values for square term of temperature (A^2) was 0.6267 ($P < 0.01$), showing that the square term for temperature is most significant (Table 2).

Sensory evaluation :

Sensory evaluation was done to select most acceptable quality product based on quality attributes. The overall acceptability of the product extruded at processing conditions of 125°C die temperature, 22 per cent feed moisture content (w.b) and 310 rpm screw speed was found to be the highest as shown in Table 4.

Table 4 : Mean sensory score for the overall acceptability of the extruded product

Die temperature (°C)	Screw speed (rpm)	MC % (w.b)	Mean sensory score
125	310	20	6.9
125	310	22	6.6
129	310	20	6.1
130	350	22	6.0

Conclusion :

A nutritious ready to eat expanded product based on maize grits, rice flours and aonla was developed for school going children (6-16 years). Feed moisture content have maximum influence on bulk density whereas, the screw speed and die temperature had maximum influence on colour and expansion ratio of the product, respectively. Blends of maize grits, rice flours and aonla (80:10:10) were used as the ingredients for extrusion that would provide the vitamin C requirement of the targeted population with a minimum cost. Based on organleptic evaluation, product extruded at processing conditions of 125°C die temperature, 310 rpm screw speed and 22 per cent (w.b) feed moisture content was found to be most acceptable quality extruded product.

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