Chapter 5

Effect of extrusion cooking on the physicochemical and phytochemical properties of passion fruit powder incorporated red rice extrudates, rheology of doughs and sensory evaluation of product

The Chapter 5 has been discussed under three sub-heads which are as follows;

A) Effect of extrusion parameters on the physicochemical and phytochemical properties of passion fruit powder incorporated red rice product

5.1 Introduction

Rice is the second largest produced cereal worldwide, after wheat. It is the main source for carbohydrate and a minor source of protein, vitamins and minerals. However, epidemiological studies shown that whole rice grains contain high amount of fiber and phytochemicals *viz.*, tocopherols, tocotrienols, oryzanols, vitamin B complex and other phenolic compounds.

In the recent decade a considerable approach has been taken on conversion of fruit into useful products with high shelf life. The reason behind this, fruits are most perishable in nature and increasing disposal thereby loss of valuable substances e.g. dietary fiber, lycopene, antioxidants. Few studies on fruit based food product with long shelf life are *viz.,* extruded orange pomace [16] apple spray dried powder, banana spray dried powder, strawberry spray dried powder,[26] bilberry based food.[15] Most of the attempted was made to develop a snack/breakfast cereal. The passion fruit from North-East India has not been utilized to develop a food product as snack/breakfast cereal.

Extrusion cooking is most widely used techniques for the production of snack, breakfast cereals and texturized vegetable protein.[11,6,21] Extrusion is a continuous cooking and shaping process used in the food induction. Extrusion technology merge various factors *viz.,* temperature, moisture, shearing, and mixing, to produce fruit based snacks/breakfast cereal foods. Therefore, to get a desire quality extruded product, indeed there is need of process optimization for extrusion cooking. Response surface methodology (RSM) is a widely used tool for optimization of design process and efficient mathematical and statistical techniques for analysis of empirical models which can describe the effect of independent variables and their interactions on responses.[29]

On the other hand, the effect of extrusion cooking on physicochemical and phytochemicals properties in terms total phenolic content, phenolic acid, anthocyanin and antioxidant activity of passion fruit powder incorporated red rice based extrudate is not well established. Thus, there is a need of extensive research on physicochemical and phytochemical properties of extrudate from passion fruit powder incorporated red rice.

Therefore, in the present study the extrusion processing of passion fruit powder incorporated red rice was optimized using central composite design. The effect of extrusion cooking on the phytochemical properties such as total phenolic content, phenolic acid, anthocyanin and antioxidant activity was also investigated. In addition to that the thermal, crystallinity and morphological properties of extrudate were characterized.

5.2 Material and Methods

5. 2.1 Raw material

Red rice was collected from the Manigong sub division of West Siang district, Arunachal Pradesh, India. The rice was milled into flour and kept in an air tight container for further used. Ripen passion fruit (*Passiflora edulis* Sims) was also collected in the month of July-September from the Singchung circle of West Kameng district, Arunachal Pradesh. Passion fruit pulp was obtained by squeezing the fruit and the pulp was made into powder using foam mat drying (mentioned in the chapter 4.2.3).

5.2.2   Chemicals

The phenolic acids namely ferulic, sinapic, syringic, hydroxybenzoic, *p*-coumeric, vanillic, caffeic, catechin and chlorogenic acid were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). The amberlite XAD7N resin was also purchased from Sigma-Aldrich Chemical Co. Vitamin standards namely β- carotene, (±)-α-tocopherol and D- α- tocotrienol and anthocyanin namely cynanidine-3-glucoside (C-3-G) and peonidin-3-D-glucoside (P-3-G)were purchase from Sigma-Aldrich.

5.2.3   Extrusion experiments

Extrusion experiments for the production of extruded product from red rice and passion fruit powder were carried by twin extruder with co- rotating screw (Model, FUE-1F, Flytech Engineering, Chennai, India) according to central composite design (Design-

Expert software version 7., U.S.A) which gave 30 experimental runs. Red rice flour (100g) was kept for the base material. The independent variables were temperature (80-150˚), screw speed (200-400rpm), feed moisture content (20-30 %) and amount passion fruit powder (0-15%) (Table 5.1) and dependent variables were expansion ratio (ER) (%), water absorption index (WAI), total phenolic acid (TPC) and 2, 2´-diphenyl-1-picrylhydrazyl (DPPH). After the blending the samples were kept in a LDPE zipper pouch to attain equilibrium. The feed rate was maintained constant at 17 kg/h using a volumetric gravity feeder.

The experimental data were analyzed and fitted to a second order polynomial equation as follows

$$y = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i=1}^{4} \beta_{ii} x^2_{ii} + \sum_{i=1}^{3} \sum_{j-i+1}^{4} \beta_{ij} x_i x_j$$

y is the predicted response, coefficient of the polynomial equation were β_0 (constant), β_i (linear effects), β_{ii} (quadratic effects) and β_{ij} (interaction effects). x_i and x_j are the coded levels of independent variables i and j in the equation given.

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Table 5.1 Independent variable values of the extrusion process and their corresponding level

Variables	Coded value	Level				
		-α	-1	0	+1	+α
Temperature (˚C)	x_1	80	97.5	115	132.5	150
Screw speed (rpm)	x_2	200	250	300	350	400
Feed moisture content (%)	x_3	20	22.5	25	27.5	30
Passion fruit powder (%)	x_4	0	3.75	7.5	11.25	15

5.2.3.1 Expansion ratio

Expansion ratio of the extrudate was determined according to Ding et al.[10] Vernier calliper was used to measure the cross-sectional diameter of the extrudate. The expansion ratio was calculated as the cross-sectional diameter of the extrudate divided by the cross-sectional

diameter of the die opening and the values were obtained from 10 random samples for each extrusion condition.

$$\text{Expansion ratio} = \frac{\text{Extrudate diameter}}{\text{Die diameter}}$$

5.2.3.2 Water absorption index

Water absorption index (WAI) was determined using the method described by Anderson et al.[1] Briefly, 2 g of the grounded extrudates was dispersed in 25 mL distilled water in a centrifuge tube and sample was kept in water bath for 30 min at 30˚C. Later, centrifuge tube was kept in a centrifuge at 3000 g for 10 min. The supernatant was poured carefully into a dish. WAI was calculated as the ratio of mass of the precipitate to the mass of the original sample dry weight.

$$\text{Water absorption index} = \frac{\text{Mass of the precipitate}}{\text{Mass of the original sample (dry weight)}}$$

5.2.3.3 Total phenolic content

Determination of total phenolic content of grounded extrudate was carried out by Folin–Ciocalteu assay [31] (method previously described in section 3.2.4.2).

5.2.3.4 DPPH radical scavenging activity

DPPH radical scavenging ability of the grounded extrudates was measured according to the method of Brand-William et al. [7] (method described in section 3.2.4.4).

5.2.4 Fourier transform infrared spectroscopy (FT-IR) analysis

Fourier transform infrared spectroscopy (FT-IR, Nicolet impact 410, Thermo scientific, United Kingdom) analysis was carried out to detect functional group present in extruded products (method described previously in section 3.2.4.6).

5.2.5 Differential scanning calorimeter (DSC) analysis

Thermal analysis of red rice (C) and extruded red rice with passion fruit powder (O) were carried out by differential scanning calorimeter, (DSC-60 SHIMADZU, instrument, TA-60WS, Japan) (method described previously in section 3.2.3.10).

5.2.6 X-Ray diffraction (XRD)

The method used was described in 3.2.9.

5.2.7 Morphological structure analysis by scanning electron microscopy (SEM)

Extruded samples were investigated for morphological structure (JEOL JSM-6390LV, SEM, Oxford) after undergone extrusion processing. Samples were placed carefully in a metal stud with double-sided tape, using a sputter gold coater. Morphological structure of extrudates graphs were observed at a magnification of 100X and 25000 X with accelerating voltage of 10 kV.

5.2.8 Phytochemical profiling

The phytochemical profiling of red rice (C) and red rice incorporated with passion fruit extrudate (O) were carried out in terms of β- carotene (±)-α-tocopherol and D-α-tocotrienol, cynanidin-3-glucoside (C-3-G) and peonidin-3-d- glucoside (P-3-G) content using RP-HPLC (Water Corporation, USA) with UV Detector.

5.2.8.1 Determination of β- carotene (±)-α-tocopherol and D-α-tocotrienol

The β-carotene, (±)-α-tocopherol and D-α-tocotrienol of extrudates were determined according to the modified method of Aguilar-Garcia et al. [2] (method was described previously in the section 3.6.3.6)

5.2.8.2 Determination of cynanidin-3-glucoside (C-3-G) and peonidin-3-d- glucoside (P-3-G)

5.2.8.2.1 Purification of sample

Samples (3g) were weighed and extracted with 70% ethanol. Purification of anthocyanin compound was done using activated amberlite XAD7N resin as described by Fu et al.[12]

with slight modification. The resins were kept soaked in 95% ethanol for 24 h and thoroughly washed by deionized water. Then the resins were treated by 1 mol/L HCl and Na OH solutions to remove any monomers trapped inside. Activated amberlite XAD7N resin (0.5 g) was added to a 250 mL conical flask with 40 mL of extract, shaken thoroughly at 45 rpm at 25˚C for 6 h. After adsorption, the anthocyanin was desorbed in ethanol (95%) solution for 12hr at 150 rpm. The extracts were filtered and stored in refrigerator at 4˚C for 2 days to initiate precipitation of large molecules and centrifuged at 12000 g (5˚C) for 20 min. The upper layer was concentrated and filtered through 0.45 μL syringe filter before being injected to HPLC. The HPLC pumps (LC-10AT, Shimadzu) and column were connected with a dual wavelength UV/VIS detector (SPD-10A, Shimadzu) for analysis. HPLC analysis was carried out at 25˚C with C18 column (4.6 mm x 250mm) at 530nm. The solvents mixture used were water, methanol and formic acid (75:20:5 v/v) as a mobile phase with isocratic elution at 0.5 mL/min flow rate.

5.2.9 Statistical analysis

Statistical analysis was conducted using a Design-Expert version 7.00 (Stat-Ease Inc., Minneapolis, USA). Statistical significance of the dependent and independent terms was analyzed by analysis of variance (ANOVA) for each response.

5.3 Results and discussion
5.3.1 Model fitting

The analysis of variance (ANOVA) of the experimental data were presented in Table 5.2. The Table shows the F and p values of linear, quadratic and interaction term. It was observed that the independent parameters $viz.,$ temperature, screw speed, feed moisture content and amount of passion fruit powder had significant ($P \leq 0.05$) effect on dependent parameters. The regression coefficient value for expansion ratio (%) ($R^2=0.90$), water absorption index (%) ($R^2=0.88$) total phenolic content (mg GAE/100g) ($R^2=0.84$) and DPPH scavenging activity (%) ($R^2=0.87$) were good which imply that the second order quadratic model is most suitable and the developed model can efficiently depict the relationship between dependent and independent parameters.

Table 5.2 Analysis of variance (ANOVA) for the fitted quadratic polynomial model

Source	ER		WAI		TPC		DPPH	
	F-value	*p-value*	*F-value*	*p-value*	*F-value*	*p-value*	*F-value*	*p-value*
Model	10.79	< 0.0001	8.00	0.0001	5.99	0.0007	7.78	0.0002
x_1	115.79	< 0.0001	5.55	0.0325	8.19	0.0119	71.95	< 0.0001
x_2	4.64	0.0478	40.14	< 0.0001	4.74	0.0459	5.01	0.0407
x_3	0.44	0.5172	42.59	< 0.0001	2.90	0.1092	2.05	0.1732
x_4	0.68	0.4237	0.047	0.8305	5.56	0.0323	7.69	0.0142
$x_1 x_2$	1.75	0.2054	0.36	0.5571	0.31	0.5835	4.48	0.0515
$x_1 x_3$	0.016	0.9010	0.79	0.3893	0.51	0.4880	2.12	0.1658
$x_1 x_4$	1.40	0.2545	0.18	0.6746	1.46	0.2454	0.033	0.8588
$x_2 x_3$	0.30	0.5892	0.93	0.3504	1.25	0.2816	0.58	0.4585
$x_2 x_4$	0.45	0.5121	0.31	0.5885	13.26	0.0024	0.43	0.5198
$x_3 x_4$	3.28	0.0902	0.57	0.4627	4.18	0.0588	9.581E-003	0.9233
x_1^2	6.70	0.0206	0.12	0.7302	17.40	0.0008	12.31	0.0032
x_2^2	0.74	0.4022	0.43	0.5197	20.08	0.0004	1.24	0.2996
x_3^2	2.00	0.1781	11.37	0.0042	7.26	0.0167	4.53	0.0425
x_4^2	6.09	0.0261	3.77	0.0712	14.60	0.0017	0.37	0.2507
Lack of fit	2.01	0.2283	01.39	0.3758	1.99	0.2318	3.07	0.1136
R^2	0.90		0.88		0.84		0.87	
Adjusted R^2	0.82		0.77		0.70		0.76	

5.3.1.1 Response surface analysis of expansion ratio

The expansion ratio (ER) of the extruded product was significantly affected by the independent parameters of extrusion cooking. Table 5.2, illustrated that the regression coefficient (R^2) value ($R^2=0.90$) was quite high which implies that the developed equation can efficiently represent the relationship of expansion ratio and independent parameters. The Fig 5.1(a), depicted the relationship between screw speed (rpm), temperature ($^\circ$C) and moisture content (%) on the expansion ratio of extrudates (%).

$$ER = 9.42 + 2.34x_1 + 0.47x_2 - 0.14x_3 - 0.18x_4 + 0.35x_1x_2 + 0.034x_1x_3 - 0.33x_1x_4$$
$$-0.15x_2x_3 - 0.19x_2x_3 - 0.51x_3x_4 + 0.52x_1^2$$
$$+0.17x_2^2 + 0.29x_3^2 - 0.50x^2_4$$

From the Fig 5.1a, it was observed that for the increase of screw speed there was a decrease in ER until 300 rpm, however, with further increases in screw speed slight increase in ER was observed. For the increase in barrel temperature ER of product increased significantly (Fig 5.1a). As the temperature increased from 80 to 150˚C proportionally the expansion ratio also increased from 0-20 % and similarly types of results were reported by previous worker.[10] Ding et al.[10] suggested that an increase in the barrel temperature may increase the degree of superheating of water in the extruder that enhance the bubble formation in finish product and thereby increased in expansion ratio. The effects of moisture content on the ER of extruded product has been presented in Fig 5.1b. As the moisture content of the extrudates increased (20-25%) there was a slight decrease in expansion ratio (Fig 5.1b). But later further increase of moisture content showed increased in ER of the products. Although increase of passion fruit powder in dough increased in expansion ratio, but it was found not significant (Fig 5.1b).

5.3.1.2 Response surface analysis of water absorption index

After multiple regression analysis of water absorption index of the finished product and experimental data of independent variable, a second order polynomial equation with high regression coefficient value ($R^2=0.88$) was predicted. The lack of fit of the developed model was also insignificant (Table 5.2), which implies that the developed model can efficiently explain the relationship of water absorption index and independent parameters.

$$WAI = 2.10 + 0.18x_1 - 0.48x_2 + 0.50x_3 + 0.017x_4 + 0.056x_1x_2 + 0.083x_1x_3 +$$
$$0.042x_1x_4 - 0.090x_2x_3 - 0.054x_2x_4 - 0.074x_3x_4 - 0.025x_1^2 + 0.047x_2^2$$
$$-0.24x_3^2 + 0.14x_4^2$$

The effect of screw speed and barrel temperature on water solubility index are presented in Fig. 5.1c. It can be inferred from the Figure that the increase of screw speed (200-400rpm) leads to a sharp decrease in the water absorption index (%) whereas increased temperature (80-150˚C) showed abrupt increases in the water absorption index (0.9-4.3). The similar types of result were reported by several workers during the extrusion of legumes [24] and rice [4] respectively. At higher screw speed the length of polymeric chain reduces due to shear, hence, the water solubility index of extrudate decreases. The results are in agreement with the observation reported by Alam et al.[4] Various researchers have reported the phenomenon of starch granule disrupted in high temperature processing thereby increased dextrinization which enhanced the water binding capacity of finish product and hence increased WAI.[4,18] These finding was agreement with findings during extrusion of carrot pomace and rice flour.[18]

In Fig 5.1.d, the effect feed moisture content showed an increased in WAI upto the moiture content of 25 %, further increases in moisture content showed slight decrease in WAI. Previous researchers Singh et al.[32] and Chakraborty et al.[8] reported that in higher feed moisture content, viscosity of starch in the flour might be decreased and allows the starch molecules to move freely and thereby enhancing the penetration of heat, results greater gelatinization and increases WAI of the finished product. WAI decreased with increase in moisture content, which may be attributed to the reduction of elasticity of dough through plasticization of melt at higher moisture content.[10] With increase in passion fruit powder up to 7.5%, WAI of finished product slightly decreased however, after 7.5% of passion fruit there was further increase of WAI of the product was observed (Fig 5.1f). Similar type of result was observed by Jones et al.[17] during the extrusion of rice pea blends. The results indicated that the presence of more passion fruit powder in the mixture reduced the availability for gelatinization of the starch granules, thus reduced viscosity and WAI because of the replacement of the starch by fiber component.

5.3.1.3 Response surface analysis of total phenolic content

The effect of extrusion parameters on the total phenolic content of the extruded product was mathematically expressed using the following model. It was observed that the

regression coefficient value (R^2=0.84) of TPC for the product was quite high and lack of fit was insignificant which implies that the developed second degree polynomial equation can efficiently be used to predict the relationship (Table 5.2).

$$TPC = +119.75 - 7.36x_1 - 5.6x_2 + 4.38x_3 + 6.26x_4 - 1.77x_1x_2 + 2.25x_1x_3$$
$$+4.01x_1x_4 - 3.53x_2x_3 - 12.06x_2x_4 - 6.77x_3x_4 - 9.97x_1^2$$
$$-10.71x_2^2 - 6.44x_3^2 - 9.13x_4^2$$

The effect of process variables *viz.,* screw speed (rpm) and temperature (˚C) on total phenolic content (mg/100g) is been illustrated in Fig 5.1.e, As the screw speed increased until 300 rpm, the total phenolic content also increased but later the trend showed decreasing pattern with increasing screw speed. The increase in phenolic content in the finished product may be due to the release of bound phenolic compound from the rice at high screw speed for the breakdown of endosperm.[13] The further increase in screw speed during extrusion showed a decreasing pattern of TPC content in finished product. The decrease in TPC may be ascribed either to the disintegration of phenolic compounds as a result of high shear during extrusion or to the change in molecular arrangement of phenolic compounds. Temperature variable also showed the same pattern with screw speed. With increase in temperature from 80-150˚C, the TPC also increased till 110˚C, later the TPC was decreased with the increasing temperature (Fig 5.1.f). The increase in TPC during extrusion could be due to the damage of cell structures and facilitate the release of bioactive compounds from the matrix, thus enhance the extractability of bound phenolics in the materials.[30] The decrease in the phenolic content after 110˚C may be due to the heat labile nature and lesser resistant to thermal processing.[35] Due to increase in temperature either decomposition or alteration of the molecular structure of phenolic compounds took place. This led to a reduced chemical reactivity due to a certain degree of polymerization in the sample.[3,5,23,28] In the Fig 5.1.h, TPC increase with increase in moisture content (20-25 %), and later it showed a negligible decrease in the TPC when moisture content further increased up to 30 %. This was supported by a study conducted by Dlamini et al.[9] The higher moisture content probably upgraded phenolic and tannin polymerization, which affect extractability of polyphenols *viz.,* phenols and tannins, and degrade antioxidant activity. In the Fig 5.1i, the TPC showed an increase pattern in the finished product, as the passion fruit ranged increased to 7.5 %, beyond that the TPC content remained constant with the further increase in passion fruit powder. Increase in the TPC amount may be

attributed to high phytochemical content of passion fruit and during extrusion, it may realese fron the cell and inceased the TPC content.

**5.3.1.4 Response surface analysis of DPPH scavenging activity**

The second order polynomial relationship between DPPH scavenging activity and independent parameters. The Table 5.2, shows that the regression coefficient value (R^2=0.87) was quite high and the lack of fit of the model was insignificant which implies that the developed model can efficiently depict the relationship.

$$DPPH \text{ s}cavenging \text{ } activity = 37.88 - 6.85x_1 - 1.81x_2 - 1.15x_3 + 2.31x_4 - 2.10x_1x_2$$
$$-1.45x_1x_3 - 0.19x_1x_4 + 0.75x_2x_3 - 0.69x_2x_4 - 0.10x_3x_4 - 2.63x_1^2$$
$$-0.81x_2^2 - 1.66x_3^2 - 0.90x_4^2$$

Screw speed showed significant effect on DPPH scavenging activity, as the screw speed increased from 200-300 rpm, DPPH scavenging activity also increased (Fig 5.1g). Further increase in screw speed, DPPH scavenging activity decreased. The increases in scavanging activity of the extrudat product has been widely reported.[28] The DPPH scavenging activity is directly depended upon the TPC of the sample. Therefore change in TPC content in the extrudate product due to screw speed proportional changed the DPPH scavging activity. As the temperature increased from 80-110°C, DPPH scavenging activity increased and beyond that a decrease pattern in scavenging activity was observed till 150°C (Fig 5.1g). Similar type of obseravtion was reported by Sharma et al.[28] The increase in scavenging activity may be due to the increase in TPC in the product for the lysis of cell structure or Maillard reaction. The decrease in scavenging activity may be due to the decrease in TPC during higher temperature extrusion.[5] Moisture content showed a significant effect on the DPPH content. As the moisture content increased from 20-30 %, DPPH scavenging activity also increases which was similar to the behavior of TPC in product. Passion fruit powder has showed a significant effect on DPPH content, as the temperature increased from 0-7.5% the DPPH content increases and beyond that there was a slight decrease in scavenging activity (Fig 5.1h). This observation was quite similar as observed in TPC in the product.
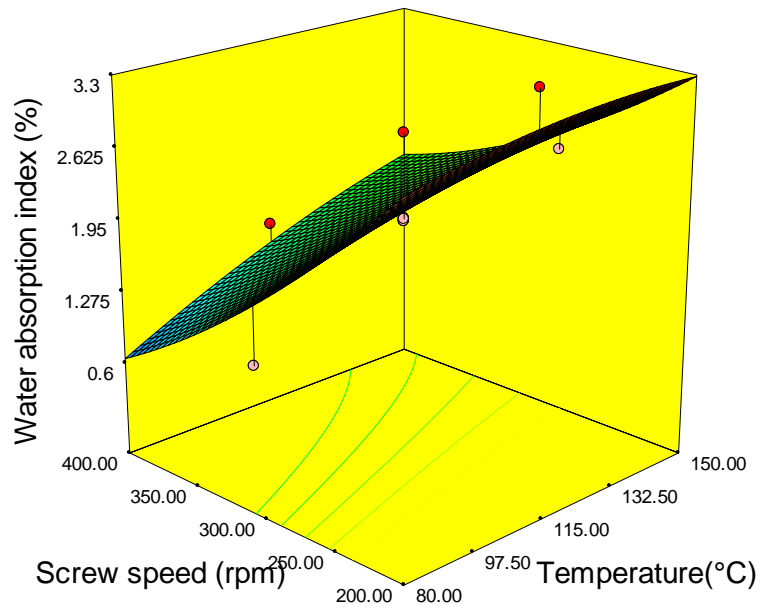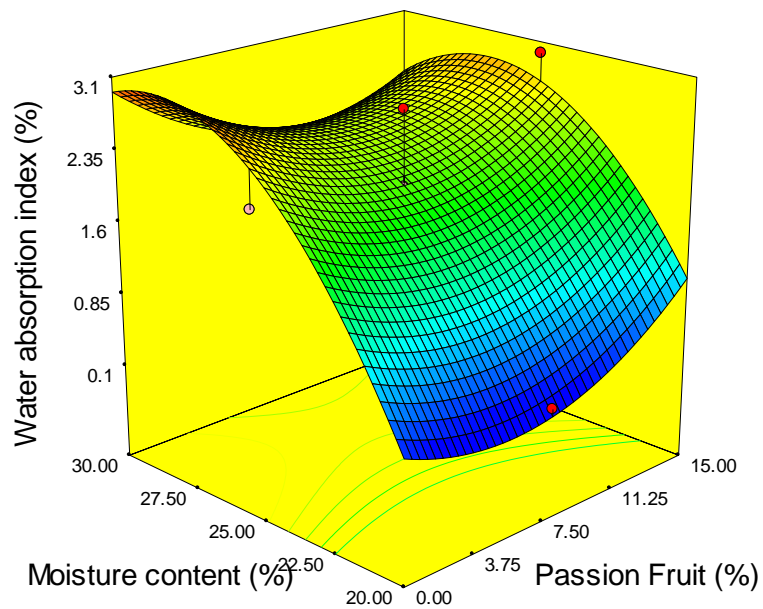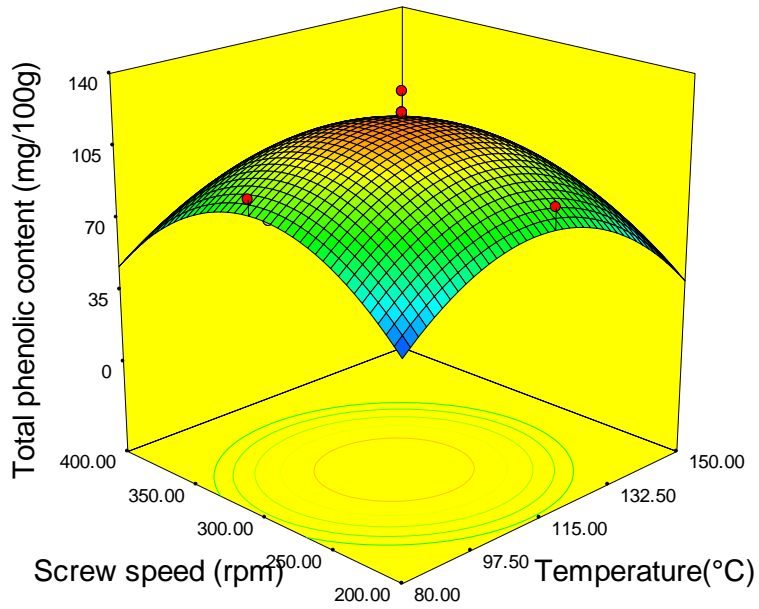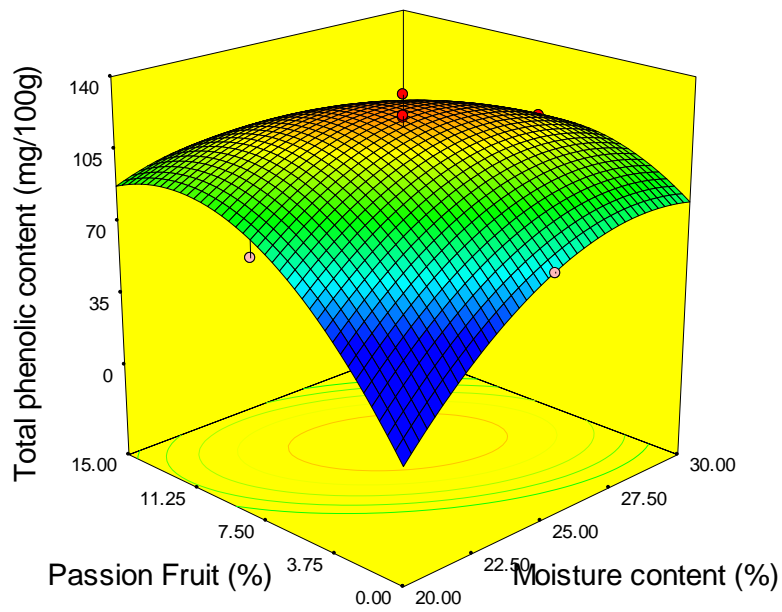
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(b)

(c)
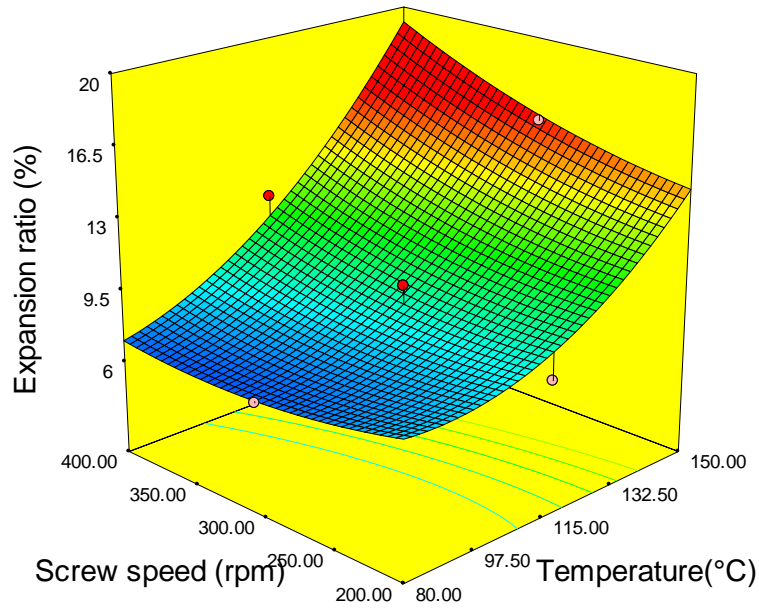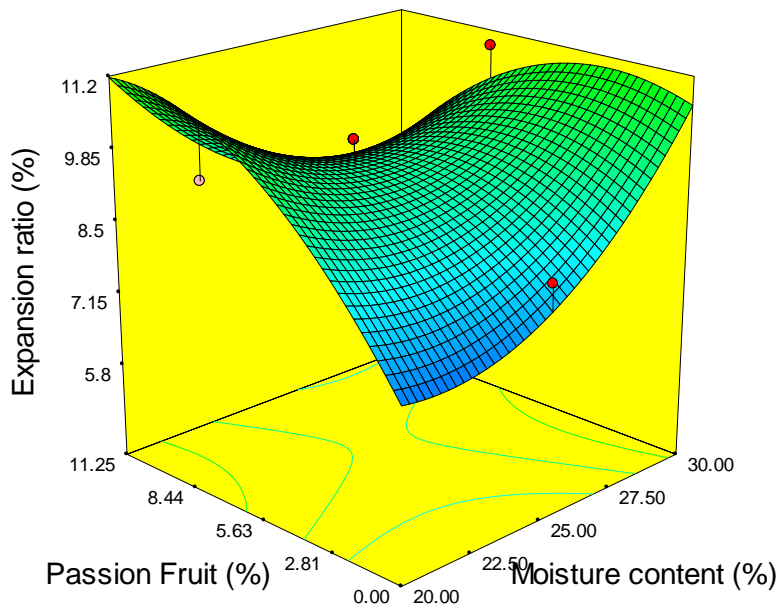
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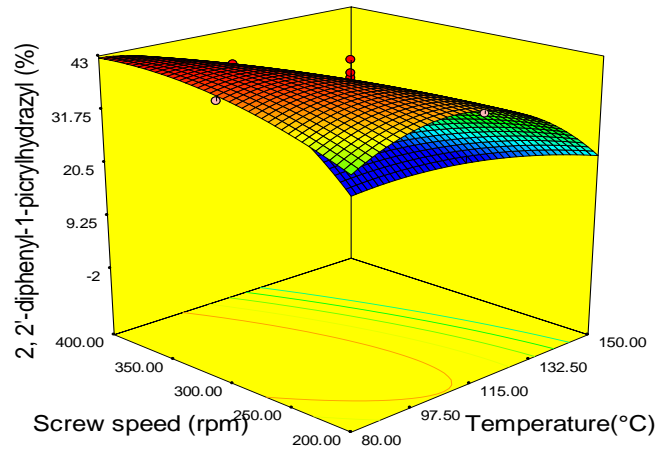
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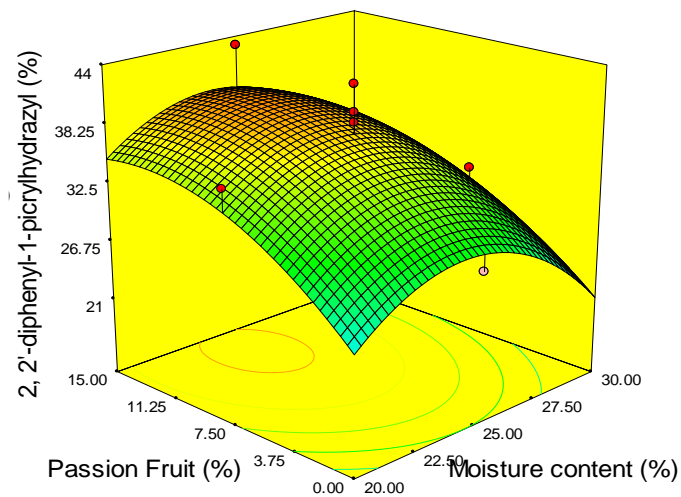
(h)

Fig. 5.1 Response surface 3D graphs on; (a-b) Effect of screw speed (rpm), temperature (˚C) and moisture content (%) on expansion ratio (%); (c-d) Effect of screw speed (rpm), temperature and moisture content (%) on water absorption index (%); (e-f) Effect of screw speed (rpm); total phenolic content (mg/100g); (g-h) Effect of screw speed (rpm) and temperature (˚C), moisture content and temperature (˚C) on DPPH (%).

5.3.2 Optimization and validation

After the response surface analysis, the extrusion process was optimized. The process was optimized in terms of maximum desirability value. The highest desirability value was 0.906 and the extrusion conditions were temperature 97.50˚C, screw speed 250 rpm, feed moisture content 25.20% and passion fruit powder 11.25 %. At the optimum condition, the predicted values of response were ER 8.05, WAI 2.77, TPC 129.492 mg GAE/100g and DPPH scavenging activity 65.79%. After optimization, the responses were validated. During validation, the experiment was conducted at optimized condition and observed experimental values of ER (7.08 %), WAI (2.18), TPC (130.10 mg GAE /100g) and DPPH scavenging activity (63.01%) and did not differ significantly.

5.3.3   Characterization of extrudates

5.3.3.1   Fourier transform infrared spectroscopy (FT-IR) analysis

In FT-IR spectrum of optimized sample (Fig. 5.2) was compared with the control sample. The figure shows various peaks in different wavelengths ranges from 562.60.70-3978.34 cm^{-1} and predicts about major functional groups. The band peaks found approximately in the region of 826.60 cm^{-1} indicated α-glycosidic linkages of the glycosyl residues [33] which confirmed the samples were carbohydrate in nature. The frequency of the vibration at 1498 cm^{-1} corresponds to COOH group. The small peaks at around 2322 cm^{-1} were the characteristics of –NH and NH+ group, respectively. There were numbers of sharp peaks in between 3350.00 to 3821.87 in both the samples. Various researchers have suggested that these broad bands observed from 3610–3640 cm^{-1} and 3200–3500 cm^{-1} is attributed to –OH stretching vibrations and hence, indicates the presence of phenolic OH.[25] The products showed that even after the extrusion technology the wavelengths predicted the presence of various functional groups and was present in both samples.
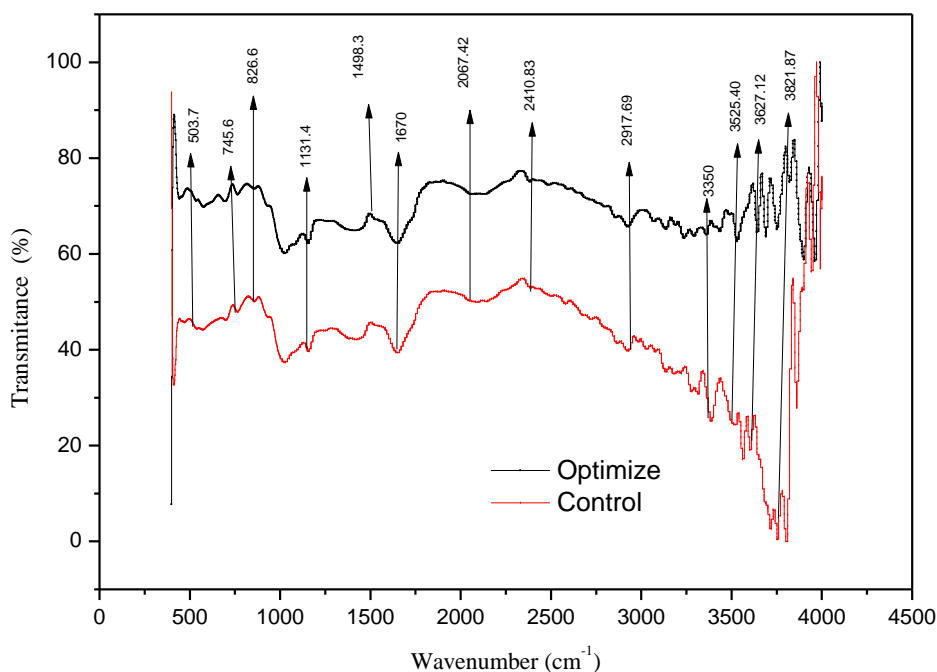
Fig.5.2 FT-IR spectra of control (C) and optimized (O) extrudate

5.3.3.2 Differential scanning calorimetry (DSC) of sample

The thermal properties of the optimized product were analyzed using differential scanning calorimetry (DSC). DSC thermograph showed an endothermic behavior of extruded product (Fig 5.3) Thermal properties of extruded products was presented at Table 5.3 The onset (61.31± 0.71) and peak temperature (62.810 ±0.1˚C) of control sample was higher than the onset (45.77±0.21˚C) and peak temperature (50.53±0.37˚C) of optimized sample. But end set temperature (84.43± 0.39) of optimized sample showed higher range than control sample (65.55±0.38). Kaur et al.[19] reported that this type of phenomena in cereal flour may be attributed to the extrusion technology that helps the starch to become pre gelatinized. Loss of birefringence, which later indicates the disorder of the starch molecules was also found. Therefore, extruded products flours attain gelatinization temperature at lower temperature as compared to the raw cereal flours.

Table 5.3 DSC thermograms of rice flours

Types	Gelatinization (˚C)		
	T_0	Tp	Tc
C (control)	61.31± 0.71	62.81 ±0.1	65.55 ±0.38
O (optimized)	45.77±0.21	50.53±0.37	84.43± 0.39

Note: T_c, endset temperature; T_o, onset temperature; Tp, peak temperature
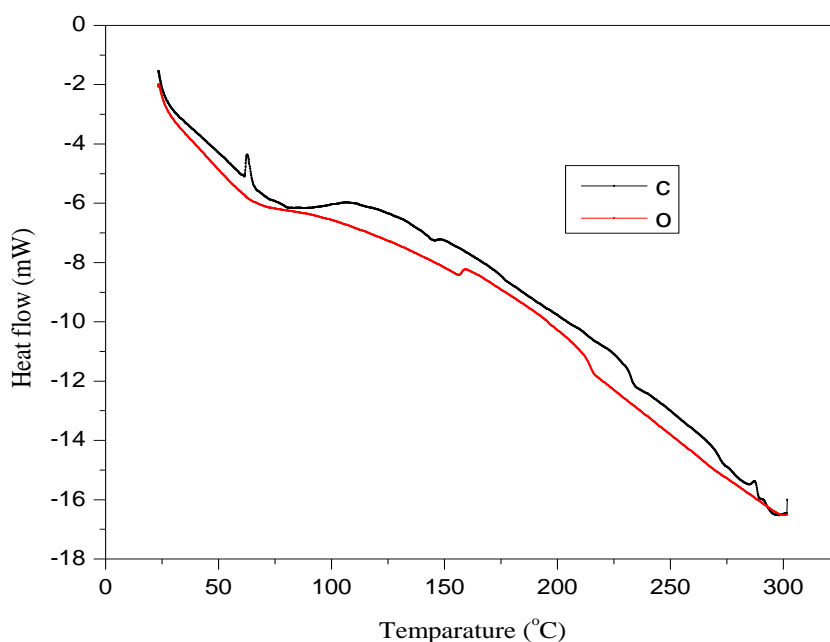
Fig.5.3 DSC graph of control (C) and optimized (O) extrudate

5.3.3.3 X-ray diffraction (XRD) pattern of sample

X-ray diffraction pattern provide "fingerprint" information of the crystal structure within starch of grains.[37] From the Fig 5.4, the XRD analysis of samples revealed strong peaks of control sample at 2θ *viz.*, 12.72,18 and 18.82 and for optimized sample were 18.18,20 and 23.50. According to various researchers, peaks obtained at 15 and 18 confirmed the presence A-type which are the characteristic of starch present in cereals and also supported by Taylor et al.[34] Weak peaks were also observed at 15, 18.82, 19.82 and 23.5. Moorthy [22] stated that peak at 2∅ = 15 and 23.5 showed mixed pattern and 18 possess C type pattern.[36]

Both the sample shows similar types of peaks which indicates the presence of A-type starch in red rice and passion fruit powder. Gat and Ananthanarayan [14] stated that during extrusion process loss of granular structure of pregelatinized rice flour and give mixed pattern of starch. % Crystallinity of control extrudates were 56.22 % and optimized was 65 %.
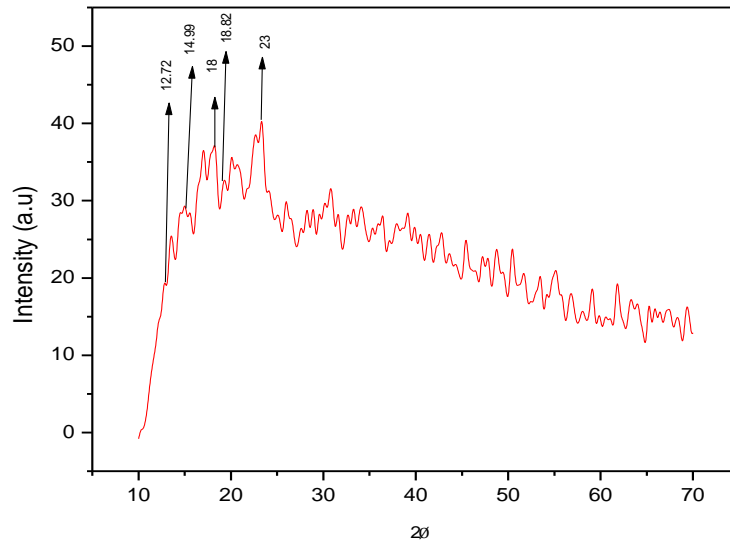
(a)
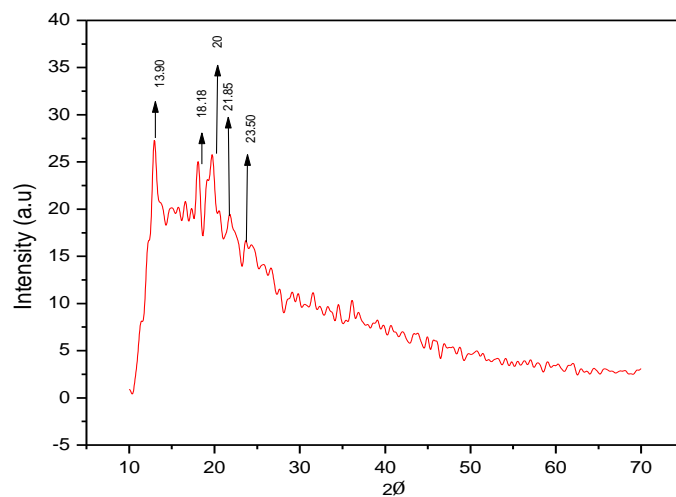
(b)

Fig.5.4 XRD graph of control (C) and optimized (O) extrudate

5.3.3.4 Morphological analysis of sample

Scanning electron microscopy (SEM) images of the surface and cross sections of two extruded products at three magnifications 100X and 2500X. Fig 5.5, revealed that control sample (C) had smoother surface than the optimized (O) sample. It could be seen from the figure that the internal structures of the product were affected by the addition passion fruit powder. The control sample was characterized as having a continuous structure that appeared smoother and aggregated. Marked changes were observed by incorporating passion fruit powder where surface became scratched, cracked, and rougher. The optimized extruded product had large numbers of flattened and sheared granules than the control product.
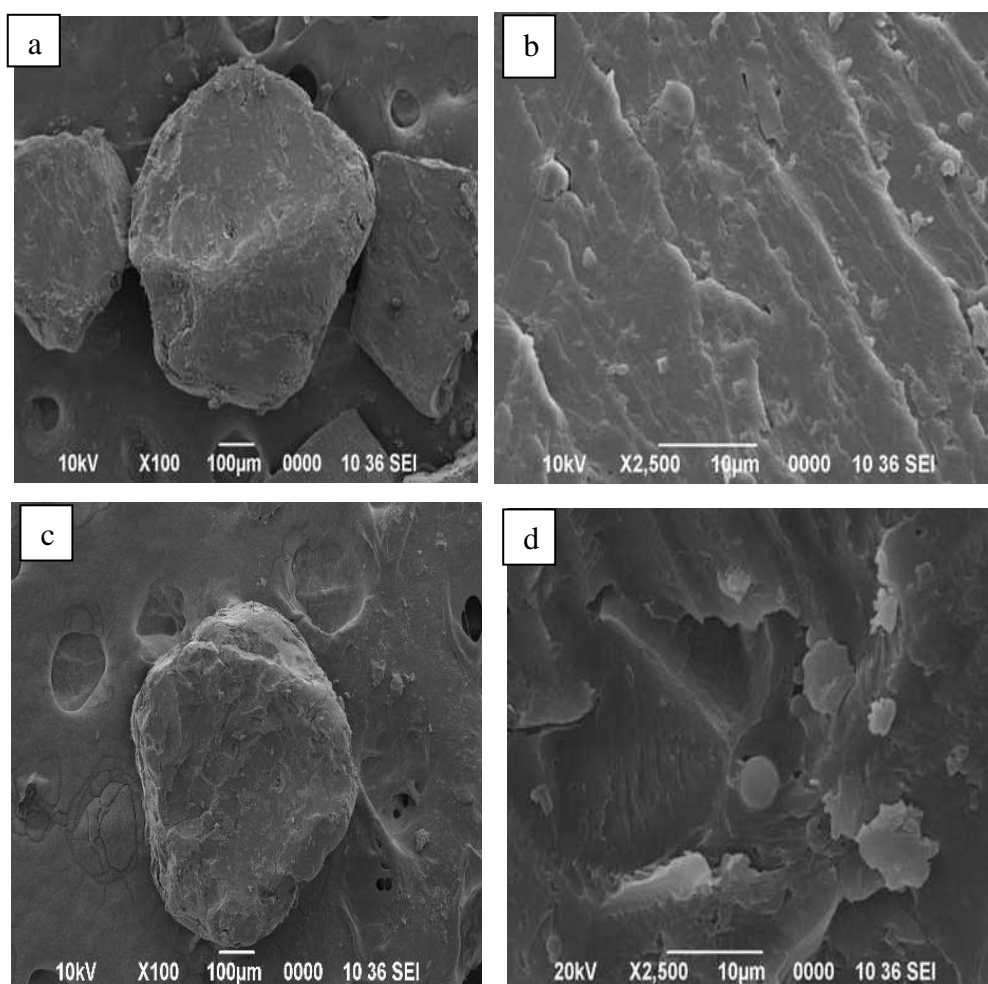

Fig 5.5 SEM of control (a and b) and optimized (c and d) sample at 100 and 2500 magnification

5.3.3.5 Phytochemical profile of sample

The phytochemical properties of control sample and optimized sample were analyzed by quantification of compounds *viz.,* vitamins and anthocyanin. In the Table 5.4, among three vitamins, optimized product (red rice incorporated with passion fruit foam mat powder) sample showed higher content of (±)-α-tocopherol and D-α-tocopherol than control. This may be due to addition of foam mat fruit powder which retain more bioactive compounds than the normal drying process. Anthocynanin *viz.,* cynanidine-3-glucoside (C-3-G) and peonidin-3-D-glucoside (P-3-G) content in control and optimized samples showed very less amount of both anthocyanin compound. The reduction may be due to the extrusion processing on the red rice. Literature revealed that the unprocessed red-pigmented rice varieties contained 19.36-37.00 mg/kg vitamin E with an average of 29.77 mg/kg.[22] Laokuldilok et al.[20] stated that aromatic red rice content very important anthocyanin compounds like cyanidin-3-glucoside (179.0±77 µg/g) and peonidin-3-glucoside (9.1±1.4 µg/g).

Table 5.4 Quantification of compounds vitamins and anthocyanin of control (C) and optimized (O) extrudate

Compounds (mg/L)	Retention time (min)	Sample	
		C (control)	O (optimized)
Vitamins			
β-Carotene	3.00	1.33310	1.31090
(±)-α-tocopherol	3.50	3.99810	9.57140
D-α-tocopherol	3.80	3.99690	9.03690
Anthocyanin			
Cynanidine-3-glucoside (C-3-G)	11.00	0.00003	0.000003
Peonidin-3-D-glucoside(P-3-G)	13.00	0.0093	0.00546

5.4   Conclusion

Extrusion cooking of passion fruit powder incorporated rice based extrudate was optimized successfully using CCD. In this study it has been observed that the incorporation of passion fruit powders has an impact on the physical and phytochemical characteristics of extrudates. The optimal extrusion process condition was found to be temperature 97.50˚C, screw speed 250 rpm, feed moisture content 25.20% and passion fruit powder 11.25 %. After optimization of extrusion process, the optimum product was compared with control sample in terms of physicochemical and phytochemical properties. The thermal and morphological properties of product showed that the incorporation of passion fruit powder has a significant effect.

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B) Rheological properties of gluten free dough

5.5 Introduction

Rheology explains about the flow and deformation of food. Rheology plays a vital role in food manufacture and marketing nowadays *viz.,* design of handling systems, quality control and evaluation of sensory stimuli of viscosity.[3] It also concerned with how all food materials respond to applied forces and deformations. Basic concepts of stress (force per area) and strain (deformation per length) are keys to all rheological evaluations. Stress (r) is always a measurement of force per unit of surface area and is expressed in units of Pascals (Pa). The direction of the force with respect to the impacted surface area determines the type of stress. Normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression. Shear stress occurs when the forces act in parallel to a surface. Various food show different rheological behavior and categorized into solid and liquids stages. It basically means that food varies their characteristic in viscous and elastic behaviors commonly known as viscoelasticity of food cause by entanglement of long chain molecules with other molecules.[1]

Nowadays, the use of additives has become a common practice in the cereal processing industry. Additives in dough help to improve dough handling properties, increase nutritional quality and extend the shelf-life of stored product. However, few study has been conducted on addition of fruit powder in rice base food product [10] and scanty of research on the incorporation of passion fruit powder in rice dough are available. The acceptability of a food product for consumer mainly depend upon structure, mouthfeel, acceptability and shelf-life of the product. All these parameters are directly or indirectly related with rheological properties of dough and is pertinent to investigate the role of different rheological parameters of passion fruit incorporated rice dough.

Extruded foods products behave as non-Newtonian Fluids and their viscosity can be predicted by the Power Law model.[7] The Power law (Ostwald) and Bingham models [19, 2] reported to have adjustable parameters and most widely used. Rheological properties of fluid foods are complex and dependable on composition, shear rate, duration of shearing, and previous thermal and shear histories.[14, 22]

Samyor et al. (2017). Effect of passion fruit powder on rheological properties of gluten free red rice dough. Journal of Texture Studies (Under Review).

Therefore, the effect of passion fruit foam mat powder on rheological properties of red rice dough using shear stress (Pa) versus shear rate (s^{-1}) data was carried out. Different Flow models were used to describe shear rate (γ) versus shear stress (σ) data.

5.6 Materials and methods

5.6.1 Materials

Red rice was collected from Arunachal Pradesh, India and moisture content of grain was maintained around 12 % and stored in air tight container. Rice flour was prepared by milling in a lab grain mill. Passion fruit powder was obtained from foam mat drying.

5.6.2 Sample preparation

For rheological study, weighted amount of red rice flour was taken in a bowl and mixed with 11,25 % (w/w) passion fruit powder. The control sample was only red rice. The moisture content of the dough was maintained 35%.

5.6.3 Shear rheological study

For the shear rheological study, a rotational rheometer (Antron Paar, Physical MCR 301, and PP-50) equipped with a plate and plate geometry was used. The plate system was used with a diameter of 50 mm and a gap between plates of 0.1 mm. Sample (1g) was placed between the plates and edges of samples were carefully trimmed out with a spatula. The models were listed in the Table 5.5. Following were the rheological models used :

5.6.3.1 Power law

Power law model describes the data of shear-thinning and shear thickening fluids

$$\sigma = k(\gamma)^n \tag{1}$$

Where, γ is the shear rate, k =Apparent viscosity or consistency index and η = Flow behavior index

5.6.3.2 Bingham model

Bingham model gained popularity due to its simplicity.[16] The model exhibits a yield which also known as viscoplastic models.[4] Yield stress are very important rheological parameter to validate processing performance of sample. There is a certain level of internal structure which has to be overcome to initiate the flow.[21]

$$\sigma - \sigma_0 = n'\gamma \tag{2}$$

Where η' *is* called the Bingham plastic viscosity or flow behavior index, γ is the shear rate and σ_0 is the yield stress.

5.6.3.3 Herschel –Bulkley model

Yield stress occurrence considered to be an engineering reality and in many food products it plays a major role.

$$\sigma = K_k \gamma'^{n_H} + \sigma_{OH} \tag{3}$$

Where K_k = Consistency index, γ is the shear rate, n_H = Flow behavior index, σ_{OH} = Yield stress.[13]

5.6.3.4 Casson model

Casson model is a structure based model which is popularly used for food dispersions.[6]

$$\sigma^{0.5} = K_{oc} + K_c (\gamma)^{0.5} \tag{4}$$

Where $(\sigma)^{0.5}$ is the square root of shear stress, γ is the shear rate, K_c is the slope and K_{0c} is intercept. The Casson model is also used for cooked rice flour dispersions.[9]

5.6.3.5 Mizrahi and Berk model

Mizrahi and Berk model is a three-parameter viscoplastic model[11] which also exhibits yield stress [17], and eq. is given below.

$$\sigma^{0.5} = K_M \gamma'^{n_M} + \sigma_{OM} \tag{5}$$

Where K_M = Apparent viscosity or consistency coefficient, σ_{OM} = Yield stress and n_M = Flow behavior index

5.6.4 Dynamic rheological properties

The dynamic rheological properties of samples were assessed using a rotational rheometer (Antron Paar, Physical MCR 301, PP 50) equipped with a plate and plate geometry. The plate system was used with a diameter of 50 mm and 0.1 mm gap was maintained between plates. The sample was placed between the plates and edges of samples were carefully trimmed out with a spatula. Before testing, dough was rested at room temperature for 20 min for the relaxation of the residual stresses.[8] A thin layer of silicon oil was used on the exposed surface of the sample to prevent drying during testing. Frequency sweep tests

(mechanical spectra) from 1 to 200 W/s were performed at 30°C. For analysis, rice dough samples were used on the plate and excess sample was removed carefully by using a sharp razor blade. The oscillatory rheology depends upon (G') and viscous or loss modulus (G'') data and replicates of each measurement were done. The storage modulus (G'), loss modulus (G''), complex viscosity (η^*) and dynamic viscosity (η') were calculated for each samples and the data were analyzed using Rheoplus Version 3.61 software.

Table 5.5 Different models for rheological study

Sl. No.	Model name	Equation	Constant models
1	Power law	$\sigma = k(\gamma')^n$	k =Apparent viscosity or consistency index η = Flow behaviour index
2	Bingham	$\sigma - \sigma_0 = n'\gamma'$	σ_0 = Yield stress n' = Flow behaviour index
3	Herschel – Bulky	$\sigma = K_k\gamma'^{n_H} + \sigma_{OH}$	K_k = Consistency index n_H = Flow behaviour index σ_{OH} = Yield stress
4	Casson	$\sigma^{0.5} = K_{oc} + K_c(\gamma')^{0.5}$	K_{oc} = Yield stress K_c =Consistency coefficient
5	Mizrahi and Berk	$\sigma^{0.5} = K_M\gamma'^{n_M} + \sigma_{OM}$	K_M = Apparent viscosity or consistency coefficient σ_{OM} = Yield stress n_M = Flow index

Where σ = shear stress (Pa), y = shear rate (s^{-1}), *K= consistency coefficient, n=flow behaviour index,* σ_0 =yield stress (Pa)

5.6.5 Statistical analysis

The data were fitted in different rheological model by using Matlab R 2008a. Origin 8.5 software was used to plot the graphs.

5.7 Results and discussion

Table 5.6 Effect of passion fruit powder on steady shear rheological properties of dough

Models	Models constant	R^2	Adjusted R^2	RMSE	Constant models	R^2	Adjusted R^2	RMSE
		Control			Optimized dough			
Power	$k = 518$ $n = 0.23$	0.46	0.46	73.13	$K = 1394$, $n = 0.29$	0.34	0.34	291.50
Bingham	$\sigma_0 = 377.50$ $n' = 3.10$	0.80	0.79	42.91	$\sigma_0 = 1053$ $n' = 11.29$	0.82	0.81	148.00
Herschel – Bulkley	$K_k = -5.73$ $n_H = 0.47$ $\sigma_{OH} = 398$	0.81	0.81	43.83	$K_k = -7.85$ $n_H = 0.89$ $\sigma_{OH} = 1026$	0.83	0.82	149.40
Casson	$K_{oc} = 506.70$ $K_c = 1.17$	0.75	0.75	49.37	$K_{oc} = 38.76$ $K_c = -2.95$	0.68	0.68	201.10
Mizrahi and Berk	$K_M = -0.05$ $n_M = 0.46$ $\sigma_{OM} = 382.59$	0.83	0.83	40.68	$K_M = 0.006$ $n_M = 0.88$ $\sigma_{OM} = 982.82$	0.87	0.86	129.8

5.7.1 Steady shear rheological analysis

The flow behavior of red rice dough and passion fruit powder incorporated red rice dough were investigated. The shear stress (Pa) versus shear rate (s^{-1}) data obtained for red rice dough and optimized rice dough with incorporate passion fruit powder (Table 5.6) was fitted to Power, Bingham, Herchel–Bulkley, Casson, and Mizrahi and Berk models. These rheological models were compared among each other depending on R^2 and root mean square error (RMSE). The higher R^2 with lower RMSE showed the best fitted model. For both the samples Herschel-Bulky and Mizrahi and Berk model showed the highest R^2 in (Table 5.6) similar type of result was observed for mango pulp [5] and for brown flour from Indica rice.[23] For the Herschel - Bulkley and Mizrahi and Berk model the yield stress of

control sample was 398 and 382.59 Pa, respectively. However, the yield stress of optimized sample was 1026 and 982.82 Pa, obtained from Herschel–Bulky and Mizrahi and Berk model, respectively. Therefore, it can be inferred from the yield stress data that incorporation of passion fruit powder in red rice flour increased the yield stress. Flow index, n, for control sample was 0.46 to 0.47 for Herschel-Bulky and Mizrahi and Berk model, respectively (Table 5.6). For the optimized sample the flow index values varied from 0.88-0.89. The flow index parameter for both the red rice flour were below one (<1) and it can be inferred that the rice flour and passion fruit incorporated rice flour were pseudoplastic and shear thinning in nature [5] and therefore, incorporation of powder showed significant effect on the dough rheology.
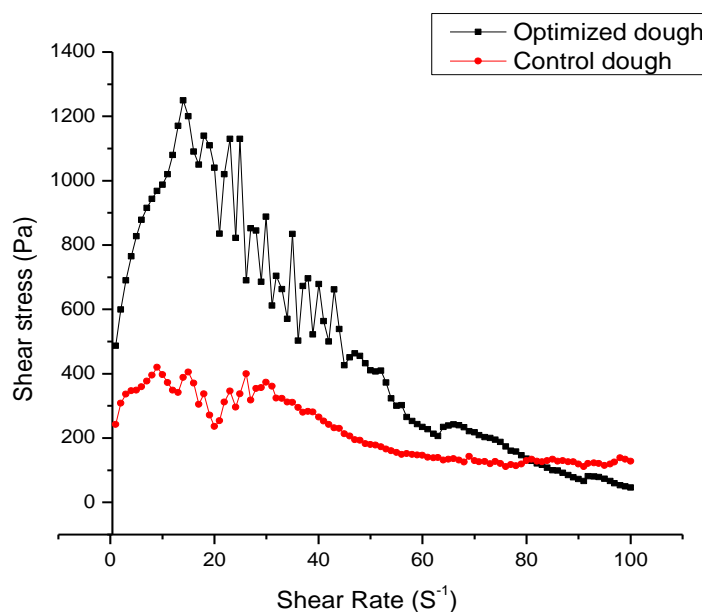

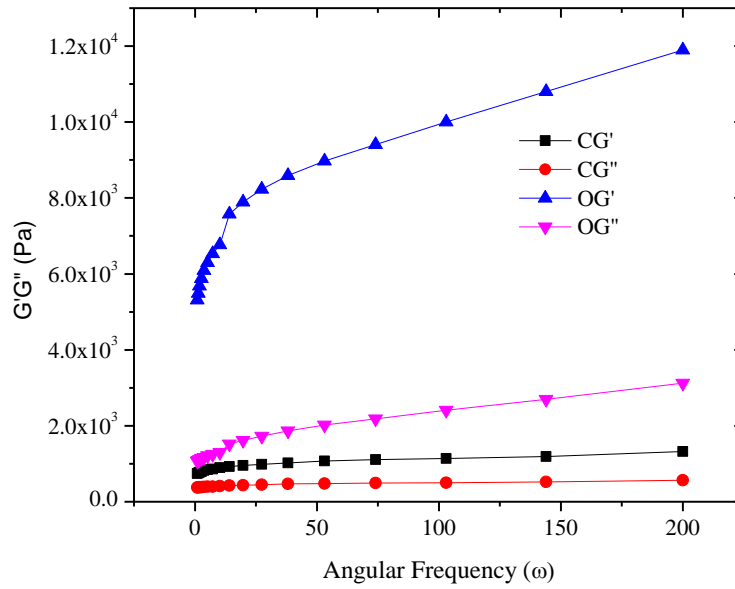**Fig 5.6** Shear stress vs. shear rate of (a) control and (b) optimized product

Fig 5.7 Angular frequency (ω) vs. storage modulus (G') and loss modulus (G'')

CG´- storage modulus of rice flour
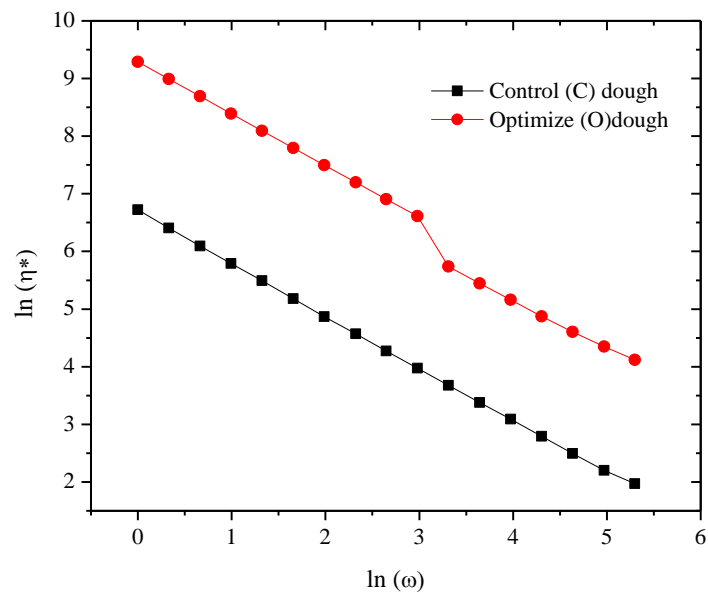
OG´´- storage modulus of rice flour + passion fruit powder

Fig. 5.8 Angular frequency (ω) vs. complex modulus ($\eta*$)

5.7.2 Dynamic oscillatory rheology

The effect of passion fruit powder on the rheological response functions (storage modulus, loss modulus, and complex viscosity) is illustrated in Fig.5.7 and 5.8. The dynamic G' (storage modulus) and G''(loss modulus) parameters which are function of frequency (ω) for the samples were measured to provide information on changes of biopolymer structure.[18] The dynamic G' is a measure of the energy stored and recovered from material (per cycle of sinusoidal deformation) whereas G'' is a measure of the energy dissipated (lost per cycle).[20] η^* is a measure of the overall resistant of flow (Pa.S).[24] The storage (G') and loss (G'') modulus of red rice dough and rice dough with passion fruit powder as a function of frequency (ω) shown in Fig.5.8 Oscillation rheology experiment allows continuous measurement of storage and loss modules during frequency sweep testing of rice dough. Incorporation of passion fruit powder in rice dough led to a remarkable change in oscillatory rheological behaviours of rice dough. Storage moduli of rice dough (G') and rice dough with passion fruit powder (G') were plotted against the angular frequency ranges from 0 to 200 Ws^{-1} (Fig.5.7). The storage modulus (G') and loss modulus (G'') of both the samples exhibited linear viscoelastic behaviour and revealed that lower dependence of moduli on frequency. G' was higher than G'' (Fig.5.8) and elucidated a prominent solid like behaviour (viscoelastic rather than elastoviscous) of these rice dough sample.[12] It may be attributed to the gelatinization of rice starch that enhances the overall pasting capacity of the starches and thereby increased the elastic properties of rice flour. A sharp increase in G' was observed for rice dough with passion fruit powder (Fig.5.7) over red rice flour and suggested more prominent solid like behaviour of rice flour with passion fruit powder than red rice flour only. Thereby, it revealed that incorporation of passion fruit powder had a significant effect on dough rheology of rice flour. It may be due to the reinforcement effect of passion fruit powder on the three-dimensional gel network of red rice dough and increased the elasticity of dough. According to fractal scaling theory, the elastic properties of a network of close-packed particle flocs is dependent on the strength of the interfloc links.[15] Therefore, the increase in G' might be attributed to the more integration of the intermolecular bond between rice flour and passion fruit powder, formed during dough mixing. Fig.5.8 illustrated complex viscosity (η^*) of rice dough and rice dough with passion fruit powder when and plotted against ω and observed that the magnitudes of η^* of dough were parallel to each other and decayed linearly with increase in frequency which revealed the frequency dependence of complex viscosity (η^*) for both

the samples. These results showed that the elastic properties of rice dough decreased at higher frequency due to the decrease in the rate of chain rearrangement and inclined tends to form a more ordered structure or crystalline structure.

5.8 Conclusion

Rheological studies of red rice based dough showed a different behaviour. The incorporation of powder showed significant effect on the dough rheology. The flow behavior of red rice and passion fruit incorporated red rice doughs can be explained by the Mizrahi and Berk model (R^2=0.83) and (R^2=0.87). The incorporation of powder showed significant effect on the dough rheology. The storage modulus (G´) and loss modulus (G´´) of both the samples revealed a linear viscoelastic behaviour and showed lower dependence of moduli on frequency. Complex viscosity (η*) of rice dough (C) and rice dough with passion fruit powder (O) stated that the elastic properties of rice dough were decreased at higher frequency due to the decrease in the rate of chain rearrangement.

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C) Sensory evaluation of red rice based extruded products by fuzzy logic tool

5.9 Introduction

In urban and semi urban population, the concept of snacks are very popular and liked by consumers irrespective of ages.[14] Extrusion processing plays a vital role in the production of snack items. The attributes of extrudates *viz.,* crispiness, appearance, taste, size, and various shape attract the customers. The choice of addition of ingredients define the final products quality. The starchy materials for instant corn starch, flour, or grits, rice products etc. produce the best extruded products due to their superior expansion characteristics.[1, 3, 6, 9, 12] Nevertheless, cereal grains are low in protein with a very low biological value which may be due to meagre essential amino acid contents.[11] Nutritious snack items can be prepared by incorporation of legumes, vegetables and fruits into the formulation.[14]

Linguistic decision can be analyze and manage consistently the uncertainty and vagueness of the information during sensory evaluation.[10] Jaya and Das[4] stated that fuzzy logic is an important decision-making tool for comparing a developed product with similar products available in the market. Fuzzy logic tool is used for sensory evaluation of various products *viz.,* mango drinks,[4] coffee,[7] black rice wine fortified [5], dahi powder[13] etc. Therefore, in the present study a sensory evaluation was conducted between a red rice extruded products (C) and red rice extruded products incorporated with passion fruit powder (O) by using fuzzy logic.

5.10 Material and methods

5.10.1 Raw materials

Extruded products were developed from combination of red rice (*Oryza sativa* L.) flour and foam mat passion fruit powder. The product development was done by twin extruder with co- rotating screw (Model FUE-1F, Flytech Engineering, Chennai, India).Control extrudate was prepared from red rice dough and optimized extrudate was prepared by the combination of red rice and passion fruit foam mat dried powder (detail has been elaborated in chapter 5A).

5.10.2 Sensory evaluation of extrudates

The sensory evaluation of two extruded products (C) and (O) were carried out. The total number of panel members were 30 including faculties and research scholars of the Department of Food Engineering and Technology, Tezpur University, Assam. During the evaluation, panel members were been told about the terminology, definition of quality attributes, method of scoring used in sheet and also given instructions to rinse and swallow water between samples of testing.[4]

5.10.3 Fuzzy analysis

Fuzzy is a powerful tool of linguistic data which showed inference regarding acceptance, rejection, ranking, strong and weak attributes of food. Ranking of the extruded products was carried out using triangular fuzzy membership distribution function, explained by Das[2] and sensory scores of the samples were acquired using fuzzy scores given by the 30 judges, converted to triplets and further used for estimation of similarity values used for ranking of sample.[8]

Product.........breakfast cereal item ....Made on...................... Tested on..................

Please rate the samples for quality attributes by putting ($\sqrt{}$) mark against the appropriate grade

	Quality attributes	**Poor**	**Fair**	**Medium**	**Good**	**Excellent**
Appearance(A)	Control					
	Optimized					
Colour (C)	Control					
	Optimized					
Taste (X)	Control					
	Optimized					
Texture (T)	Control					
	Optimized					
Mouthfeel (M)	Control					
	Optimized					

Please indicate the weightage you would like to assign for each quality attributes by putting (√) mark against the appropriate choice

Quality attributes	Not important	Somewhat important	Important	Highly important	Extremely important
Appearance					
Colour					
Taste					
Texture					
Mouth feel					

Comments if any

Signature of the evaluator

Fig. 5.9 Fuzzy logic score card for evaluation of extruded products

5.11 Results and discussion

Sensory evaluation of samples were carried out successfully by using fuzzy logic tool. It tackles the evaluation process mathematically. Table 5.7, presents the sum of the number of judges with different preferences and quality attributes were appearance, color, taste, texture and mouthfeel. Two extruded products (control and optimized) were denoted as SM1 and SM2, respectively.

Table 5.7 Sum of sensory scores for the quality attributes of extruded samples

Quality attributes		Poor/not satisfactory	Fair	Medium	Good	Excellent	Total
Appearance	C	10	11	9	0	0	30
	O	11	15	3	1	0	30
Color	C	15	8	5	2	0	30
	O	16	7	5	2	0	30
Taste	C	5	6	9	10	0	30
	O	6	7	8	9	0	30
Texture	C	3	6	12	7	2	30
	O	3	4	14	7	2	30
Mouthfeel	C	3	7	10	10	0	30
	O	2	5	11	12	0	30

Table 5.8 Preferences to the importance of quality attributes of the extrudates

Sensory response / Attributes	Not important	Somewhat important	Important	Highly important	Extremely important
Appearance (A)	0	1	12	10	7
Color (C)	0	7	17	2	4
Taste (X)	0	12	13	3	2
Texture (T)	0	4	16	6	4
Mouthfeel (M)	0	10	12	4	4

5.11.1 Triplets associated with sensory scales

In triplets associated with sensory scales, "triplet," terms were used for set of three numbers. The scale is a user-defined scale and subjective in nature. Ranking of the (C) and (O) samples were carried out using triangular fuzzy membership distribution function (Lazim and Suriani)[7]. The 5-point sensory scale were 'Not satisfactory/Not at all important (0,0,25), Fair/Somewhat important (25,25,25), Medium/Important (50,25,25), Good/Highly important (75,25,25) and Excellent/Extremely important (100,25,0)'.[4,2] The Matlab 7.6 (The Math Works Inc., Natick, MA) was used for fuzzy logic evaluation.

5.11.2 Triplets for sensory quality of samples

The triplets corresponding of control (C) and optimized (O) to a particular quality attributes can be obtained from the sum of score obtained for each of the sensory scale and the number of judges. Triplets numbers for sensory quality of the extruded samples were calculated for

$$\text{appearance (S1A)} = \frac{n_1(0\ 0\ 25)+n_2(25\ 25\ 25)+n_3(50\ 25\ 25)+n_4(75\ 25\ 25)+n_5(100\ 25\ 0)}{n_1+n_2+n_3+n_4+n_5} \tag{1}$$

Where, n_1 (10), n_2 (11). n_3 (9). n_4 (0) and n_5 10 at the numerator and denominator denote the number of judges conducted the evaluation. After calculation, the three values in the matrix represent the distribution function of judges' preference on the sensory scale for extruded products. Furthermore, the values of the triplets for color (SMI_A), taste ($SM1_X$), texture ($SM1_T$) and mouthfeel ($SM1_M$) were obtained as follows:

$$SM1_A = \frac{10(0,0,25)+11(25,25,25)+9(50,25,25)+0(75,25,25)+0(100,25,0)}{10+11+9+0+0}$$

$$
\begin{aligned}
&SM1_A \quad (20.0000 \quad 15.8333 \quad 25.0000)\\
&SM1_C \quad (19.1667 \quad 11.6667 \quad 25.0000) \qquad\qquad\qquad (2)\\
&SM1_X \quad (41.6667 \quad 20.0000 \quad 25.0000)\\
&SM1_T \quad (50.8333 \quad 22.5000 \quad 23.3333)\\
&SM1_M \quad (52.5000 \quad 23.3333 \quad 25.0000)
\end{aligned}
$$

Similarly, for optimized (O) product the values of the triplets for appearance ($SM2_A$), color ($SM2_A$), taste ($SM2_X$), texture ($SM2_T$) and mouthfeel ($SM2_M$) were obtained and are mentioned below:

$$
\begin{aligned}
&SM2_A \quad (24.1667 \quad 16.6666 \quad 25.0000)\\
&SM2_C \quad (20.0000 \quad 12.5000 \quad 25.0000) \qquad\qquad\qquad (3)\\
&SM2_X \quad (45.0000 \quad 20.8333 \quad 25.0000)\\
&SM2_T \quad (49.1666 \quad 22.5000 \quad 23.3333)\\
&SM2_M \quad (47.5000 \quad 22.5000 \quad 25.0000)
\end{aligned}
$$

5.11.3 Triplets for judges' preference to the importance of quality attribute

In this step, the most important attributes i.e. appearance, colour, taste, texture and mouthfeel of extrudate products will be identified on the basis of scores. Triplets for individual preference to the importance of attributes was calculated from the data (1) the sum of sensory scores (Table 5.6), (2) triplets associated with the sensory scales and (3) number of the panelists. For the control sample (C) the triplicates of attributes were calculated as follows;

$$Q1A = \frac{0(0,0,25)+1(25,25,25)+12(50,25,25)+10(75,25,25)+7(100,25,0)}{(0+1+12+10+7)} \quad (4)$$

$Q1_A$ (69.1666   25.0000   19.1666)

$Q1_C$ (52.5000   25.0000   21.6666)

$Q1_X$ (45.8333   25.0000   23.3333)

$Q1_T$ (58.3333   25.0000   21.6666)

$Q1_M$ (51.6666   25.0000   21.6666)

5.11.4 Overall sensory scores of the extruded samples triplets

Here, triplets obtained from (Eq. 2) were multiplied with triplets obtained from (Eq.4) to get an overall sensory score of each extrudate sample. The following eq. were obtained from multiplication of triplets (a, b, c) and (d, e, f):

$(a, b, c) \times (d, e, f) = (a \times da \times e + d \times ba \times f + d \times c)$ \quad (5)

Where, values of a and d ranged between 0 and 100, product a × d ranged between 0 and 1,000. Value of the first digit of the overall sensory ranged between 0 and 40,000. Therefore, value of the first digit of overall sensory score between 0 and 100 is necessary. Eq.4 were reduced by the factor $1/Q_{sum}$, where Q_{sum} is the sum of the first digit of the triplets of products

(control and optimized). "Relative weightage of the quality attribute" for appearance is defined as

$QA_{rel} = QA/Q_{sum}$,

Colour: $QC_{rel} = QC/Q_{sum}$,

Taste: $QX_{rel} = QX/Q_{sum}$,

Texture: $QT_{rel} = QT/Q_{sum}$ and

Mouthfeel: $QM_{rel} = QM/Q_{sum}$.

Therefore, Q_{sum} was calculated from Eq.4

$Q_{sum} = (69.16 + 52.50 + 45.83 + 58.33 + 51.66)$

$= 277.5$

After Q_{sum}, the triplicates for relative weightage of quality attributes *viz.,* appearance (QA_{rel}) was further as

$$QA_{rel} = \frac{QC}{Q_{sum}} \tag{6}$$

$= (69.16/277.5 \quad 25/277.5 \quad 19.16/277.5)$

$$
\begin{aligned}
QA_{rel} &= (0.2492 \quad 0.0901 \quad 0.0691) \\
QC_{rel} &= (0.1892 \quad 0.0901 \quad 0.0781) \\
QX_{rel} &= (0.1652 \quad 0.0901 \quad 0.0841) \\
QT_{rel} &= (0.2102 \quad 0.0901 \quad 0.0781) \\
QM_{rel} &= (0.1862 \quad 0.0901 \quad 0.0781)
\end{aligned}
\tag{7}
$$

Now, using Eq.5, overall sensory score SOC (control extrudate) can be obtained as,

$$SO_C = S1A*QA_{rel} + S1C*QC_{rel} + SIX*QX_{rel} + SIT*QT_{rel} + S1M*QM_{rel}$$

$= (36.4196 \quad 35.6225 \quad 39.2157) \tag{8}$

$$SO_O = S2A*QA_{rel} + S2C*QC_{rel} + S2X*QX_{rel} + S2T*QT_{rel} + S2M*QM_{rel}$$

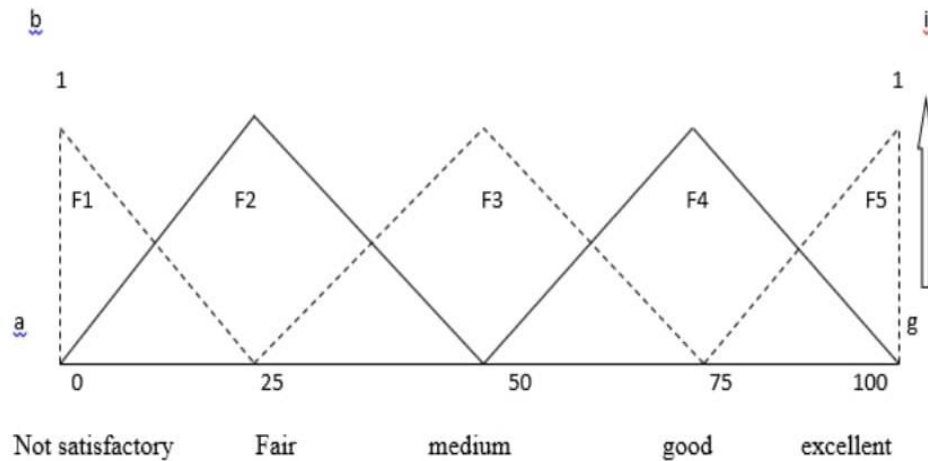$= (35.9543 \quad 35.1245 \quad 39.1030) \tag{9}$

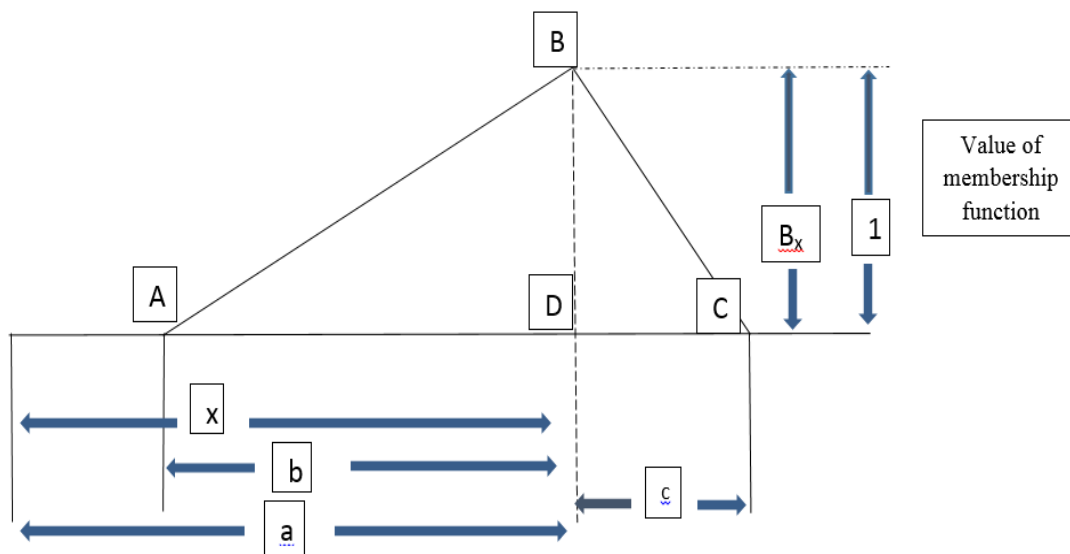**Fig.5.10** Distribution of 5-point sensory scale [2]

Fig.5.11 Graphical representation of triplet (a,b,c) and its membership function [2]

5.11.5 Standard fuzzy scale and ranking of products

Triangular membership function (Fig.5.10) also referred as standard fuzzy scale. The linguistic expressions of the standard fuzzy scale were set as not satisfactory/not at all necessary, fair/somewhat necessary, satisfactory/necessary, good/important and excellent/extremely important, respectively. In Fig 5.11, graphical representation of triplet (a, b, c) and was represented by a triangle ABC. The location of the centroid of the triangle ABC are depicted by the triplet (a, b, c). Triangular membership function distribution

pattern of 5-point scale was presented in the Fig 5.10. and symbols were F1, F2, F3, F4 and F5. Each symbol represents sensory scales, and membership function of each of the sensory scale follows triangular distribution pattern showed in the graph where the maximum value of membership is 1, the values of which are defined by a set of 10 numbers.

$$X = \frac{a - (b - c)}{3}$$

(10)

Therefore, the ranking of control (X_C) and optimized (X_O) extrudate sample were

X_C 37.61   (11)

X_O 37.28

Value of X (Eq.7) ranked both the sample ranked on the basis of overall quality of sample which is as follows: X_C (control) > X_O (optimized).

5.11.6 Quality attribute ranking of extruded samples in general

Using Eq.10, quality attributes *viz.,* appearance (X_{QA}), color (X_{QC}), taste (X_{QX}), texture (X_{QT}) and mouthfeel (X_{QM}) were;

X_{QA}	67.22222
X_{QC}	51.38889
X_{QX}	45.27778
X_{QT}	57.22222
X_{QM}	50.55556

(12)

Therefore, the ranking of quality attributes was appearance >taste> color > mouthfeel >texture

Table 5.9 Membership function of 5 point linguistic scale

Scale factor	Symbols	Attribute values in fuzzy scale						
Poor/Not satisfactory	F1	1	0.5	0	0	0	0	0
Fair	F2	0.5	1	1	0.5	0	0	0
Satisfactory	F3	0	0	0.5	1	1	0.5	0
Good	F4	0	0	0	0	0.5	1	1
Excellent	F5	0	0	0	0	0	0	0.5

5.11.7 Membership function of overall sensory scores

Standard fuzzy scales values from F1, F2, F3, F4 and F5 were used to obtained value of membership function of overall scores of extrudates. Graphical presentation (Fig.11) showed that value of membership function is 1.

Bx can be expressed as,

$$B_X = \frac{X-(a-b)}{b} \text{ for (a-b)<x<a} \tag{13}$$

$$= \frac{(a+c)-X}{c} \text{ for a<x< (a+c)}$$

$$= 0 \text{ for all other values of X}$$

$BX_1 = (0 \quad 0.2610 \quad 0.5457 \quad 0.8304 \quad 0.8965 \quad 1 \quad 0.6408 \quad 0.3850 \quad 0.1293 \quad 0)$

$BX_2 = (0 \quad 0.2583 \quad 0.5390 \quad 0.8197 \quad 0.9087 \quad 1 \quad 0.6537 \quad 0.3987 \quad 0.1437 \quad 0)$ \hfill (14)

5.11.8 Similarity analysis for products

Two samples obtained their respective membership functions (BX_1 and BX_2) from Eq. 8 BX_1 and BX_2 values were compared with the corresponding values of the membership function of standard fuzzy scale (F1-F5) from Table 5.9. Values of membership functions F1,F2,F3,F4 and F5 were obtained (Table 5.8) and also showed matrix having 10 elements. Similarity analysis is very used for distributing the overall sensory score (which has been obtained as a single triplet) out of five sensory scales of standard fuzzy scale. Similarity value (S_m) for the samples was defined as

$$S_m = \frac{F \times B^T}{Maximum\ of\ \left(F1 \times F1^T\ and\ B1 \times B1^T\right)} \tag{15}$$

Table 5.10 Similarity values for extruded samples

Quality attributes	Similarity values for extruded samples	
	Control (C)	Optimized (O)
Poor/Not satisfactory	0.0373	0.0380
Fair	0.3487	0.3558
Satisfactory	0.7215	0.7278
Good	0.6665	0.6642
Very good	0.2511	0.2430
Excellent	0.0208	0.0188

In the Table 5.10, control extrudate product which has only red rice as the main ingredient showed highest similarity value 0.7215 (satisfactory) and optimized extrudate product which contain red rice and passion fruit powder showed highest similarity value 0.7278 (satisfactory). Therefore, highest similarity predicts the better acceptability by fuzzy logic tool.

5.12 Conclusion

In the present chapter, two extruded products namely C (control: red rice) and O (optimized:red rice incorporated with passion fruit powder) were carried out for sensory evaluation using fuzzy logic. Quality attribute *viz.,* appearance, colour, taste, texture and mouthfeel ranking of extruded samples in general were appearance >taste> color > mouthfeel >texture. The ranking of two products control and optimized were almost negligible X_C 37.61 > X_O 37.28. Similarity values for extruded samples showed that both samples were satisfactory.

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