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Research Article

Physicochemical, Phytochemical and Nutrimental Impact of Fortified Cereal Based Extrudate Snacks: Effect of Jackfruit Seed Flour Addition and Extrusion Cooking

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Abstract: Aim of present study was to estimate quantitative changes in nutrimental, physicochemical and phytochemical properties of rice-jackfruit seed flour blend extrudates. Rice-jackfruit seed flour blend was prepared at 70:30 proportions and was subjected to extrusion cooking. Effect of barrel temperature (140-180°C) and screw speed (100-300 rpm) on nutrimental, physicochemical (expansion, density, WSI, WAI and hardness) and phytochemical (TPC and TFC) properties were studied. Rice flour extrudate was found to have 6.63% protein and 0.17% fiber which were further increased to about 8.44 and 0.8%, respectively after addition of jackfruit seed flour at 180°C with 300 rpm. Extrusion cooking at lower barrel temperature resulted in increase in TPC and TFC. Rice-jackfruit seed flour blend extrudate at 180°C with 100 rpm resulted in highest antioxidant capacity and reducing power (208.56 μmol of TE/g and 0.26 mg of AAE/g of dry powder respectively). Practical applications: Although there is increased use of extrusion processing, but still there is no fully developed theory to predict the effects of process variables on various raw materials and their mixtures. Any change in feed composition and process variables can influence extrusion performance as well as product quality. Therefore, it is crucial to study the effect of extrusion process parameters (barrel temperature and screw speed) on extrudate characteristics. Also, the researchers, so far, tried lots of combinations for nutraceutical enrichment of extrudate snacks. To the best of our knowledge, this is first report on extrusion cooking of RF fortified with JFSF. In future, this data could be useful for food processing industries. Originality of this study demonstrates the feasibility of developing value added extrudates with improved nutrimental and nutraceutical appeal. Present study shows potential for utilization of jackfruit seed which is part of the waste generated in large quantities when the fruit is processed or consumed.

Keywords: Extrudate characteristics, extrusion, jackfruit seed flour, nutrimental analysis, phenolic content

INTRODUCTION

Extrusion cooking technology plays a key role in many food processing industries as a continuous cooking, mixing, shearing and forming process. It is used especially for production of cereal-based snacks. Extrusion cooking is very efficient technology having advantage of low cost, High Temperature Short Time (HTST) process and a versatile nature (Harper, 1981). Consumer preference of extruded foods is mainly due to convenience, attractive appearance and texture. Rice provides all the features for production of highly acceptable extruded snack foods, but its nutrimental value is far from satisfying the needs of health-conscious consumers.

Several attempts have been made to improve the nutrimental profile of RF extrudate (Camire, 2000). Among other materials, incorporation of fruit or vegetable waste has been shown to cause a positive impact on levels of proteins and dietary fiber of cereal-based extruded snacks (Grigelmo-Miguel and Martin-Belloso, 1999; Nawirska and Kwasnievska, 2005). Nutrimental and economical aspects of JFSF appears to be promising in production of extruded snacks for fortifying RF. High in protein and low in fat, JFSF consumption has been associated with reduced risk of coronary diseases. In addition, there is solid scientific evidence that JFSF possess phenolic compounds such as flavonoids and phenolic acids which exhibit strong antioxidant capacity (Soong and Barlow, 2004). Consequently, fortification of RF with JFSF is believed to promote the utilization of JFSF for food use as a result in product with high nutrimental and nutraceutical appeal.

Consumption of cereal-based snacks as breakfast cereal is increasing mainly by child population. Therefore, any attempt to enhancement protein and fiber content is highly convenient. In addition, the supplementation of RF with JFSF can have positive impact not only in health aspect but also sustainability. The researchers, so far, tried lots of combinations for nutraceutical enrichment of extrudate snacks. To the

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best of our knowledge, this is first report on extrusion cooking of RF fortified with JFSF. In future, this data could be useful for food processing industries. Present work aimed to determine:

- The effect of addition of JFSF
- The effect of extrusion cooking parameters (barrel temperature and screw speed) on nutrimental, physicochemical, phytochemical and antioxidant properties of extrudate snacks

MATERIALS AND METHODS

Sample preparation: Sample of low cost polished rice (Variety: Ratna (IET-1411)) was obtained from Rice Research Centre Karjat, India. For this study jackfruit seeds were used which were further dried in tray dryer at 50±3°C for 3 h (moisture content 13%). Rice and jackfruit seeds were separately ground and passed through 80 mesh (British standard) sieve. Powdered RF and JFSF samples were used for physicochemical and phytochemical analysis. JFSF was incorporated with RF at 30% concentration level (optimized unpublished data). For making extrudates, about 1 kg of blended materials was conditioned to 14% moisture and packed in polyethylene bags and allowed to equilibrate for 12 h.

Analysis of flour sample: JFSF was analyzed for bio-chemical compounds by FTIR (SHIMADZU) spectrometer. The FTIR spectrum was recorded for the range of 400 to 4000/cm.

Extrusion: Extrusion cooking was performed in duplicate using a laboratory-scale-co-rotating twin-screw extruder (KETSE 20/40 Brabender GmbH and Co. KG, Duisburg, Germany) with 20:1 barrel length to diameter ratio. Extruder barrel consisted of four heating/cooling zones. Extruder was fitted with a circular die having nozzle of 4 mm diameter. Feed rate was kept constant at 14 kg/h. During extrusion cooking screw rotation speeds were 100 and 300 rpm and barrel temperatures were at 140 and 180°C while feed moisture was kept constant at 14%. After extrusion cooking extrudates were cooled to room temperature (25±3°C), packed in polyethylene bags and stored at room temperature till further analysis.

Nutrimental evaluation: Proximate analysis of raw formulations and extrudate samples were determined. Moisture was determined by drying to a constant weight at 105°C. Ash content was determined at 550°C (method 923.03) according to AOAC International (1995). Crude protein (N×6.25) content was determined by the microKjeldahl procedure (method 960.52) of the AOAC International (1995). Crude lipid content was quantified by extracting the sample with petroleum ether in a Soxhlet apparatus. Dietary fiber content was determined according to procedure (method 99.43) of the AOAC International (1995). Carbohydrate content was determined by difference. All determinations were done in triplicate.

Physicochemical analysis: Physicochemical properties such as extrudate expansion, density, Water Solubility Index (WSI), Water Absorption Index (WAI), texture, colour parameters (L*, a*, b*, ΔE), Browning Index (BI) and Whiteness Index (WI) were analysed.

Sectional expansion i.e., ratio of diameter of extrudate and the diameter of the die was used to express expansion of extrudate (Ding *et al*., 2005). Ten random readings were taken for each sample and their average was taken as the mean diameter of the extrudate. Diameter of the die was 4 mm.

Extrudate density was calculated as described by method of Alvarez-Martinez *et al*. (1988):

$$Density = 4m/\pi d^2 L$$

where, m is the mass (g) of a length L (cm) of cooked extrudate with diameter d (*cm*).

Ten random readings were taken for each sample and their average was taken as the mean value.

WSI and WAI were determined using the method of Anderson *et al*. (1969). Extrudates were ground to pass through 30 mesh sieve. (2.5 g) ground extrudate was suspended in 25 mL water at room temperature for 30 min, with intermediate stirring, and then centrifuged at 3000 g for 15 min. Supernatant was decanted into an evaporating dish with a known weight. WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample whereas WAI is the weight of residue obtained after removal of the supernatant per unit weight of original dry solids, and is given as follows:

WSI (%) = (Weight of dry solids in supernatant/Dry weight of extrudate) ×100

WAI (g/g) = Weight of sediment/sample dry weight

WSI and WAI measurements were reported as an average of three to four replicates.

Hardness of the extrudate was determined using a Stable Micro System TAXT2i texture analyzer (Serial No. 4650, TEE version 2.64, UK). 2 mm cylindrical probe was used for the measurement of hardness of the extrudates (Ding *et al*., 2005). Maximum force needed to break the sample was recorded and analysed by Texture Exponent software associated with the texture analyser. Ten measurements were performed for each sample and their average was taken as the mean value.

Color parameters (L*, a*, b*) for the raw formulations and extrudates were measured using a Hunter Lab colorimeter (Labscan XE) coupled with Easy Match QC software. Numerical total color difference (ΔE), Browning Index (BI) and Whiteness Index (WI) were calculated as given by Cemalettin and Mustafa (2010). Ten measurements were performed for each sample and their average was taken as the mean value.

Extraction of samples: Raw materials and extrudate flours (1 g) were extracted for 3 h with 10 mL of 70% acetone (optimized unpublished data) on an orbital shaker set at 180 rpm at 30±5ºC. Sample suspension was centrifuged at 10,000×g for 15 min at 30°C. Supernatant was collected and stored at -20°C till further analysis.

Phytochemical analysis:

Total Phenolic Content (TPC) and Total Flavonoids Content (TFC): Total phenolic content was determined spectrophotometrically using the Folin-Ciocalteu assay (Jesus *et al*., 2012). Gallic acid was used as a standard and results were expressed as mg of GAE/g of dry powder.

Total flavonoid content of all extracts was measured by colorimetric method (Jagtap *et al*., 2010). Quercetin was used as a standard and results were expressed as mg of QE /g of dry powder.

Trolox Equivalent Antioxidant Capacity (TEAC): Trolox Equivalent Antioxidant Capacity (TEAC) was estimated as 2, 2'-Azino-Bis (3-ethylbenzthiazoline)-6-Sulfonic (ABTS) radical cation scavenging activity (Carlos *et al*., 2012). Trolox was used as standard and results were expressed in µmol of TE /g of dry powder.

Readings were taken in triplicates for determination of phytochemical analysis.

Reducing power assay: Reducing power was measured spectrophotometrically (Sharma *et al*., 2012). Standard curve was prepared using various concentration of ascorbic acid and results were expressed as mg of AAE/g of dry powder.

Statistical analysis: Analysis of variance test was carried out using commercial statistical package, SPSS ver.11.5 (SPSS Inc., Chicago, IL, USA). All data were recorded as means±std dev. Mean values were compared and significant differences were given using Duncan's test (p≤0.05). Pearson's correlation analysis was used to determine correlations among means.

RESULTS AND DISCUSSION

FTIR analysis of JFSF flour: FT-IR spectrum of JFSF is shown in Fig. 1. The absorption bands and the wave number (cm^{-1}) of dominant peaks obtained from absorption spectrum are presented in Table 1. The observed bands for amines, amides, amino acids indicate the presence of protein. Some other absorption bands indicate the presence of biomolecules like carbohydrates, polysaccharides and lipids.

These observations are in agreement with the work reported by Theivasanthi and Alagar (2011). Presence of alkanes, alkenes, aromatics, alcohols, ethers, nitrates, sulfonates and organic halogen compounds are also observed. Aromatic compounds indicate existing of flavanoids. Sulphur derivatives compounds are present in jackfruit seeds which exhibit some anti-microbial properties.

Effect of JFSF addition and extrusion cooking on nutrimental properties of extrudate: Proximate

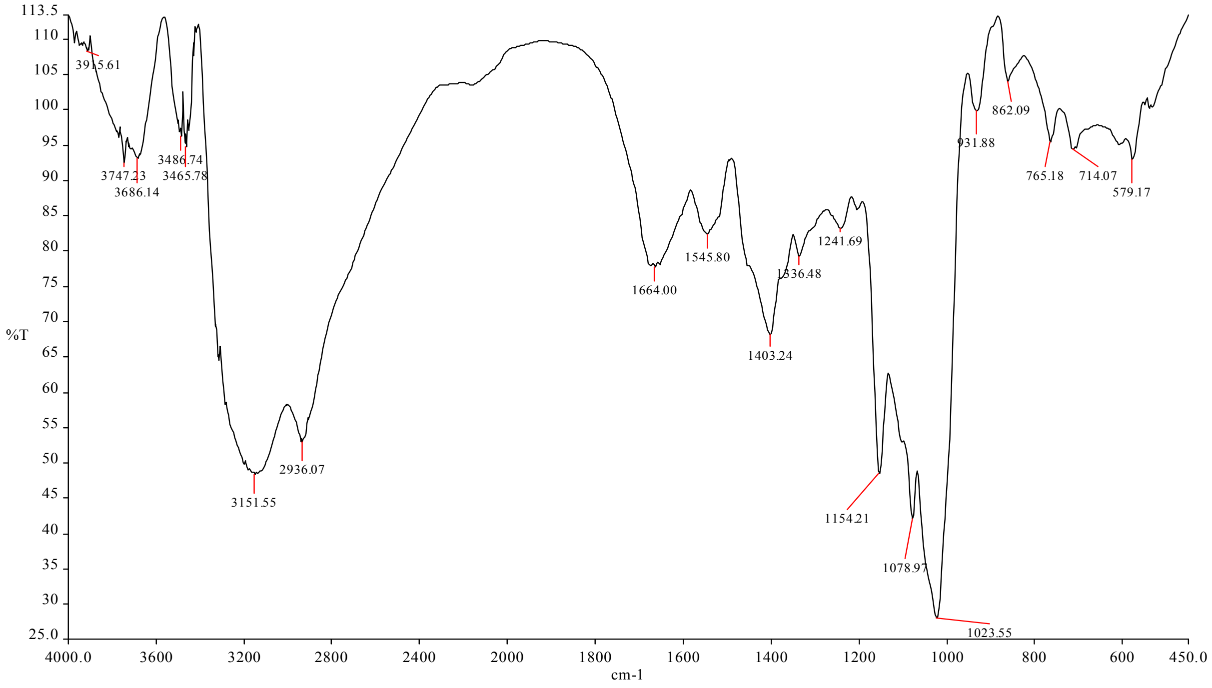

Fig. 1: Wave number (cm^{-1}) of dominant peaks obtained from FT-IR absorption spectrum

Table 1: FTIR bio-chemical compounds analysis

Bio-chemical compounds		Wave number (cm^{-1})
Amines	N-H stretching	3386, 3465
	N-H bending	1664
	C-N stretching	1336, 1078, 862
Amides	N-H stretching	3486, 3465
	C-O stretching	1154, 1336, 1403, 1664
Amino acids	N-H stretching	3486, 3465
	N-H bending	1664, 1241, 1154
	C-O stretching	1336
Carboxylic acids	O-H stretching	
	C-O stretching	1154, 1336, 1403, 1664
Carbohydrates	N-H wagging	862, 765
Polysaccharides	C-O-C stretching	1241, 1154, 1078, 862, 765
Lipids/alkanes	C-H stretching	2936
Alkenes	C = C stretching	1664
	C-H out-of plane bending	931, 862, 765
Aromatics	C-H out-of plane bending	931, 862, 765
Alcohols, ethers, esters, anhydrides	C-O stretching	1154
Nitrates	N-H bending	1664, 1241, 1154
Nitro	N = O	1336
Sulfonyl and sulfonate	S = O stretching	1078, 1023, 862
Chlorate	C-H stretching	2936
Chloride	C-Cl	765
Fluoride	C-F	1154, 1078, 1023
Bromide, iodide	C-Br, C-I	579

Table 2: Nutrimental composition of raw materials and extrudates

	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Carbohydrate (%)
RF	11.02±0.02^{c}	0.34±0.04^{e}	6.71±0.06^{d}	0.39±0.03^{b}	0.20±0.01^{c}	81.53
JFSF	13.19±0.03^{a}	3.01±0.02^{a}	13.07±0.04^{a}	0.57±0.02^{a}	2.60±0.05^{a}	70.16
RF+JFSF (70:30)	12.73±0.03^{b}	1.07±0.03^{c}	8.53±0.02^{b}	0.43±0.03^{b}	0.88±0.06^{b}	77.25
RF Extrudate (180°C, 300 rpm)	7.01±0.01^{e}	0.41±0.04^{d}	6.63±0.03^{e}	0.33±0.03^{c}	0.17±0.03^{c}	85.61
RF+JFSF extrudate (180°C, 300 rpm)	8.22±0.03^{d}	1.19±0.01^{b}	8.44±0.04^{c}	0.41±0.02^{b}	0.83±0.03^{b}	81.74

Mean values with different superscripts on the same column differ significantly (Duncan's test, $p<0.05$)

Table 3: Physicochemical properties of extrudates

	Expansion (%)	Density (g/cm^{3})	WSI (%)	WAI (g/g)	Hardness (N)
RF extrudate					
(180°C, 300 rpm)	3.42±0.02^{a}	0.20±0.04^{d}	38.89±0.04^{a}	9.26±0.05^{a}	41.37±0.07^{e}
RF+JFSF extrudate					
(140°C, 100 rpm)	2.21±0.03^{d}	0.36±0.03^{b}	19.05±0.05^{e}	8.06±0.03^{b}	47.66±0.06^{b}
(140°C, 300 rpm)	1.99±0.01^{e}	0.42±0.02^{a}	21.82±0.02^{d}	7.61±0.02^{c}	49.11±0.04^{a}
(180°C, 100 rpm)	2.71±0.01^{b}	0.26±0.02^{c}	24.13±0.03^{c}	6.17±0.02^{d}	44.23±0.04^{d}
(180°C, 300 rpm)	2.54±0.04^{c}	0.31±0.04^{b}	26.80±0.05^{b}	5.37±0.07^{e}	46.02±0.06^{c}

Mean values with different superscripts on the same column differ significantly (Duncan's test, ($p<0.05$)

analysis showed that the RF used in this study contained 11.02% moisture, 0.39% crude fat, 0.20% crude fiber, 0.34% ash and 81.53% total carbohydrates (calculated by difference). Protein content of RF sample is 6.71% and after JFSF addition it increased to about 8.53% for raw RF-JFSF blend. This increased protein content of raw RF-JFSF blend is attributed to the inherent higher protein content (13.07%) of JFSF. Fiber content of RF alone and JFSF incorporated RF blend ranged from 0.20 to 0.88%. Raw RF showed lowest ash value of 0.34%. Ash content of raw RF-JFSF blend increased to about 1.07% with incorporation of JFSF (Table 2). Extrusion cooking process did not cause any remarkable change in the chemical composition except for the decrease in the moisture content, probably as consequence of one of the aim of extrusion cooking is to produce dry product. Henceforth, moisture content of raw RF-JFSF blend was 12.73% while after extrusion cooking it was significantly decreased to 8.22% ($p<0.05$). During extrusion cooking due to high pressure and mechanical shearing significant change in protein content is observed. Protein content of raw RF-JFSF blend was 8.53% while after extrusion cooking it was decreased to 8.44% ($p<0.05$).

Effect of JFSF addition and extrusion cooking on physicochemical properties of extrudate:

Expansion and density: In starchy extrudates one of the most important textural properties is the ability of material to expand at the die. From Table 3 it is seen that overall expansion of RF extrudate at 180°C with 300 rpm screw speed was maximum (3.42%) which is attributed due to the ability of rice to expand well. Whereas RF-JFSF blend extrudate at 180°C with 300 rpm screw speed shows significant decrease in expansion value ($p<0.05$). It is well known that starch has positive effect on increasing expansion while protein and/or fiber have a negative and lowering effect

Table 4: Correlation coefficients among physicochemical properties of extrudates

	Expansion	Density	WSI	WAI	Hardness
Expansion	1	-0.922**	0.670**	0.324	-0.990**
Density		1	-0.512	-0.168	0.946**
WSI			1	-0.916**	-0.611*
WAI				1	-0.262
Hardness					1

**: Correlation is significant at 0.01 level; *: Correlation is significant at 0.05 level

Table 5: Color analysis and browning index of extrudates

	L*	a*	b*	ΔE	BI	WI
RF extrudate						
(180°C, 300 rpm)	78.19 ± 0.14^{a}	0.63 ± 0.02^{e}	14.37 ± 0.27^{e}	79.48 ± 0.13^{a}	20.20 ± 0.15^{e}	73.96 ± 0.15^{a}
RF+JFSF extrudate						
(140°C, 100 rpm)	50.88 ± 0.00^{c}	10.09 ± 0.02^{b}	21.82 ± 0.07^{d}	56.28 ± 0.02^{c}	69.43 ± 0.20^{c}	45.31 ± 0.02^{c}
(140°C, 300 rpm)	61.38 ± 0.02^{b}	7.76 ± 0.04^{d}	23.12 ± 0.05^{c}	66.05 ± 0.04^{b}	55.61 ± 0.01^{d}	54.33 ± 0.02^{b}
(180°C, 100 rpm)	45.13 ± 0.02^{e}	11.35 ± 0.01^{a}	24.22 ± 0.06^{a}	52.47 ± 0.02^{e}	92.56 ± 0.00^{a}	38.96 ± 0.04^{e}
(180°C, 300 rpm)	49.65 ± 0.02^{d}	9.86 ± 0.06^{c}	23.56 ± 0.03^{b}	55.83 ± 0.01^{d}	77.23 ± 0.04^{b}	43.54 ± 0.03^{d}

Mean values with different superscripts on the same column differ significantly (Duncan's test, $p<0.05$)

on expansion of extrudate. At high and low barrel temperatures (180 and 140°C) with increase in screw speed (100-300 rpm) significant decrease in the expansion value was observed. Effect of screw speed on product expansion is usually complex and is temperature dependent. Change in expansion at higher extruder temperatures can be attributed to increase in degree of cooking. These observations are in agreement with the work reported by Bhattacharya (1997). Statistical analysis revealed that expansion was negatively correlated with density and hardness ($R = -0.922$, $p<0.01$ and $R = -0.990$, $p<0.01$, respectively) (Table 4).

Density and expansion are the indices of degree of puffing of extrudates. Low density (a desirable characteristic of expanded product) was achieved at high barrel temperature (180°C). Table 3 indicates reduction in protein can lead to decrease in density and hence lowest density value (0.20 g/cm^3) was observed for RF extrudate at 180°C with 300 rpm screw speed. Although at the same extrusion cooking conditions after addition of JFSF density was significantly increased to 0.31 g/cm^3. High level of temperature and screw speed leads to maximum thermal and mechanical energy causing structural damage which produces product with low density. Statistical analysis revealed that density was negatively correlated with expansion and positively correlated with hardness ($R = -0.922$, $p<0.01$ and $R = 0.946$, $p<0.01$, respectively) (Table 4).

WSI and WAI: WSI is used as an indicator of degradation of molecular components. It measures the amount of soluble components released from starch after extrusion cooking. Table 3 indicates that RF having high starch content, extrudate at 180°C with 300 rpm screw speed shows highest WSI value (38.89%). Although at same extrusion cooking conditions with addition of JFSF value of WSI was decreased significantly ($p<0.05$). Increase in barrel temperature (140-180°C) with increase in screw speed (100-300 rpm) increases WSI of extrudate. WSI increases with increasing temperature if dextrinization or starch melting prevails over the gelatinization phenomenon (Ding *et al*., 2006).

WAI measures the volume occupied by the granule or starch polymer after swelling in excess water. RF extrudate at 180°C with 300 rpm screw speed shows highest WAI value 9.26 g/g whereas RF-JFSF blend extrudate at same extrusion cooking conditions shows significant decrease in WAI value ($p<0.05$). Extrusion cooking parameters such as barrel temperature and screw speed had significant effect on WAI. Increase in barrel temperature (140-180°C) as well as increase in screw speed (100-300 rpm) significantly decreases the WAI of extrudate (Table 3).

This might be attributed to the higher amount of damaged polymer chains formed at higher shear rate, reducing the availability of hydrophilic groups to bind more water molecules, resulting in a decrease in values of WAI (Guha *et al*., 1997). Statistical analysis revealed that WSI was negatively correlated with WAI ($R = -0.916$, $p<0.01$) (Table 4).

Hardness: Hardness of cereals and starches is generally governed by extrusion cooking parameters. Table 3 indicates lowest hardness value (41.37 N) for RF extrudate whereas at same extrusion cooking conditions (180°C, 300 rpm) higher hardness value (46.02 N) was observed for RF-JFSF blend extrudate due to increase in protein content. Increasing barrel temperature significantly decreased hardness of the extrudate. From Table 3 it is seen that, at high and low barrel temperatures (180 and 140°C) with increase in screw speed (100-300 rpm) hardness value increased significantly ($p<0.05$). Previous studies have also reported that hardness of extrudate increased as the barrel temperature decreased (Liu *et al*., 2000). Statistical analysis revealed that high density product naturally offers high hardness evident by high correlation between product density and hardness (Table 4).

Color parameters and browning index: L*, a*, b* and ΔE values of RF extrudate were compared with JFSF added at different extrusion cooking conditions (Table 5). WI values clearly indicate the effect of JFSF addition, for RF extrudate WI value was 73.96 while after addition of JFSF at the same extrusion cooking

Table 6: Correlation coefficients among color parameters and phytochemical properties of extrudates

	L*	a*	b*	ΔE	BI	WI	TPC	TFC	TEAC	Reducing power
L*	1	-0.972**	-0.848**	0.997**	-0.964**	0.996**	-0.568**	-0.501*	-0.579**	-0.806**
a*		1	0.898**	-0.965**	0.940**	-0.981**	0.716**	0.664**	0.732**	0.820**
b*			1	-0.811**	0.921**	-0.890**	0.668**	0.617**	0.688**	0.809**
ΔE				1	-0.942**	0.988**	-0.554**	-0.488*	-0.564**	-0.787**
BI					1	-0.978**	0.558**	0.492*	0.570**	0.829**
WI						1	-0.598**	-0.533**	-0.610**	-0.823**
TPC							1	0.994**	0.998**	0.742**
TFC								1	0.995**	0.683**
TEAC									1	0.734**
Reducing power										1

**: Correlation is significant at 0.01 level; *: Correlation is significant at 0.05 level

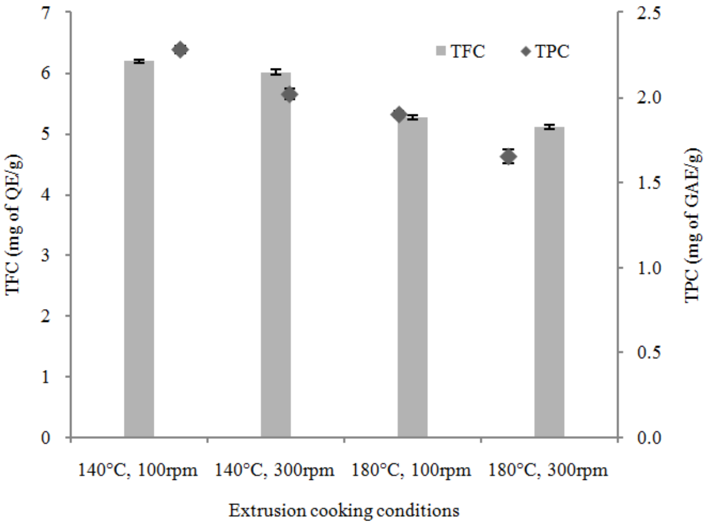

Fig. 2: Effect of extrusion cooking conditions on TPC and TFC

conditions (180°C, 300 rpm) WI value decreased significantly ($p<0.05$). Results showed that the colour change was greater after addition of JFSF. BI of the extrudates varied from 20.2 to 92.56. Table 5 indicates, at high and low barrel temperatures (180 and 140°C) with increase in screw speed (100-300 rpm) BI value decreases significantly which means a longer residence time that cause more destructive and produced a synergistic effect. Browning index of RF extrudates was increased from 20.2 to 77.23 with addition of JFSF at same extrusion cooking conditions (180°C, 300 rpm). Presence of more amino acids in the RF-JFSF blend reacts with reducing sugar triggering more BI values. Statistical analysis revealed that WI was positively correlated with ΔE and negatively correlated with BI of extrudate ($R = 0.988$, $p<0.01$ and $R = -0.978$, $p<0.01$, respectively) (Table 6).

Effect of JFSF addition and extrusion cooking on phytochemical properties of extrudate:

Total Phenolic Content (TPC) and Total Flavonoid Content (TFC): It was observed that total phenolic content of raw RF and JFSF was 0.29 and 4.42 mg of GAE/g, respectively. While phenolic content of raw RF-JFSF blend (70:30) was 2.50 mg of GAE/g. Researchers have demonstrated that JFSF had higher phenolic content (Soong and Barlow, 2004), hence it can be incorporated with RF to increase total phenolic content of extrudate. Raw RF-JFSF sample shows 2.50 mg of GAE/g phenolic content which was decreased significantly after extrusion cooking ($p<0.05$). These results are also consistent with previous study carried out on the extrusion cooking of bean-corn mixture (Delgado-Licon *et al*., 2009). Highest decrease in phenolic content was observed with increase of barrel temperature (140-180°C) and increase of screw speed (100-300 rpm) (Fig. 2). An increase in screw speed results in greater mechanical energy input to the system and shearing effect is increased. Although increased screw speeds associates with decreased residence times (i.e., shorter reaction times) it can be suggested that the increased shearing effects were more dominant than the effect of residence time on the destruction of polyphenols over the extrusion conditions studied.

Flavonoids have generated interest because of their broad human health promoting effects, most of which are related to their antioxidant properties. It was observed that total flavonoid content of raw RF and JFSF was 0.07 and 15.51 mg of QE/g respectively. Whereas, flavonoid content of raw RF-JFSF blend (70:30) was 6.67 mg of QE/g. A significant decrease in the Total Flavonoid Content (TFC) was observed upon

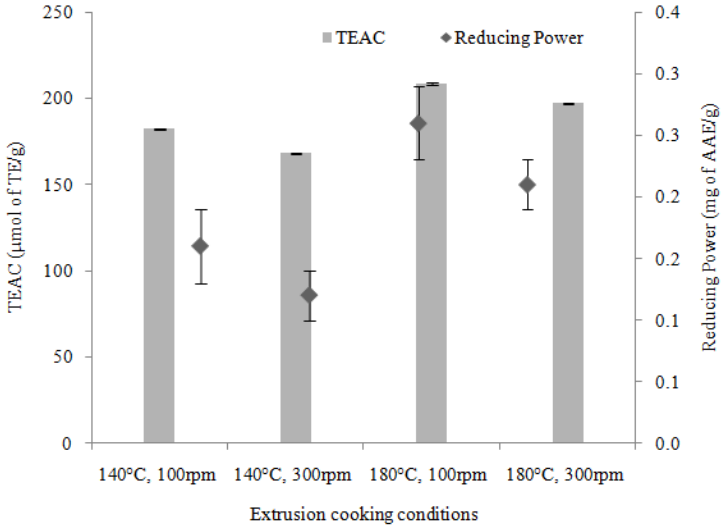

Fig. 3: Effect of extrusion cooking conditions on TEAC and reducing power

extrusion cooking. RF extrudate shows increase in the flavonoid content when compared with its raw formulation but this increase in flavonoid content was not significant. During extrusion cooking when temperature was increased from 140 to 180°C, with increase in screw speed from 100 to 300 rpm a significant decrease in TFC was noticed (Fig. 2). Flavonoid compounds are heat-liable and can break at the exposure to high temperatures. Therefore, losses in the flavonoid content of the formulations under extrusion are expected to occur, due to break down of complex polyphenols to other phenolic or non-phenolic compounds, at a consequence of high temperatures conditions (Xu and Chang, 2008). Statistical analysis indicates that flavonoids showed a significant positive correlation with TPC and TEAC (R = 0.994, p<0.01 and R = 0.995, p<0.01, respectively) (Table 6).

Effect of JFSF addition and extrusion cooking on Trolox Equivalent Antioxidant Capacity (TEAC) of extrudate: Antioxidant capacity of raw RF and JFSF was 2.77 and 447.51 µmol of TE/g respectively. Whereas, antioxidant capacity of raw RF-JFSF blend (70:30) was 134.85 µmol of TE/g. RF extrudate indicates increase in antioxidant capacity when compared with its raw formulation but this increase in antioxidant capacity was not significant. During extrusion cooking when the barrel temperature were increased (140 and 180°C) and screw speed was decreased from 300 to 100 rpm, antioxidant capacity was increased significantly from 168.09 to 182.38 µmol of TE/g and 197.11 to 208.56 µmol of TE/g, respectively (Fig. 3). Antioxidant capacity of the raw formulations and extruded products could be attributable to the effect of extrusion on:

- Breaking complex polyphenols into low molecular weight phenolic compounds with scavenging activity
- Formation of Maillard reaction products (Rufian-Henares and Delgado-Andrade, 2009)

The dark color pigments (brown color) are produced at higher temperature conditions during the thermal processing of foods due to the Maillard browning. These pigments (particularly melanoidins) are extensively known to have antioxidant activity. Increase in antioxidant activity could be explained by the formation of Maillard browning pigments which enhanced the antioxidant capacity of extrudates as compared to their corresponding control samples. Similar results indicating increase in antioxidant capacity due to thermal processing has been widely reported by Dewanto *et al.* (2002). Antioxidant capacity indicates a significant positive correlation with TPC, TFC and reducing power (R = 0.998, p<0.01, R = 0.995, p<0.01 and R = 0.734, p<0.01) (Table 6).

Effect of JFSF addition and extrusion cooking on reducing power of extrudate: It was observed that reducing power of raw RF and JFSF was 0.04 and 0.23 mg of AAE/g of dry powder respectively. While reducing power of raw RF-JFSF blend (70:30) was 0.09 mg of AAE/g of dry powder. Reducing power of raw RF-JFSF blend is mainly due to the phenolic compounds and flavonoids present in JFSF. Phenolic compounds and flavonoids have the ability to donate electrons and act as reductones (Omwamba and Hu, 2010) and play a major role in the reducing power of the extracts. Figure 3 indicates that, when temperature of extrusion cooking was kept constant (180°C) and screw speed was decreased from 300 to 100 rpm, reducing power activity was increased significantly. Whereas at low temperature (140°C) with decrease in

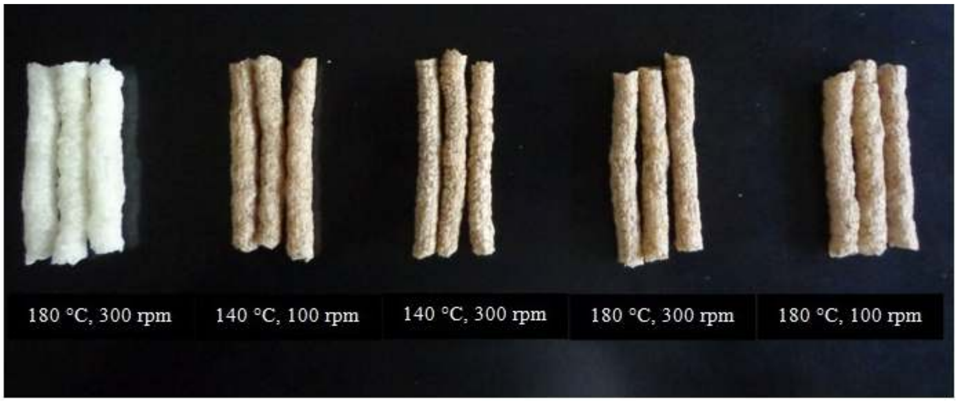

Fig. 4: Effect of extrusion cooking conditions on extrudate product prepared from RF and RF-JFSF blend

screw speed (300-100 rpm) reducing power increased but this increase in reducing power was not significant. Reducing power is also considered as an indicator of antioxidant activity which is associated with the presence of reductones. Similar results in agreement were reported by other authors upon thermal processing in different cereals (Xu and Chang, 2008). Table 6 indicates that reducing power showed a significant positive correlations with TPC, TFC and antioxidant activity ($R = 0.742$, $p<0.01$, $R = 0.683$, $p<0.01$ and $R = 0.734$, $p<0.01$) (Fig. 4).

CONCLUSION

Addition of JFSF in rice based extrudates improved the nutrimental and nutraceutical properties. Extrusion cooking (barrel temperature and screw speed) exhibited a significant effect on the physicochemical properties of extrudates. Extrudate RF-JFSF blend shows decrease in phenolic content and flavonoid content while increase in antioxidant capacity and reducing power upon extrusion cooking as compared to their raw formulations.

LIST OF ABBREVIATIONS

WSI	:	Water Solubility Index
WAI	:	Water Absorption Index
TPC	:	Total Phenolic Content
TFC	:	Total Flavonoid Content
TEAC	:	Trolox Equivalent Antioxidant Capacity
RF	:	Rice Flour
JFSF	:	Jackfruit Seed Flour
BI	:	Browning Index
WI	:	Whiteness Index
GAE	:	Gallic Acid Equivalent
QE	:	Quercetin Equivalent
ABTS	:	2, 2'-Azino-bis (3-ethylbenzthiazoline) -6-sulfonic
AAE	:	Ascorbic Acid Equivalent

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