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Effect of extrusion processing on microstructural, physical, functional, antioxidant and textural properties of jackfruit flesh flour, rice flour and pigeon pea flour based extrudates

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Abstract

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The present work focused on the utilisation of jackfruit flesh flour mixed with a legume (pigeon pea) and cereal (rice) flour in different proportions to produce extrudates using twin-screw extrusion cooking. Preliminary trials were carried out for selection of variables, and extrusion cooking was carried out using a twin-screw extruder at extrusion parameters namely temperature: 130°C for two different heating zones, die diameter: 4 mm, and screw speed: 270 rpm. In the finished product, the ash content increased from 1.86 to 2.93% with a concomitant reduction in fat from 1.38 to 0.02% and protein content from 13.50 to 11.56% with the addition of jackfruit flesh flour in the extrudates. The hardness of extrudates increased while a reduction in expansion ratio was observed with the addition of jackfruit flesh flour. Microstructural analysis indicated the absence of uniform structure of starch granules in all the extrudates. Sensory evaluation revealed that extruded sample C (containing 5% jackfruit flesh flour) had the highest overall acceptability. The results indicated that composite flour (jackfruit flesh, rice and pigeon pea) in the ratios of 5:47.5:47.5 could be used to produce quality extrudates.

Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.) belongs to family Moraceae, and is believed to have emerged in the south-western rainforests of India. The size of the whole fruit varies from 8 in to 3 ft, and weigh from 20 to 50 kg. The flavour of jackfruit pulp is sometimes very mild and sometimes strongly scented (Butool and Butool, 2015). The tender jackfruit is a popular vegetable commonly used in preparing soups and pickles. The juicy pulp of the ripe fruit is consumed fresh or preserved in syrup, and has broad prospects for making jam, jelly, chips, papads, and numerous other value-added products. There have been few researches however mentioning the possibility of processing jackfruit into durable and nutritious food products.

Rice (*Oryza sativa* L.) is the third most popular crop cultivated worldwide, after sugar cane and maize (FAOSTAT, 2012). It is a staple food and source of energy for nearly half of the world population, especially in Asia. Based on the extent of milling, rice kernel consists of 20% hull, 8 - 12% bran and embryo, and 70 - 72% endosperm. Cereals particularly rice flour have been particularly used as raw materials for extrusion because of its functional properties, low cost, bland taste, attractive white colour and ease of digestion (Mangaraj *et al*., 2018). Commercial exploitation in different value-added products however is still a challenge.

Pigeon pea (*Cajanus cajan* (L.) Millsp.) is a valuable source of low-cost vegetable proteins, vitamins and minerals, and plays a very predominant role in human nutrition (Okpala and Ekwe, 2013). Pigeon pea is a legume comprises of 20 - 22% protein, 1.2% fat, 65% carbohydrate and 3.8% ash (Ayodele, 2017). Pigeon pea seeds are very hard to cook and dehull. These factors limit the utilisation of pigeon pea in numerous products (Fasoyiro *et al*., 2005). Pulse powder, which is the by-product of the

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milling process, is easily accessible at a relatively lower price in contrast to red gram dhal. Pulse powder has high protein content (22%). Mixtures of cereals and legumes result in products with higher content of proteins (Kumari and Sangeetha, 2017). Many researches on the extrusion of cereals has been reported (Björck *et al*., 1984; Ilo *et al*., 1996), and on the extrusion of cereal-legume composites (Colonna and Mercier, 1985; Falcone and Phillips, 1988).

Extrusion is one of the major processes for producing conventional and convenience foods. During extrusion, ingredients are subjected to various unit operations like mixing, heating, shearing and forced under pressure to pass through a die that result in the expansion of ingredients. Extrusion is a high-temperature short-time (HTST) technique, and when the processing conditions and extruder die are differently manipulated, various shapes and textures of products can be produced.

Fernandez-Molina *et al*. (2003) studied the effect of extrusion temperature and screw speed on the blend of rice and pigeon pea flour, and observed that these parameters significantly ($p < 0.05$) influenced the properties of extrudates. Panasawat *et al*. (2008) extruded a blend comprising rice flour, menhaden oil, fish powder and vitamin E at a feed rate of 10 kg/h utilising a co-rotating twin screw extruder. Kumar *et al*. (2010) developed and characterised extruded product by utilising carrot pomace, rice flour and pulse powder. Ma *et al*. (2012) studied the properties of extruded expandable breadfruit (belonged in same family with jackfruit) products, and stipulated that breadfruit had the potential to produce new value-added extrudates with modified sensory and physicochemical characteristics. Dar *et al*. (2014) studied the effect of extrusion temperature on the microstructure, textural and functional attributes of carrot pomace-based extrudates. With the increase in temperature, harder and compact structure of extrudates was observed using the scanning electron microscope (SEM).

Nowadays great interest is given in fortifying cereals with ingredients having functional value and to get a better balance of nutrients in extruded snack products (Obatolu and Cole, 2000). The effect of extrusion process parameters on antioxidant activity and polyphenol content in the extruded snack bars made up of corn, oat, chickpea, carrot and hazelnut was reported by O″zer *et al*. (2006). Several researchers developed ready-to-eat fortified products by blending cereals with vegetables and fruits. The addition of legume and fruits to cereal-based products could be a good option for increasing the intake of legumes and fruits (Satusap *et al*., 2014). Jackfruit flesh flour, rice flour and pigeon pea flour have unique attributes. But no systematic study has been carried out to utilise jackfruit flesh flour in combination with cereal and legume flour to produce extrudates. The combination of grain with legume proteins would provide better overall health benefits.

Keeping in view the consumer demand of value-added extruded products from rice flour supplemented with pulse flour, fruit flour and unavailability of these products in the current market, the present work was therefore designed to develop jackfruit flesh flour, rice and pigeon pea flour supplemented extrudates, and to analyse the nutritional compositions of the composite flour. The evaluation on its various microstructural, physicochemical, functional, textural, sensorial and antioxidant properties was also conducted.

Materials and methods

Materials

Jackfruit (commercial variety) from a local market, rice flour from a rice mill, and pulse powder from a pulse mill were all locally obtained in Sangrur, Punjab, India.

Preparation of jackfruit flesh flour

Jackfruit flesh flour was prepared by carrying out several unit operations like washing, cutting into two halves from middle, removal of outer rind, cutting jackfruit flesh of uniform thickness (10 mm), removal of seeds, drying in tray dryer (60°C, 10 h), grinding, sieving (2 mm; mesh number 7) and storage in polythene pouches.

Preparation of blends

Blends were formulated by mixing rice flour (RF), pigeon pea flour (PF) and jackfruit flesh flour (JF) as follows: control: 50% PF + 50% RF; sample A: 0.5% JF + 99.5% equal proportion of RF and PF; sample B: 1% JF + 99% equal proportion of RF and PF; sample C: 5% JF + 95% equal proportion of RF and PF; sample D: 10% JF + 90% equal proportion of RF and PF; sample E: 20% JF + 80% equal proportion of RF and PF; sample F: 30% JF + 70% equal proportion of RF and PF. Formulated blends were then kept in impermeable containers for further use.

Preliminary trials for extrusion

Preliminary trials were conducted to decide the range of independent variables. A feed proportion in different selected ratios was used to produce extrudates at different screw speeds of 230, 240, 250, 260, 270, 280, 290, 300 and 310 rpm, and at different barrel temperatures of 100°C, 110°C, 120°C and 130°C. The least expansion ratio was observed at a screw speed of 230 rpm. On the other hand, screw speed of more than 280 rpm created non-uniform expansion and coiling over the extrudate. Therefore, the range of screw speed was considered in between 240 - 280 rpm. Preliminary trials of samples with feed proportion in different selected ratios were carried out at different screw speeds (240 - 280 rpm) and different temperatures (100 - 130°C). It was found that extrudates from the different feed proportions were having maximum expansion at 130°C and 270 rpm screw speed. Therefore, optimised values of different variables for extrusion processing were: screw speed (270 rpm); and temperature (130°C). Kumar *et al*. (2010) outlined the moisture content in the range of 17 to 21% to develop extrudates of good quality.

Preparation of feed for extrusion

The prepared blends were segregated in polyethylene bags and kept in a refrigerator for 24 h prior to extrusion. Preliminary trials of samples with feed proportion in different selected ratios were carried out for selecting moisture content of samples. A control sample was prepared from rice and pigeon pea flour with the proportion of 50: 50 under the optimum conditions (screw speed 270 rpm, barrel temperature 130°C, feed moisture 18%). Moisture was calculated and regulated by sprinkling distilled water in the appropriate proportion of dry ingredients. All the ingredients were weighed and then blended using a food processor for 10 min. Next, the mixture was allowed to pass through a 2 mm sieve for screening. This process prevented lump formation due to the inclusion of moisture.

Extruder and extrusion cooking

For extruding the feed mixture, a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd. Kolkata, India) equipped with 4 mm diameter die was used. The length to diameter (L/D) ratio of the extruder barrel was 8:1. The barrel was supplied with two electric heaters and two water cooling jackets. The screw speed of the extruder was adjusted to 270 rpm, while the feed rate was maintained consistently at 28 g/min. The extruder barrel temperature was maintained at 130°C, and the moisture was adjusted to 18% by adding the appropriate amount of water to all the blends. The twin-screw extruder was kept running for 0.5 h to sustain the set temperatures, and a sample was then poured into a hopper for smooth and uninterrupted operation. Extrudates were received at the die end and packed in previously numbered zipped lock pouches for effective preservation.

Proximate analysis

Moisture, ash, fat, fibre, and protein of extrudates were measured following the standard method (AOAC, 2000). Total carbohydrate of extrudates was determined by the difference method (Bolade and Bello, 2006). The energy value of the extrudates was enumerated by applying 4, 9 and 4 factors for each gram of protein, lipid and carbohydrate, respectively (Akubor *et al*., 2003). The energy was calculated using Eq. 1:

$$\text{Energy value (calories)} = 4(\text{protein}) + 9(\text{fat}) + 4(\text{carbohydrate}) \quad \text{(Eq. 1)}$$

Moisture retention

The moisture retention of extrudates was determined following AOAC method 925.10 (AOAC, 2005). Percent moisture retention of extrudates was calculated using Eq. 2:

$$\text{Moisture retention (\%)} = \frac{\text{moisture content of product} \times 100}{\text{moisture content of the feed}} \quad \text{(Eq. 2)}$$

Extrudate diameter (de)

The extruded samples were cut, and the diameter of cross-section was measured using a digital Vernier calliper. For each extruded sample, at least ten measurements were taken. The arithmetic mean of the extruded samples was taken into consideration for final extrudate diameter value (Raphaelides *et al*., 2010).

Expansion ratio

The ratio of extrudate diameter to the diameter of the die is known as expansion ratio. Extrudate diameter was determined by taking arithmetic mean of ten arbitrary values using a digital Vernier calliper. The expansion ratio of extrudates was calculated using Eq. 3:

$$\text{Expansion ratio} = \frac{\text{Diameter of extrudate}}{\text{(Diameter of die)}} \quad \text{(Eq. 3)}$$

Colour characteristics

Hunter colorimeter Model D 25 (Hunter Associates Laboratory Inc., Reston, VA, USA) was employed for determining the colour values (L^*, a^*, b^*) of extrudates. A standard red-coloured reference tile (L_s = 25.54, a_s = 28.89, b_s = 12.03) was used for calibrating the instrument. The total colour difference (ΔE) of extrudates was calculated using Eq. 4:

$$\Delta E = [(L_s - L^*)^2 + (a_s - a^*)\ 2 + (b_s - b^*)\ ^2]^{1/2} \quad \text{(Eq. 4)}$$

The whiteness index (WI), which is defined as the combination of both lightness and yellow-blue colour; was calculated using Eq. 5(Hsu *et al*., 2003):

$$WI = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{½} \quad \text{(Eq. 5)}$$

Bulk density

The bulk density of extrudates was determined following the method proposed by Alvarez-Martinez *et al*. (1988). The volume of the extrudates was calculated by knowing the mean diameter and mean length of 25 measurements of extrudates using Eq. 6:

$$\text{Volume (cm}^3) = \pi d^2\ L/4 \quad \text{(Eq. 6)}$$

where d = mean diameter of extrudates; and L = mean length of extrudates in cm.

After obtaining the volume of extrudates, its bulk density was measured using Eq. 7:

$$\text{Bulk density} = \frac{\text{(Mass of extrudates (kg)}}{\text{(Volume of extrudates (cc)}} \quad \text{Eq. 7)}$$

True density

The true density of extrudates was quantified by the procedure suggested by Deshpande and Poshadri (2011). Approximately 1 g of minced extrudate sample was put in a burette comprising of toluene. The raised in toluene level was then noted. This process was repeated twice and the mean of two readings was recorded. The true density was then calculated using Eq. 8:

$$\text{True density} = \frac{\text{(Weight of the ground sample of extrudates)}}{\text{(Rise in toluene level)}} \quad \text{(Eq. 8)}$$

Water activity

The water activity of extrudates was measured using a water activity analyser (Rotronic Hygro lab, Cole-Parmer WW-37910-25). The sample to be measured was placed in a sealed container/ sample storing cups. The probe was equilibrated with ambient temperature. At equilibrium, the water activity of samples was noted.

Hardness

The hardness of extrudates was quantified using a texture analyser (TA.XT2 Plus, Stable Microsystem, UK). The test settings were as follows: test speed: 2.0 mm/s; post-test speed: 10.0 mm/s; distance: 48 mm; trigger type: button; data acquisition rate: 400 pps; strain: 50%. The results were expressed as the mean of three replications. The peak force required by a parallel plate probe for penetrating the extrudate is known as hardness. Hardness is directly proportional to the force required for penetrating the extrudate.

Water absorption index, water solubility index and swelling power

The water absorption index (WAI) and water solubility index (WSI) of extrudates were calculated following the procedure recommended by Kaushal *et al*. (2012). Briefly, 2.5 g of flour sample was dissolved into 30 mL of distilled water with a glass rod. Heating of the dispersion was then carried out at 90°C for 15 min in a water bath. The cooked paste was then allowed to cool to room temperature and further transferred to a pre-weighed centrifuge tube. Centrifugation was then carried out at 3,000 g for 10 min. The supernatant after centrifugation was poured into a pre-weighed evaporating dish. The supernatant was evaporated overnight at 110°C for determining the dry solid content. The sediment was also weighed. Triplicate measurements were carried out. WSI and WAI of extrudates were determined using Eq. 9 and Eq. 10, respectively:

$$\text{Water absorption index} = \frac{\text{Weight of sediment (g)}}{\text{Weight of flour sample (g)}} \quad \text{(Eq. 9)}$$

$$\text{Water solubility index (\%)} = \frac{\text{Weight of dissolved solids in supernatent} \times 100}{\text{Weight of flour sample)}} \quad \text{(Eq. 10)}$$

The swelling power (SP) of extrudates was determined using Eq. 11:

$$\text{Swelling power} = \frac{\text{Weight of sediment (g)}}{\text{Weight of flour sample (g) - weight of dissolved solids in a supernatant (g)}} \quad \text{(Eq. 11)}$$

Water absorption capacity and oil absorption capacity

The water absorption capacity (WAC) of extrudates was determined following the centrifugation procedure recommended by Kaushal *et al*. (2012). Extrudate sample (3.0 g) was dispersed in 25 mL of distilled water, and put in pre-weighed centrifuge tubes. The dispersions were occasionally stirred, held for 30 min, followed by centrifugation for 25 min at 3,000 g. The supernatant was decanted and the excess moisture was removed from centrifuge tubes by drying at 50°C for 25 min in a hot air oven, and reweighed. Triplicate observations were carried out for determining the WAC of extrudates. The WAC of extrudates was expressed as a gram of water bound per gram of the sample on a dry basis, and calculated using Eq. 12:

$$\text{Water absorption capacity} = \frac{\text{Weight of centrifuge tube after drying (g)} - \text{weight of centrifuge tube (g)} - \text{weight of sample (g)}}{\text{Weight of sample (g))}} \quad \text{(Eq. 12)}$$

The procedure proposed by Lin *et al*. (1974) was used for determining the oil absorption capacity (OAC) of extrudates. Briefly, sample (0.5 g) was mixed with 6 mL of corn oil in a pre-weighed centrifuge tube. The dispersions were agitated for 1 min using a thin brass wire to completely disperse the sample in the oil. Centrifugation of tubes was then carried out at 3,000 g for 25 min, after a resting period of 30 min. The separated oil was then detached using a pipette and the tubes were upturned for 25 min to extract the oil subsequent to weighing. Triplicate determinations were done for the adequate precision of OAC of extrudates. The OAC of extrudates were expressed as a gram of oil bound per gram of the sample on a dry basis, and calculated using Eq. 13.

$$\text{Oil absorption capacity} = \frac{\text{Weight of tube with sample after removing oil (g)} - \text{(weight of tube (g)} + \text{weight of sample (g)}}{\text{Weight of sample (g)}} \quad \text{(Eq. 13)}$$

Sensory analysis

The sensory assessment of extrudates was conducted at Food Engineering and Technology Department, SLIET, Longowal, Punjab, India. The panel of 25 members consisted of staff and postgraduate students of the Department of Food Engineering and Technology, SLIET, Longowal, Punjab, India. The panellists were uninformed of project objectives. Samples were organised and coded using numbers. Panellists were given written instructions and asked to judge the products for overall acceptability based on its texture, flavour and colour using nine-point hedonic (1 = extremely disliked, to 9 = extremely liked) method.

Total antioxidant activity

The total antioxidant activity of extrudates was determined following the improved procedure suggested by Brand-Williams *et al*. (1995). The DPPH solution used in the experiment was adjusted to the concentration of 6 x 10-5mol/L, by dissolving 2.3 mg of DPPH in 100 mL of methanol. Extrudates (100 mg) were extracted with 5 mL of methanol for 2 h and centrifuged at 3,000 g for 10 min. The supernatant (100 µL) was then added to 3.9 mL of DPPH stock solution. The absorbance (A) at 515 nm was read at 0 and 30 min using a methanol blank. The total antioxidant activity was calculated in terms of DPPH radical scavenging activity, using Eq. 14:

$$\text{DPPH radical scavenging activity} = [1 - \frac{\text{Absorbance of the sample at t=30}}{\text{Absorbance of control at t=0]}} \times 100 \quad \text{(Eq. 14)}$$

Scanning electron microscopy

To determine the shape and surface feature of extrudates and to visualise extrudates in three dimensions, scanning electron microscope (SEM) (Jeol, JSM 6510LV, Tokyo, Japan) was utilised at an accelerating voltage of 15 kV. Extruded samples and control were placed on stubs with tacky tape and sputter plated gold, around 190 A° thick for 2.5 min at 10 mA before examination with scanning electron micrographs. Different micrographs were taken at 1,000× magnification for all the extruded samples.

Statistical analysis

All experiments were conducted in triplicates. The means, standard deviations and correlations between various properties were obtained through Microsoft Excel 2007. The significant differences were determined by one-way analysis of variance (ANOVA) and Duncan's multiple range test at 95% confidence level ($p < 0.05$).

Results and discussion

Proximate analysis

The proximate composition of extrudates are presented in Table 1. The moisture content of all extrudates was almost consistent, of around 6%. However, dissimilarities were observed in protein, ash and carbohydrate contents of extrudates. The calorific (energy) values of the extrudates ranged from 361.78 to 375.06 kcal. It was noticed that with an increase in jackfruit flesh flour concentration in the extrudates, the calorific value decreased. The decrease in calorific value may be due to a decrease in protein and crude fat of the extrudates.

Moisture content is very crucial to shelf-life of foodstuffs. Higher moisture levels (> 14%) in food products are undesirable and would require further processing to improve their shelf life. The moisture content of the extrudates varied from 6.10 to 6.65% (Table 1). An insignificant ($p > 0.05$) increase in moisture content was observed with increasing jackfruit flesh flour concentrations in the extrudates. The moisture levels of the extrudates were within the permitted limit (< 14%) for preservation. The protein content in extrudates significantly ($p < 0.05$) decreased from 13.50% to 11.56%. This could be due to the denaturation of protein, which on the other hand may improve the nutritional profile of extrudates (Brennan, 2006). Proteins undergo many changes during extrusion, with the most important being denaturation (Camire, 2000). Denaturation during extrusion results in a reduction of protein solubility, cross-linking reactions also occur and possibly, some covalent bonds form at high temperatures; thereby decreasing protein content of extrudates (Maurya and Said, 2014). The decrease in protein content could be due to an increased moisture content of the extrudates by the addition of jackfruit flesh flour. The highest protein content was observed in control (13.50%) whereas least protein content (11.56%) was found in sample F (Table 1).

A significant ($p < 0.05$) reduction in fat content was observed as the amount of jackfruit flesh flour in the extrudates increased. The fat content in extrudates significantly ($p < 0.05$) decreased from 1.38% to 0.02% (Table 1). This agrees with Filli *et al*. (2011) and Anuonye *et al*. (2010) who noticed a similar decrease in the fat content of extrudates when soybean and cowpea were mixed with acha, millet, and rice respectively.

Ash content represents the amount of mineral content of jackfruit flesh flour extrudates, which ranged from 1.86 to 2.93% (Table 1). A significant ($p < 0.05$) variation in ash content of extrudates was observed. This increase may be due to an increase in jackfruit flesh flour in the formula. Minerals are generally stable since extrusion temperature and feed moisture is not expected to cause a significant change in their composition (Gbenyi *et al*., 2016).

Extrudate diameter and expansion ratio

The results of the extrudate diameter are summarised in Table 2. The diameter significantly decreased ($p < 0.05$) with an increase in the concentration of jackfruit flesh flour in the extrudates. The highest extrudate diameter (12.40 mm) was observed in control followed by sample A (12.26 mm), whereas the lowest extrudate diameter (8.64 mm) was observed in sample F (Table 2). The reason lies in jackfruit flesh flour incorporation within the legume and rice flour and mutual expansion which led to a decrease in the radial size of the extrudate (Brncic *et al*., 2009). This may be due to the denaturation of protein during extrusion which affected the radial size and expansion ratio of extrudates. Oke *et al*. (2013) studied the effect of moisture content on radial size and expansion ratio, and concluded that increased moisture content of extrudates decreased the drag force, thereby exerting less pressure at the die and resulting in lesser expansion of extrudates at the exit which in turn decreased the radial size and expansion ratio of extrudates. Another reason may be due to the decrease in the protein content of extrudates (Table 1) that influences the extensional properties of the extrudates (Moraru and Kokini, 2003). The results obtained by measuring the bulk density of extrudates are in conformity with the outcomes of the expansion ratio i.e. lower values of the extrudate diameter and expansion ratio results in extrudates having a higher bulk density (Table 3). Extrudate diameter greatly affected the hardness of extrudates as extrudates with lower expansion ratio had higher hardness and lower fracture ability (Table 3).

The expansion ratio is mainly caused by modification of structure, swelling, nucleation, bubble growth and collapse. A higher expansion ratio is advantageous in the generation of extrudates to achieve a lighter and crispier product. An appropriate level of moisture is desirable for the expansion of an extruded product, which depends on extrusion conditions and feed composition. Different types of extruded products composed of different amounts of starch (amylose: amylopectin content), protein and fat, and result in differences in expansion ratio. The expansion of extrudates depends on the size, number, and distribution of air cells surrounded by the cooked material. Highly expanded products are acquired with high starch content (Abd El-Hady *et al*., 2002).

Table 1. Proximate analysis of control and jackfruit flesh flour based extrudates.

	Control	Sample A (0.5% JF)	Sample B (1% JF)	Sample C (5% JF)	Sample D(10% JF)	Sample E (20% JF)	Sample F (30% JF)
Moisture (%)	6.10 ± 0.34[a]	6.12 ± 0.62[ab]	6.16 ± 0.36[ab]	6.24 ± 0.63[ab]	6.39 ± 0.43[b]	6.45 ± 0.68[b]	6.65 ± 0.56[b]
Protein (%)	13.50 ± 0.23[e]	13.48 ± 0.15[d]	13.40 ± 0.14[d]	12.49 ± 0.18[c]	12.26 ± 0.25[c]	12.03 ± 0.27[b]	11.56 ± 0.25[a]
Fat (%)	1.38 ± 0.05[g]	1.34 ± 0.14[f]	1.30 ± 0.11[e]	1.02 ± 0.10[d]	0.63 ± 0.06[c]	0.17 ± 0.30[b]	0.02 ± 0.01[a]
Ash (%)	1.86 ± 0.17[a]	1.92 ± 0.09[b]	2.35 ± 0.23[c]	2.38 ± 0.24[d]	2.48 ± 0.25[e]	2.84 ± 0.28[f]	2.93 ± 0.35[g]
Carbohydrate (%)	77.16[f]	77.14[b]	76.79[a]	77.87[d]	78.24[c]	78.51[e]	78.84[a]
Energy (kcal/100g)	375.06[f]	374.54[e]	372.46[d]	370.62[d]	367.67[c]	363.69[b]	361.78[a]

JF: jackfruit flesh flour; PF: pigeon pea flour; RF: rice flour; control: (50% PF + 50% RF); sample A (0.5% JF + 99.5% equal proportion of RF and PF); sample B (1% JF + 99% equal proportion of RF and PF); sample C (5% JF + 95% equal proportion of RF and PF); sample D (10% JF + 90% equal proportion of RF and PF); sample E (20% JF + 80% equal proportion of RF and PF); sample F (30% JF + 70% equal proportion of RF and PF). Data are mean ± SD with different superscripts in a row indicating significant difference ($p < 0.05$).

Table 2. Extrudate diameter, expansion ratio and colour characteristics of control and jackfruit flesh flour based extrudates.

	Control	Sample A (0.5% JF)	Sample B (1% JF)	Sample C (5% JF)	Sample D (10% JF)	Sample E (20% JF)	Sample F (30% JF)
Extrudate diameter (mm)	12.40 ± 1.32[f]	12.26 ± 1.22[f]	11.68 ± 1.17[e]	10.67 ± 1.06[d]	10.78 ± 1.08[c]	10.11 ± 1.01[b]	8.64 ± 0.86[a]
Expansion ratio (Er)	3.309 ± 0.33[d]	3.065 ± 0.31[cd]	2.920 ± 0.29[bcd]	2.695 ± 0.26[bc]	2.666 ± 0.26[b]	2.527 ± 0.25[a]	2.161 ± 0.22[a]
L*	81.5 ± 1.65[g]	80.4 ± 1.04[f]	78.5 ± 1.65[e]	75.5 ± 1.45[d]	73.1 ± 1.31[c]	69.4 ± 1.84[b]	66.6 ± 1.77[a]
a*	10.1 ± 0.66[a]	10.6 ± 0.78[a]	11.5 ± 0.15[b]	13.3 ± 0.17[c]	15.2 ± 0.14[d]	16.0 ± 0.18[e]	17.2 ± 0.15[f]
b*	21.2 ± 1.45[e]	20.7 ± 1.32[d]	19.2 ± 1.23[c]	18.6 ± 1.26[b]	17.3 ± 1.65[ab]	17.1 ± 1.68[ab]	16.5 ± 1.56[a]
ΔE	59.74[g]	58.47[f]	56.20[e]	52.75[d]	49.77[c]	45.99[b]	42.92[a]
WI	70.11[f]	69.59[f]	68.97[e]	66.49[d]	64.59[c]	61.47[b]	58.97[a]

JF: jackfruit flesh flour; PF: pigeon pea flour; RF: rice flour; control: (50% PF + 50% RF); sample A (0.5% JF + 99.5% equal proportion of RF and PF); sample B (1% JF + 99% equal proportion of RF and PF); sample C (5% JF + 95% equal proportion of RF and PF); sample D (10% JF + 90% equal proportion of RF and PF); sample E (20% JF + 80% equal proportion of RF and PF); sample F (30% JF + 70% equal proportion of RF and PF). Data are mean ± SD with different superscripts in a row indicating significant difference ($p < 0.05$).

Table 3. Density, water activity and hardness of control and jackfruit flesh flour based extrudates.

	Control	Sample A (0.5% JF)	Sample B (1% JF)	Sample C (5% JF)	Sample D (10% JF)	Sample E (20% JF)	Sample F (30% JF)
Bulk density (×10-5kg/cm3)	2.78 ± 0.01[a]	2.84 ± 0.02[ab]	2.87 ± 0.01[b]	3.90 ± 0.02[c]	4.22 ± 0.13[d]	4.49 ± 0.12[e]	5.52 ± 0.05[f]
True density (kg/cm3)	0.50 ± 0.02[a]	0.53 ± 0.12[a]	0.69 ± 0.13[b]	0.78 ± 0.05[c]	0.82 ± 0.04[d]	0.90 ± 0.11[e]	0.95 ± 0.14[f]
Water activity (aw)	0.451 ± 0.02[a]	0.459 ± 0.10[b]	0.460 ± 0.05[b]	0.468 ± 0.03[c]	0.469 ± 0.14[d]	0.484 ± 0.06[e]	0.501 ± 0.05[f]
Hardness (kgf)	8.56 ± 0.86[bc]	8.57 ± 0.12[a]	8.86 ± 0.15[b]	9.17 ± 0.15[b]	10.10 ± 0.18[d]	11.95 ± 0.05[e]	12.77 ± 0.14[e]

JF: jackfruit flesh flour; PF: pigeon pea flour; RF: rice flour; control: (50% PF + 50% RF); sample A (0.5% JF + 99.5% equal proportion of RF and PF); sample B (1% JF + 99% equal proportion of RF and PF); sample C (5% JF + 95% equal proportion of RF and PF); sample D (10% JF + 90% equal proportion of RF and PF); sample E (20% JF + 80% equal proportion of RF and PF); sample F (30% JF + 70% equal proportion of RF and PF). Data are mean ± SD with different superscripts in a row indicating significant difference ($p < 0.05$).

The results of the expansion ratio of extrudates are summarised in Table 2. With the increase in jackfruit flesh flour concentration in the extrudates, the expansion ratio of the extrudates significantly ($p < 0.05$) decreased. The highest expansion ratio was seen in control (3.309) followed by sample A (3.065), whereas the lowest expansion ratio was observed in sample F (2.161) (Table 2). The decrease in fat content (Table 1) could be responsible for a decreased expansion ratio of extrudates (Table 2). Fat acts as an influential lubricant that effects extrusion and reduces product expansion (Ilo *et al*., 1999). Similar results have been reported by Filli *et al*. (2012) where an increased level of soybean flour marginally decreased the expansion ratio because of the high fat in the soybean flour. Low amount of moisture content in extrudates results in reducing shear strength. This results in the decrease of moisture evaporation at the die exit, thereby causing a low expansion ratio of extrudates. This is because foods with lower moisture tend to be more viscous than those with higher moisture, therefore, the pressure differential would be smaller for higher moisture foods, leading to a less expanded product (Singh *et al*., 2007). Similar results were outlined by Jozinović *et al*. (2012), where the expansion ratio of corn extrudates decreased with the inclusion of buckwheat and chestnut flours.

Control had the highest expansion ratio (3.309) followed by sample A (3.065). The highest expansion ratio in control could be due to the higher carbohydrate content (Table 1). The shape of extrudates depends on starch gelatinisation (Devi *et al*., 2013). The increased ratio of starch to protein content results in the evolution of a continuous starch matrix that causes expansion of water vapour. Gujska and Khan (1991) reported that well-cooked samples at higher temperature resulted in improved expansion.

Colour characteristics

Colour is a predominant quality characteristic since it affects the level of chemical reactions and extent of cooking that occurs during extrusion. Colour changes in the extrudates correlates to pigment degradation, the degree of browning reactions, and the extent of extrusion. According to Rosentrater *et al*. (2009), protein denaturation and Maillard reactions play major roles in colour alterations during extrusion. L^* values of the extrudates varied from 66.6 - 81.5 (Table 2). The highest L^* value (81.5) was observed in control whereas the lowest L^* value was observed in sample F (66.6). The decrease in L^* value might have been caused by the pigments (carotenoids and flavonoids) present in the jackfruit flesh flour. The formation of intermediates from Maillard reactions and the destruction of heat sensitive pigments caused darkening of the extrudates. All these differences could have also been due to the shear forces generated during extrusion which accelerated the Maillard reaction that took place during extrusion (Guy, 2001). It is well known that under high processing temperatures, reducing sugars and proteins in foods combine to encourage Maillard reaction, which causes darkening of the final product.. Ahmed (1999) also demonstrated the decrease in the lightness of corn-based extrudate prepared from the inclusion of flaxseed.

The a^* values of the extrudates ranged from 10.1 - 17.2 (Table 2) whereas the b^* values ranged from 16.5 to 21.2. With the increase in the concentrations of jackfruit flesh flour in the extrudates, the b^* values decreased. The changes in colour values during extrusion are mainly generated by the consequences of non-enzymatic browning and pigment destruction reactions.

The total colour difference (ΔE) of the extrudates ranged from 42.92 - 59.74 (Table 2). The highest ΔE value was observed in control (59.74), whereas the lowest ΔE value (42.92) was observed in sample F. Highest ΔE means darker products with more intense yellow and red colour. This agrees with the b^* values of extrudates as the highest value of b^* was observed in control (Table 2). The colour change during extrusion could be used to assess the magnitude of the process in terms of chemical and nutritional changes. The whiteness index (WI) of extrudates ranged from 58.97 - 70.11. The highest WI (69.59) was observed in control, whereas the lowest WI (58.97) was observed in sample F. This may be due to the biochemical changes occurring inside the extruder and changes in the moisture content of the ingredients before processing.

Density of extrudates

The density of extrudates connotes the overall expansion, development of pores and the alterations in the cell structure of the extrudates during processing. The ratio of the mass of extrudates to the apparent volume of a distinct container is known as bulk density. Several variables such as die design, temperature, pressure, the extent of expansion and feed compositions can affect the bulk density of extrudates. Significant ($p < 0.05$) increase in the bulk density of extrudates was observed with increasing jackfruit flesh flour concentrations (Table 3). This increase may be due to the gelatinisation of starch and a decrease in the expansion ratio of extrudates. The highest bulk density was observed in sample F, whereas the lowest bulk density was observed in sample A (Table 3). Extrudates with lower values of extrudate diameter and expansion ratio (Table 2) had higher bulk density. The inclusion of high-fibre and high-protein content raw materials to starch-based extrudates, generally result in higher bulk density (Onwulata *et al*., 2001). A similar trend of increase in bulk density was also shown in sorghum extrudates containing increasing amounts of cowpea flour (Seth and Rajamanickam, 2012). Bulk density and expansion ratio are also linked to gelatinisation of starch. Temperature greatly affects the bulk density of extrudates. At high temperature, sufficient heat would be available to produce steam and therefore high expansion index which results in the reduction of bulk density of extrudates.

True density is the ratio of a mass of a particle divided by its volume, eliminating loose and closed pores. True density of extrudates varied from 0.50 to 0.95 kg/cm3. A significant increase ($p < 0.05$) in true density was observed with increasing jackfruit flesh flour concentrations in the extrudates. The highest true density (0.95 kg/cm3) was observed in sample F, whereas the lowest true density (0.50 kg/cm3) was observed in control (Table 3). During extrusion, loose and closed pores are formed in the extrudates. Gelatinisation of starch and protein denaturation also occur during extrusion. These changes might have resulted in maintaining the extrudate structure by entrapping the air for a longer span which led to an increase in the true density of extrudates (Chevanan *et al*., 2007). Rosentrater *et al*. (2005) reported higher true density values in an extruded corn masa by-product which may be due to the fact that many pores were opened to the surface during extrusion.

Water activity and hardness

Water activity estimates the existing free/unbound water in a material, which in the present work ranged from 0.451 - 0.501 (Table 3). The water activity of the extrudates significantly increased ($p < 0.05$) with increasing jackfruit flesh flour concentration. The highest water activity was observed in sample F (0.501), whereas the lowest water activity was observed in control (0.451). This may be due to the degradation of mechanical energy into thermal energy, thereby affecting water evaporation at the die exit (Raphaelides *et al*., 2010). These results agree with Hussain *et al*. (2009). The lower value of water activity is desirable for safe preservation of foods. The water activity of less than 0.6 extends the shelf life of most food products (Lowe and Kershaw, 1995). It was observed that the water activity of all extrudates was below 0.5 indicating good shelf life of extruded products.

Texture is a crucial characteristic in consumer's consideration of food and buying assessment. The textural properties of extrudates are generally outlined by the hardness and crispiness. The hardness of extrudates is linked with expansion and cell structure of the product. The hardness of the extrudates ranged from 8.56 to 12.77 kgf (Table 3). With the increase in jackfruit flesh flour concentration, the hardness of extrudates significantly increased ($p < 0.05$). This may be due to an increase in bulk density of extrudates (Table 3). It is possible that proteins and hydrolysed starches present in the jackfruit flesh flour acted as binders and resulted in increased hardness of the extrudates. Increased hardness of extrudates indicates the presence of more compact matrix. Several researchers have reported a positive correlation between bulk density and hardness recommending that a low-density product naturally results in lower hardness (Altan *et al*., 2008; Meng *et al*., 2010). The expansion ratio of the extrudates was inversely correlated with its hardness. In other words, the relatively harder extrudates (extrudates produced from the jackfruit flesh flour) measured lower expansion ratios. The hardness of control was 8.56 kgf (Table 3). Many studies have shown that moisture content has the strong impact on the texture of extrudates (Brnčić *et al*., 2006; Petrova *et al*., 2010), but other parameters like temperature, screw configuration, and screw speed are also very important (Saeleaw *et al*., 2012). Hagenimana *et al*. (2006) outlined that low moisture content during extrusion is correlated with the increased amount of degraded starch granules resulting in the formation of increased water-soluble products; thereby influencing hardness of extrudates.

Physicochemical and functional properties of extrudates

Water absorption index quantifies the amount of water absorbed by starch and can be used as an indicator of gelatinisation. It is an estimate of damaged starch along with protein denaturation and new macromolecular composite formations. Extrusion temperature and feed moisture content had a strong impact on gelatinisation during extrusion, thereby influencing the water absorption index. The water absorption index was found to be maximum in control (5.41 g/g) followed by sample A (5.38 g/g) (Table 4). The water absorption index of the extrudates significantly decreased ($p < 0.05$) with the increase in jackfruit flesh flour in the composite mixes. The decrease in the water absorption index could probably be due to dextrinisation. The variation in water absorption index of extrudates may be due to several factors like protein denaturation and starch gelatinisation that occurred during extrusion. This effect was attributed to the relative decrease in starch content with the addition of jackfruit flesh flour which may influence the extent of starch gelatinisation in the barrel, thereby resulting in reduced water absorption. Another reason might be due to the reduction in carbohydrate content of jackfruit flesh flour based extrudates.

Water solubility index measures the degree of starch dextrinisation and degradation of molecular compounds during extrusion. It computes the level of soluble polysaccharide released from the starch component after extrusion. The water solubility index was highest in sample F (66.48%) as compared to control (42.98%) (Table 4). The water solubility index of the extrudates significantly increased ($p < 0.05$) with increasing jackfruit flesh flour concentrations. These observations are in accordance with the results outlined by Shirani and Ganeshranee (2009) where an increase in water solubility index of extrudates formulated from fenugreek and fenugreek polysaccharide was observed in contrast to those formulated from the chickpea–rice blend. An increase in water solubility index is the outcome of the increased level of dextrinised starch during extrusion (Kebede *et al*., 2010).

The swelling power of extrudates ranged from 8.31 - 12.41 g/g (Table 4), and significantly increased ($p < 0.05$) with increasing concentrations of jackfruit flesh flour. This may be due to an increase in water absorption capacity of extrudates with the addition of jackfruit flesh flour. Loos *et al*. (1981) related swelling power to the water absorption capacity of the extrudates. The high swelling power of extrudates is advantageous as it helps in utilising the starch in a wide range of applications. The results are summarised in Table 4.

Water absorption capacity is a macroscopic parameter that relies on several factors like state of the protein and starch molecules and the range of void spaces accessible in the extrudate. The water absorption capacity and oil absorption capacity of extrudates are presented in Table 4. Addition of jackfruit flesh flour significantly ($p < 0.05$) influenced the water and oil absorption capacities of extrudates. The water absorption capacity of extrudates ranged from 4.06 to 4.41 g/g; the lowest was observed in control (4.06 g/g) and the highest (4.41 g/g) was observed in sample F. This may be due to the increased number of hydrophilic constituents as a result of the addition of jackfruit flesh flour in the extrudates (Table 1). Water absorption capacity value was influenced by a chemical component of the polysaccharide content of the extrudates. Ning and Vilota (1994) also proposed that the water absorption capacity was directly influenced by the porosity of the extrudates.

Oil absorption capacity is a physical binding of fat by chemical compounds, especially protein, and is one of the indicators of extrudate quality, which is influenced by the interaction of oil and starch mixture. Oil absorption capacity depicts the rate of binding of proteins and fat in food formulations. Absorption of oil in foodstuff enhances their mouthfeel and flavour retention. Water and oil absorption capacity of food protein rely on the vital factors like the amino acid composition and surface polarity. A significant decrease ($p < 0.05$) in oil absorption capacity of extrudates was observed with increasing jackfruit flesh flour concentrations. Oil absorption capacity value of extrudates varied from 1.64 to 2.15 g/g; the highest was 2.15 g/g observed in control, and the lowest was 1.64 g/g observed in sample F. This might be due to the distinctness in protein content of extrudates (Table 1). Oil and starch mixture influenced the physical characteristics of starch because oil can form a complex with amylose that inhibits starch granule swelling.

Total antioxidant activity (TAA)

The total antioxidant activity of extrudates decreased with increasing concentrations of jackfruit flesh flour (Table 4). Fruits and vegetables are good sources of antioxidants. But processing of fruits into flours might affect the total antioxidant activity. Drying is one of the most efficient processes that help in reducing microbial growth. But still, quality is affected during drying. The temperature employed in drying might affect various antioxidants present in jackfruit; thereby affecting the total antioxidant activity of the finished products. Temperature higher than 60°C can cause degradation of the heat-sensitive compounds and catalyse oxidation in food products.

Sensory evaluation

Extrudates prepared using different concentrations of jackfruit flour was subjected to different attributes such as appearance, mouthfeel, texture, taste and overall acceptability. The overall acceptability of a product reflects the various individual attributes that altogether make the product attractive and acceptable to the consumer. The rating of overall acceptability of extrudates varied from 6.87 to 8.31 (Table 4). The increase in the jackfruit flour led to a decrease in overall acceptability of extrudates. Sensory evaluation revealed that sample C had the highest ranking scores in all the five attributes. The sample

Table 4. Physicochemical, functional properties and sensory analysis of control and jackfruit flesh flour based extrudates.

	Control	Sample A (0.5% JF)	Sample B (1% JF)	Sample C (5% JF)	Sample D (10% JF)	Sample E (20% JF)	Sample F (30% JF)
WAI (g/g)	5.41 ± 0.04	5.38 ± 0.05	5.27 ± 0.02	5.16 ± 0.01	5.02 ± 0.01	4.95 ± 0.10	4.76 ± 0.03
WSI (%)	42.98 ± 1.15	43.05 ± 1.10	44.81 ± 0.09	55.27 ± 0.07	60.15 ± 0.05	62.66 ± 0.10	66.48 ± 0.06
SP (g/g)	8.31 ± 0.08	8.35 ± 0.05	9.61 ± 0.10	11.31 ± 0.05	11.71 ± 0.04	12.31 ± 0.15	12.41 ± 0.20
WAC (g/g)	4.06 ± 0.02	4.08 ± 0.01	4.12 ± 0.02	4.16 ± 0.03	4.27 ± 0.04	4.31 ± 0.05	4.41 ± 0.03
OAC (g/g)	2.15 ± 0.10	2.08 ± 0.09	2.01 ± 0.05	1.97 ± 0.05	1.88 ± 0.05	1.72 ± 0.10	1.64 ± 0.15
TAA (%)	28.85	28.51	27.00	26.68	25.94	25.59	24.83
Appearance	8.75 ± 0.12	8.25 ± 0.09	8.00 ± 0.03	8.25 ± 0.02	7.75 ± 0.01	7.50 ± 0.10	7.50 ± 0.09
Mouthfeel	8.25 ± 1.10	8.50 ± 0.09	8.00 ± 0.05	8.75 ± 0.05	7.25 ± 1.12	6.85 ± 1.10	6.50 ± 1.12
Texture	8.00 ± 1.10	8.50 ± 1.10	8.00 ± 0.08	8.25 ± 0.07	7.50 ± 0.05	7.00 ± 0.08	6.50 ± 0.05
Taste	8.00 ± 0.01	8.00 ± 0.05	8.25 ± 0.10	8.25 ± 0.09	7.50 ± 0.05	7.00 ± 0.12	7.00 ± 0.10
Overall acceptability	8.25 ± 0.05	8.31 ± 0.08	8.06 ± 0.10	8.37 ± 0.10	7.50 ± 0.04	7.08 ± 0.10	6.87 ± 0.05

JF: jackfruit flesh flour; PF: pigeon pea flour; RF: rice flour; control: (50% PF + 50% RF); sample A (0.5% JF + 99.5% equal proportion of RF and PF); sample B (1% JF + 99% equal proportion of RF and PF); sample C (5% JF + 95% equal proportion of RF and PF); sample D (10% JF + 90% equal proportion of RF and PF); sample E (20% JF + 80% equal proportion of RF and PF); sample F (30% JF + 70% equal proportion of RF and PF). Data are mean ± SD with different superscripts in a row indicating significant difference ($p < 0.05$).

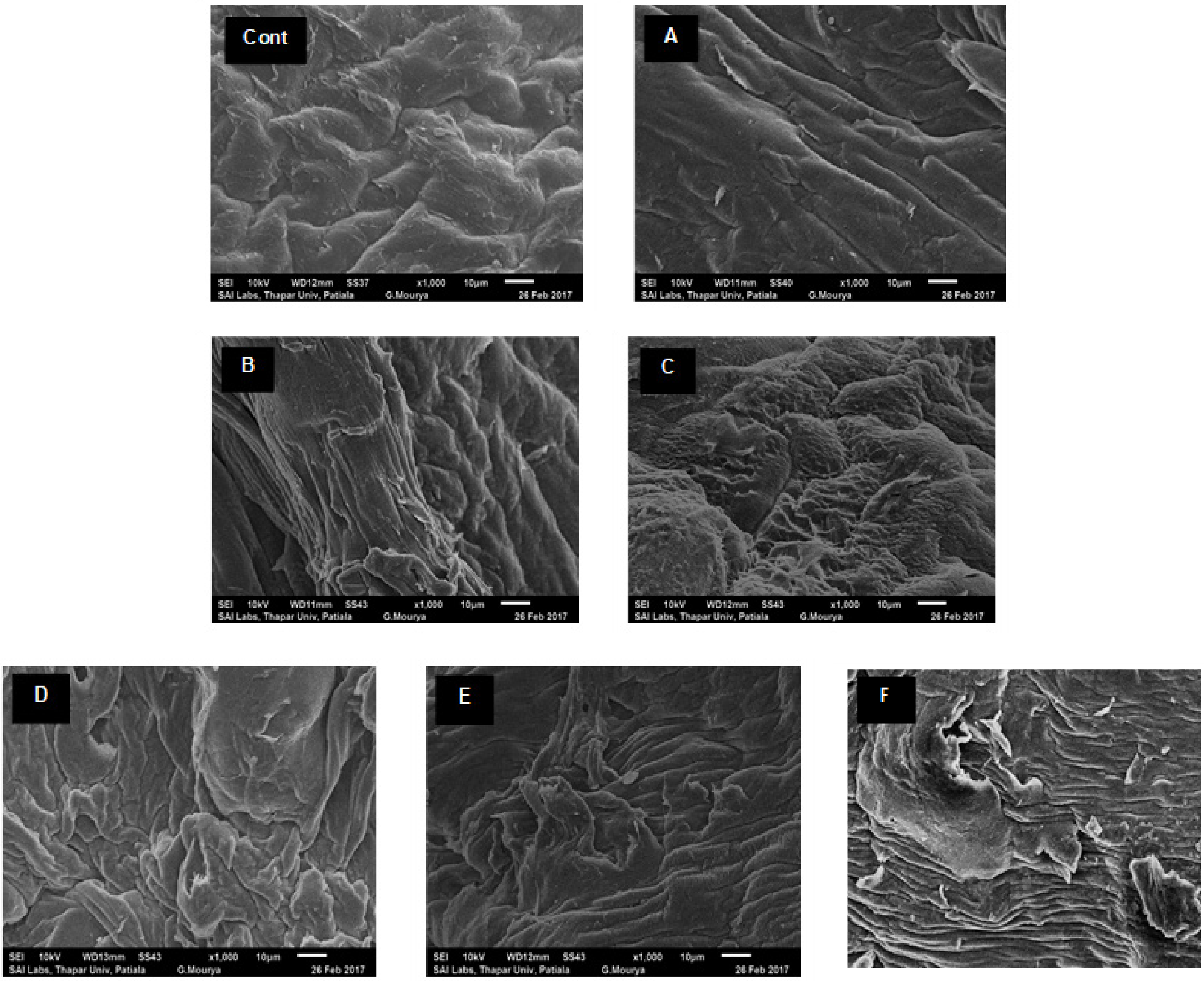

Figure 1. Microscopic structures (1,000× magnification) of control and jackfruit flesh flour based extrudates. JF: jackfruit flesh flour; PF: pigeon pea flour; RF: rice flour; control: (50% PF + 50% RF); sample A (0.5% JF + 99.5% equal proportion of RF and PF); sample B (1% JF + 99% equal proportion of RF and PF); sample C (5% JF + 95% equal proportion of RF and PF); sample D (10% JF + 90% equal proportion of RF and PF); sample E (20% JF + 80% equal proportion of RF and PF); sample F (30% JF + 70% equal proportion of RF and PF).

with the lowest score in all the attributes was sample F (Table 4). The results indicated that jackfruit, rice, pigeon pea flour in the ratios of 5: 47.5: 47.5 respectively, could be used to prepare high-quality extrudates based on sensory attributes.

Scanning electron microscopy

The microscopic structures of extrudates are presented in Figures 1(a-g). Extruded samples had open-celled and porous structures. Microstructure analysis indicated heterogeneous, network-like matrix with voids at different surfaces. Control indicated the better symmetrical arrangement of carbohydrate and protein network. Sample F had an immense number of trampled and sheared granules. Some disrupted non-symmetrical structure and shear were observed in sample E. Sample F showed maximum shear i.e. damage and smashing in a continuous uniform structure, in which starch granules were melted. Samples C and D did not reveal any significant difference in the structure as compared to control. The absence of a uniform structure of starch granules in all the extrudates revealed gelatinisation of starch granules during extrusion. With the increase in jackfruit flesh flour concentrations, lesser expansion of extrudates was observed as well as thicker walls.

Conclusions

The present work demonstrated the effects of extrusion on the characteristics of jackfruit flesh flour, rice flour, and pigeon pea flour based extrudates. It was observed that the extrudate properties were affected by the supplementation of different proportions of jackfruit flesh flour. The extrudates obtained were characterised by high bulk density and relatively low expansion ratio. Temperature affected the water solubility index, colour parameters (L^* and b^*), WAC and OAC. Extruded snacks require high L^*, low WSI and low hardness and less disruption of starch granules, which was observed in sample C. The colour of the extrudates turned slightly lighter when the jackfruit flesh flour percentage increased in the extrudates. Structural studies revealed the absence of a uniform structure of starch granules in all the extrudates which indicated gelatinisation of starch granules during extrusion. The increased percentage of jackfruit flesh flour in the extrudates contributed to decreasing the L^*, extrudate diameter, expansion ratio, and radical scavenging activity, and increased the bulk density, true density, hardness and water activity. Sensory evaluation results revealed that sample C had the highest scores in all the attributes. It can be concluded from the results that varying levels of jackfruit flesh flour could be used for the development of an extruded product depending on the desired properties of the final product. A mixture of 5% jackfruit flesh flour and remaining equal proportions of rice flour and pigeon pea flour extruded at 130°C and 270 rpm and moisture input of 18% had higher desirability for the parameters of L^*, WAI, and WSI. This thus reveals the high potentiality of generating a new appealing product of jackfruit flesh flour based extrudates in combination with rice flour and pigeon pea flour.

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