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Effect of seven non-conventional starch rich sources on physico-chemical and sensory characteristics of extruded snacks

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PAPER

Abstract

Starch-rich foods, such as cereal sources (rice, maize, and barley), are commonly used raw materials for extrusion cooking due to their excellent expansion characteristics. Other nonconventional starch sources like green banana, water chestnut, and potato can also be employed for extrusion cooking. The main aim of the study was to evaluate the extrusion behavior and sensory acceptability of nonconventional starch-rich food sources like rice, maize, barley, wheat, water chestnut, potato, and green banana. Maize, rice, wheat, potato, water chestnuts, barley, and green banana flour samples were evaluated for various physicochemical, pasting, and morphological properties, and were subjected to extrusion cooking at the moisture content of 15%, screw speed of 300 rpm, and barrel temperature of 125°C. The developed extruded snacks from selected crops were also evaluated for various physicochemical, pasting, and morphological properties. Potato flour and green banana flour recorded the highest starch content of 78.27 and 76.61%, respectively. The highest peak viscosity (6025 cp), trough viscosity (2968 cp), breakdown viscosity (3057 cp), pasting temperature (92°C), and minimum peak time (4.67 min) were recorded in the case of green banana flour. The structural assessment of all the flour samples was done through scanning electron microscopy. The highest expansion ratio (5.06), as well as overall acceptability (4.28), was recorded in the case of corn-based snacks. The highest bulk density and hardness were recorded in the case of barley-based snacks. The highest values of water absorption index and water solubility index were recorded in the case of green banana flour–based snacks.

Keywords: starch rich, green banana, potato, extrusion cooking, scanning electron microscopy, pasting properties, sensory evaluation

Introduction

Snacks, being an indispensable part of the modern diet, are an effective carrier to improve the nutrition-based needs of the population. With the growing knowledge about a healthy diet, snacks can readily be consumed to improve overall nutrition. Snacks are primarily made from starch-rich materials due to their good puffing and expansion characteristics. Extrusion is the most commonly employed multidimensional processing technique for developing snacks (Liu and Hsieh, 2008). It changes the molecular conformation of starch, which then interacts with other macromolecules by simultaneous application of high temperature and pressure.

Although starch-based materials like corn, rice, wheat, potato, barley, and water chestnut have been explored for the development of snacks through extrusion either solely or in combination with other food materials (Hernandez-Díaz *et al.*, 2007; Kaur *et al.*, 2015); Reddy *et al.*, 2014) the comparative evaluation of these starch-based food materials for the development of snacks has

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not been studied so far. In addition to this, green banana offers a significant potential to be used as a base material for the development of snacks due to its high starch content and excellent nutritional profile (Kaur *et al.*, 2015). India is the second largest producer of bananas (FAO STAT, 2017) and very limited research is documented on the processing and utilization of green bananas. Moreover, the ripening of green banana is a very tedious practice and an appreciable quantity of bananas is wasted during post-harvest handling. Thus, there exists a possibility of exploring green banana as a base material for the development of processed products like snacks. Therefore, the present study was envisaged to evaluate and compare different starch-based materials for the development of snacks with a broader aim to explore a nonconventional source of starch like green banana for extrusion processing.

Material and Methods

Raw materials

Maize (var. C-7), rice (var. Jhelum), and wheat (var. Shalimar wheat 2) were procured from Mountain Research Center for Field Crops, Khudwani, Sher-e-Kashmir University of Agricultural Science and Technology of Kashmir (SKUAST-K), India; potato (var. Shalimar potato-1) from the Department of Vegetable Sciences, SKUAST-K; water chestnuts were harvested from Wular lake of Kashmir, India, which is Asia's largest lake. Barley (a land race of Kargil, namely, "Naas") was procured from Mountain Agriculture Research and Extension Station, Kargil, SKUAST-K and green banana (var *Grand Naine*) from the Department of Fruit Science, Sher-e-Kashmir University of Agricultural Science and Technology of Jammu, India.

Flour preparation

Maize, rice, wheat, and barley were ground in a laboratory mill (3303, Perten, Hagersten, Sweden). Potatoes were washed, peeled, sliced, and dried in a tray drier (NSW-154, S-Narang, Scientific works New Delhi) at 40 ± 5°C. Before flour preparation, the usual practice is to dry the whole water chestnuts over traditional chullas (made of mud) for about 10–12 days after which the flour is made from kernels extracted from these water chestnuts. Green banana (var Grand Naine) was peeled and sliced to 0.5 to 1 cm thickness. The slices were dried in a tray drier at 40 ± 5°C. Dried potato slices and green banana slices were ground to flour in a lab mill (3303, Perten, Hagersten, Sweden). All the seven flour samples were kept in separate polybags and stored at room temperature for further analysis.

Physicochemical analysis of flour samples

Moisture content

Moisture content was determined by the AOAC method 930.04 (AOAC, 2005). Five grams of the sample was weighed and dried at 60–70°C for 6–8 h, to constant weight. The loss in weight was determined to calculate the percent moisture content.

Crude protein

Crude nitrogen was determined by Kjeldahl method (AOAC, 1995). Half a gram of the sample in powdered form was placed in Kjeldahl tubes and 5 g of digestion mixture (potassium sulfate + ferrous sulfate + copper sulfate in the ratio of 5:0.5:0.25) was added. After adding 10 mL of concentrated H_2SO_4, the mixture was heated till the color changed to green. Then, tubes were cooled and 10 mL of distilled water was added to each sample. Then 40–50 mL of NaOH (40.00%) was added to it till the color changed to brown. Tubes were fitted in assembly, subjected to steam distillation, and ammonia released from the tubes was collected in the flask fitted in assembly containing 25 mL boric acid (4%) and 5 mL red indicator. Flask containing boric acid and indicator results in the formation of ammonium borate, which was titrated with 0.1 N HCl till color changed to brown. The resulting nitrogen content was multiplied by a factor of 5.95 to get crude protein content.

$$\text{Nitrogen (\%)} = \frac{\text{Titere value} \times \text{Normality of HCl} \times 14}{\text{Weight of sample (g)}} \times 100 \quad (1)$$

$$\text{Crude protein} = \text{Crude nitrogen} \times 5.95 \quad (2)$$

Crude fiber

Crude fiber was determined by following a gravimetric procedure of AOAC (1995). One gram of sample was subjected to acid hydrolysis with 2.5 N HCL followed by alkali digestion with 0.1 N NaOH. The residue obtained was then washed with double distilled water and ignited in a muffle furnace at 600°C for 6 h. At high temperature, the organic matter in the residue got oxidized and inorganic residue was left behind. The difference in the weight before and after was determined to calculate the percentage crude fiber as:

$$\text{Crude fiber (\%)} = \frac{W_1 - W_2}{W} \times 100 \quad (3)$$

Where
W_1: weight of crucible with dry residue (g)
W_2: weight of crucible with ash (g)
W: weight of sample (g)

Crude fat

Crude fat analysis was done using Soxtec 2045 (Pelican India) (AACC, 2000). Sample for oil extraction was taken in thimble and put inside an extraction cup. The extraction cups were initially dried in oven at 130°C for 15 min and the weight of empty cups was noted. After cooling, the cups were filled with 70 mL of petroleum ether, which acted as solvent for fat extraction and the thimble containing the sample was placed inside the cup. The extraction cups were then mounted on the heating plate of the instrument and the temperature raised. After attaining the required temperature, the petroleum ether was allowed to boil for 30 min till the fat was dissolved in the petroleum ether. The solvent was then recovered for 20 min. The recovered ether was collected and the fat contained in extraction cups was estimated using the following formula:

$$\text{Fat (\%)} = \frac{\text{Weight of fat (g)}}{\text{Weight of sample (g)}} \times 100 \quad (4)$$

Ash content

Standard AACC procedure (AACC, 2000) was followed. Five grams of the sample was put in a pre-weighed silica dish, charred on the hot plate, and incinerated in a muffle furnace at a temperature of 550 ± 10°C for about 3 h. The dish was cooled, weighed, and ash content was expressed as percent ash as given below:

$$\text{Ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample (g)}} \times 100 \quad (5)$$

Carbohydrate content

Carbohydrate content was estimated by the difference method using the below given equation (AOAC, 1995).

$$\left.\begin{matrix}\text{Total}\\ \text{Carbohydrate}\\ \text{content (\%)}\end{matrix}\right\} = \left\{\begin{matrix}[100 - \%(\text{protein content}\\ +\text{fat content} + \text{moisture}\\ +\text{ash} + \text{crude fiber})]\end{matrix}\right. \quad (6)$$

Extrusion processing

Extrusion cooking was carried out in a twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India) with a 2.5 mm barrel diameter and 8:1 length to diameter ratio. The extruder was fitted with a die nozzle of 0.42 mm diameter. The preliminary trials were conducted to determine the best extrusion conditions (i.e., barrel temperature and screw speed) and moisture content of the feed material for the development of ready-to-eat snacks. The temperature at the feed zone, compression zone, and die zone were maintained at 60°C, 80°C, and 125°C, respectively, throughout the experiment and the screw speed was kept constant at 300 rpm. Earlier, the moisture content of the flour samples was adjusted to 15% through pre-conditioning. The extruder was equipped with a torque indicator, which showed the percent of torque in proportion to the current drawn by the drive motor. The extruded samples were collected in trays, cooled, and packed in high density polyethylene (HDPE) pouches for further analysis.

Determination of product responses for developed snacks

Extruded snacks developed from maize, rice, wheat, potato, water chestnuts, barley, and green banana flour were evaluated for below mentioned parameters.

System parameter

Specific mechanical energy (SME) is the ratio of net mechanical energy input (after no load correction) to mass flow rate and was calculated as per the following equation (Pansawat *et al.*, 2008):

$$\text{SME(kWh/Kg)} = \frac{\text{Actual screwspeed (rpm)}}{\text{Rated screwspeed (rpm)}} \times \% \frac{\text{torque}}{100} \times \% \frac{\text{motor power rating (kWh)}}{\text{mass flowrate (Kg/h)}} \times 1000 \quad (7)$$

Product characteristics

Bulk density

Bulk density (BD) was measured using the volumetric displacement method as described by Singh *et al.* (2016). A known weight of the sample (extrudates) was taken into a pre-weighed (W_1) measuring cylinder and the weight of the filled cylinder (W_2) as well as the volume of the sample (V_1) was noted. The BD was expressed using the following equation:

$$\text{BD } (\rho_b) = W_2 - W_1 \div V_1 \quad (8)$$

Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were determined as per standard procedure given by Singh *et al.* (2016). One gram of the sample (W_1) was mixed with 10 mL distilled water and kept at ambient temperature for 30 min and centrifuged for 10 min at 2000 rpm. Then final weight was taken (W_2), Water absorption capacity was expressed as percent water bound per gram of the sample.

$$\text{WAC (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (9)$$

WSI was determined from the amount of dried solids received by evaporating the supernatant from the water absorption index test described above. WSI was expressed as follows:

$$\text{WSI (\%)} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100 \quad (10)$$

Expansion ratio

The expansion ratio (ER) was calculated as the ratio of extrudate thickness and the die diameter by using a digital Vernier caliper of 0.001 mm accuracy (Jyothi *et al.*, 2009).

Hardness

Hardness was determined using TA-XT2i Texture Analyzer by applying a compression force (CF) using a P50 compression probe (50 mm. dia. cylinder aluminum) (Singh *et al.*, 2016).

Sensory evaluation

Sensory evaluation of the samples was done by semi-trained panelists. A panel of 30 semi-trained judges selected from the scientific staff of Division of Food Science and Technology, SKUAST-K, Shalimar, carried out the sensory evaluation in the laboratory of Food Science and Technology. Noise-free and well illuminated sensory space was used for the test. Judges were also acquainted with rating method, specific terminology used, and different sensory characteristics. Coded samples were presented to the panelists in plastic cups covered with lids. Each coded sample was evaluated thrice by judges in a randomized manner. The panelists were provided with a glass of water to rinse their mouths and were given a 10 min break post each assessment. Sensory evaluation was done on a 5-point scale (1-extremely dislike and 5-extremely like) for various attributes (i.e., appearance, color, texture, flavor, and mouthfeel). The overall acceptability of each sample was calculated as the average of scores obtained for selected sensory attributes (Naseer *et al.*, 2021).

Pasting properties

Pasting properties were determined with a Rapid Visco analyzer (RVA Starch TM, New Port, Scientific Warrie Wood, Australia) in accordance with the methods described by Kaur *et al.* (2015). The different recorded parameters were pasting temperature (PT), peak time, peak viscosity, hold/trough viscosity (TV) (minimum viscosity at 95°C), final viscosity (FV) (viscosity at 50°C), breakdown viscosity (peak viscosity – hold viscosity), and set back viscosity (—FVhold viscosity)

Scanning electron microscopy

Scanning electron microscopy (SEM) was used to study the morphology of the flour samples. The samples were glued onto a sample holder using double-sided cellophane tape and then coated with gold. The coated samples were photographed using a scanning electron microscope (Hitachi S-300H-Tokyo, Japan), at an accelerator potential of 5 kV to visualize the microstructure.

Statistical analysis

Statistical analysis of data was conducted using SPSS software (version 21). All the experiments were carried out in triplicate and data were analyzed using design factorial in completely randomized design (CRD). The significance of microwave heating was assessed by one factorial CRD at 5% level of significance. A p-value of less than 0.05 was used to designate the statistical significance in all the tested parameters.

Results and Discussion

Physicochemical analysis of different flour samples

Table 1 illustrates the proximate composition including the starch content of flour different samples. The moisture content of flour different samples was in the range of 7.56% (for potato flour) to 12.20% (for rice flour). The highest percentage of crude fiber (5.54%) was recorded in barley flour followed by wheat flour (4.51%), whereas the least crude fiber content recorded in corn flour (0.42%) was statistically at par with that of rice flour (0.62%). The highest protein content recorded in the case of barley flour (11.83%) was found to be statistically at par with that of wheat flour (11.79%), whereas the least protein content was recorded in water chestnut flour (2.82%). The highest carbohydrate content (82.04%) recorded in the case of potato flour was found statistically at par with that of green banana flour (81.74%) and water chestnut flour (81.50%). At the same time, the highest starch content (78.27%) recorded in potato flour was statistically at par with that of green banana flour (76.61%); however, the least carbohydrate content (67.39%) and starch content (62.40%) were recorded in the case of barley flour. The highest fat content (3.10%) was recorded in corn flour followed by barley flour (2.05%), whereas the least fat content recorded in rice flour (0.23%) was statistically at par with that of water chestnut flour (0.28%), which was further at par with that of potato flour (0.35%) (Table 1).

Table 1. Physicochemical analysis of different flour samples.

Parameters / Flour samples	Moisture (%)	Fat (%)	Ash (%)	Crude fiber (%)	Protein (%)	Starch (%)	Carbohydrate (%)
Rice	12.20^{a} ± 1.16	0.23^{a} ± 0.11	0.47^{a} ± 0.02	0.62^{a} ± 0.08	8.03^{a} ± 0.91	73.03^{a} ± 7.21	78.45^{a} ± 4.25
Wheat	12.15^{ba} ± 1.15	1.70^{b} ± 0.24	0.53^{ba} ± 0.02	4.51^{b} ± 0.04	11.79^{b} ± 1.35	65.18^{b} ± 4.25	69.32^{b} ± 6.33
Corn	10.72^{c} ± 1.08	3.10^{c} ± 0.51	1.69^{c} ± 0.24	0.42^{ca} ± 0.03	8.23^{c} ± 1.02	72.82^{ca} ± 5.12	75.84^{c} ± 6.42
Barley	11.95^{dab} ± 1.38	2.05^{d} ± 0.11	1.24^{d} ± 0.17	5.54^{d} ± 0.18	11.83^{db} ± 1.22	62.40^{d} ± 3.42	67.39^{d} ± 7.86
Potato	7.56^{e} ± 0.76	0.35^{e} ± 0.02	0.43^{eab} ± 0.03	2.33^{e} ± 0.01	7.29^{e} ± 0.56	78.27^{e} ± 4.56	82.04^{e} ± 5.65
Green banana	10.34^{f} ± 1.18	0.62^{f} ± 0.01	2.06^{f} ± 0.20	1.49^{f} ± 0.03	3.75^{f} ± 0.21	76.61^{fe} ± 1.86	81.74^{fe} ± 2.21
Water chestnut	9.68^{g} ± 0.84	0.28^{gae} ± 0.01	2.38^{gf} ± 0.07	3.34^{g} ± 0.00	2.82^{g} ± 0.02	70.50^{gc} ± 6.95	81.50^{gef} ± 4.87

Data are expressed as mean ± SD; values in the same column with different superscripts are statistically different.

Table 2. Pasting properties of different flour samples.

Parameters / Flour samples	Peak viscosity (cp)	Trough viscosity (cp)	Breakdown viscosity (cp)	Final viscosity (cp)	Setback viscosity (cp)	Peak time (min)	Pasting temperature (°C)
Rice	2940^{a} ± 17	1727^{a} ± 12.76	1213a ± 17.69	4343^{a} ± 25.51	2616^{a} ± 12.66	5.13^{a} ± 0.07	80.90^{a} ± 2.57
Wheat	2106^{b} ± 11.15	1292^{b} ± 11.23	814^{b} ± 20.15	3332^{b} ± 11.01	2040^{b} ± 11.67	5.60^{b} ± 0.05	77.45^{b} ± 1.69
Corn	2205^{c} ± 17.15	1329^{c} ± 10.96	876^{c} ± 23.54	3403^{c} ± 16.01	2074^{c} ±17.03	5.64^{cb} ± 0.1	73.28^{c} ± 1.74
Barley	2915^{d} ± 24	925^{d} ± 12.58	1990^{d} ± 6.80	3744^{d} ± 8.73	2819^{d} ± 15.01	5.70^{dbc} ± 0.04	85.07^{d} ± 2.28
Potato	3817^{e} ± 13.65	2490^{e} ± 11.50	1327^{e} ± 9.84	5474^{e} ± 11.53	2984^{e} ± 8.45	6.87^{e} ± 0.05	60.9^{e} ± 2.81
Green banana	6025^{f} ± 22.54	2968^{f} ± 13.15	3057^{f} ± 21.51	3302^{f} ± 12.22	334^{f} ± 5.50	4.67^{f} ± 0.03	92.00^{f} ± 2.79
Water chestnut	362^{g} ± 9.01	325^{g} ± 15.27	37^{g} ± 3.05	452^{g} ± 7.63	127^{g} ± 9.01	4.90^{g} ± 0.1	71.65^{g} ± 1.28

Data are expressed as mean ± SD; values in the same column with different superscripts are statistically different; cp: centipoise.

The highest ash content was recorded in the case of water chestnut flour (2.38%), which was statistically at par with that of banana flour (2.06%), whereas the least ash content recorded in the case of potato flour (0.43%) was statistically at par with that of rice flour (0.47%) and wheat flour (0.53%). These results are in accordance with the results reported by Qamar *et al.* (2017) for protein, ash, and carbohydrate contents of corn flour; by Onwuka *et al*. (2015) for fat, moisture, and ash contents of banana flour; by Hussain *et al.* (2019) for protein, fat, and crude fiber contents of barley and water chestnut flour.

Pasting characteristics of different flour samples

Pasting profile depicted in Table 2 demonstrates the wide range of viscosity parameters for different flour samples. PT), which indicates the onset of rise in viscosity, was found in the range of 60.9–92°C for different flour samples. The lowest PT of 60.9°C was recorded for potato flour and the highest (92°C) for green banana flour (Table 2). Lower PT of potato flour can be attributed to the tendency of large swollen starch granules to gelatinize, which was evident in the SEM micrograph (Figure 1A) as well. Danbaba *et al.* (2014) reported that tuber flour gelatinizes at relatively low temperature, with rapid and uniform swelling of granules. Higher PT of green banana flour may be attributed to its strong intermolecular forces within the flour matrix due to the closely packed smaller starch granular arrangement (Figure 1F). Peak viscosity (PV) of flour samples ranged from 362 to 6025 cp (Table 2). The lowest PV was recorded for water chestnut flour (362 cp) and the highest for green banana flour (6025 cp), which suggests the possible use of banana flour as a thickener in food application. PV indicates the water holding capacity of flour suspension and is attained before the structural breakdown of swollen starch granules takes place (Hussain *et al.*, 2014). Disintegrated starch structure in water chestnut flour (as was evident in Figure 1G) restricts swelling of starch granules, which leads to lower PV. As far as product quality is concerned, high PV is always desirable (Bhattacharya and Corke, 1996). Higher starch content (76.61%) of green banana flour together with its higher PT (92°C) may be the possible reason for its high PV. TV of flour samples ranged from 325 to 2968 cp (Table 2). The lowest TV was recorded for water chestnut flour (325 cp), whereas the highest was recorded for green banana flour (2968 cp). The high TV of green banana flour suggests its high holding strength during cooling. Interaction of starch with

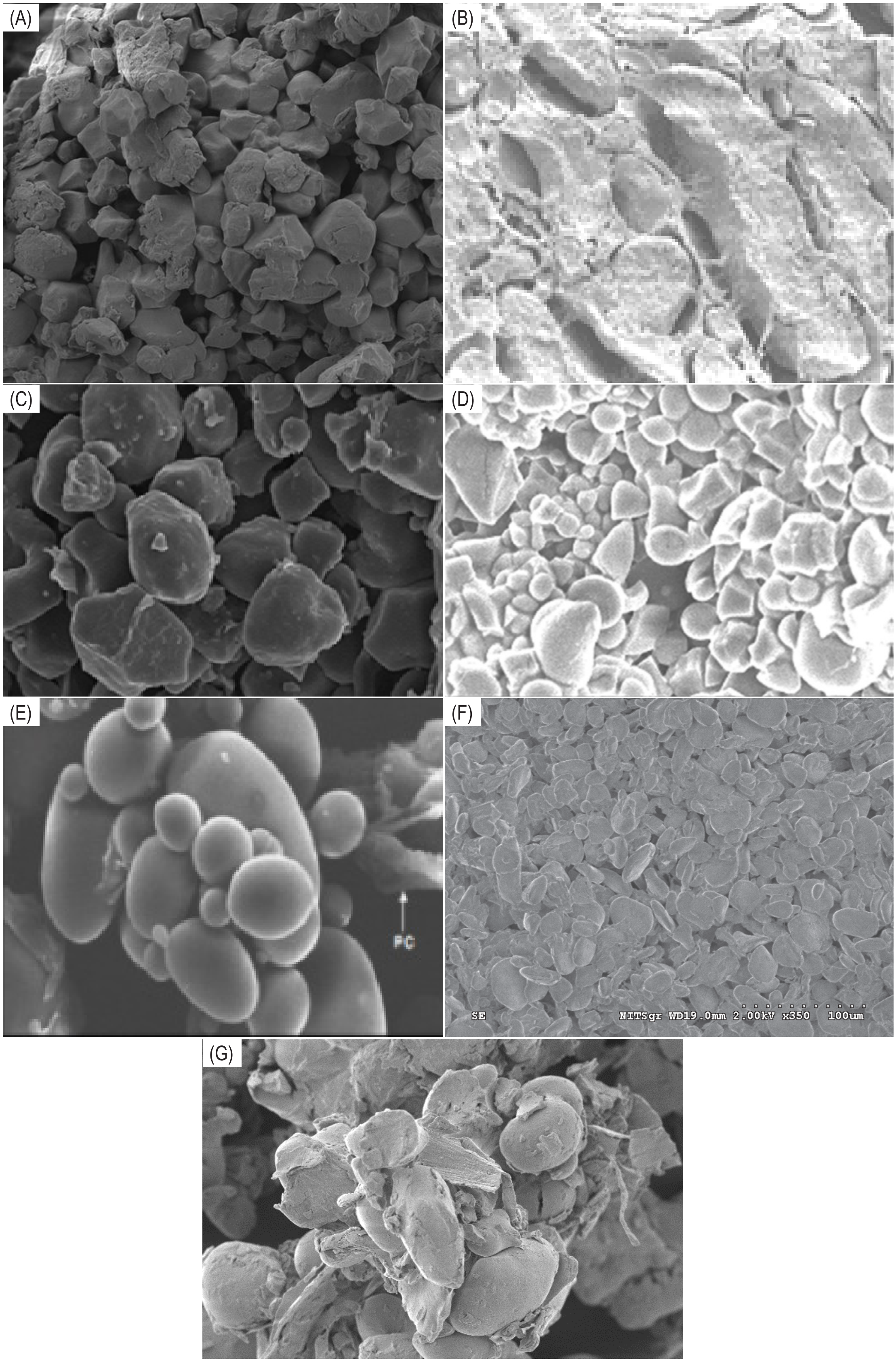

Figure 1. SEM micrographs of (A) rice flour, (B) wheat flour, (C) corn flour, (D) barley flour, (E) potato flour, (F) green banana flour, and (G) water chestnut flour.

soluble fibers in unripe banana might be responsible for its high TV (Mota *et al.*, 2000). Breakdown viscosity (BDV) of flour samples was found in the range of 37 to 3057 cp (Table 2). BDV depicts the potential of flour suspension to withstand high temperature under continuous shear conditions (Hussain *et al*., 2014). High BDV is desirable for the production of snacks (Bhattacharya and Corke, 1996). Water chestnut flour had the lowest breakdown viscosity (37 cp), which can be attributed to its lowest peak viscosity. The highest BDV (3057 cp) recorded for green banana flour indicates its high susceptibility to shear-induced degradation. FV indicates the ability of the flour to form a viscous paste after cooking and cooling and was found in the range of 452–5474 cp. The lowest FV was recorded in the case of water chestnut flour (452 cp) possibly because of its high damaged starch content (Figure 1G) which has a low tendency to develop viscous pastes. At the same time, highest FV of potato flour (5474 cp) can be attributed to its highest starch content (78.27%) (Table 1) and large-sized starch granules (Figure 1E). Setback viscosity (SBV), which denotes the tendency of cooked starchy material to re-associate and retrograde upon cooling (Hussain *et al*., 2014), ranged from 127 to 2984 cp (Table 2) for different flour samples. Lower SBV (127 cp) recorded for water chestnut flour demonstrates lower syneresis of cooked starch pastes during storage. However, the higher SBV of potato flour (2984 cp) indicates its high retrogradation tendency and ability to form a cohesive gel upon cooling. The peak time of flour samples indicates the time required to reach the peak in viscosity and ease of cooking a particular sample. The peak time of flour samples ranged from 4.67 to 6.87 min (Table 2). The minimum peak time of 4.67 min was recorded for green banana flour and the highest (6.87 min) for potato flour. The minimum peak time of banana flour demonstrates its easy cooking ability and can be attributed to its soft and smaller starch granular structure (Figure 1F). At the same time, the high peak time of potato flour can be attributed to the high swelling degree of its starch granules due to their large granular structures (Figure 1E). The peak time of wheat flour (5.60 min), corn flour (5.64 min), and barley flour (5.70 min) were found to be statistically at par with each other.

Scanning electron microscopy of different flour samples

The microstructure analysis of different flour samples showed a disparity in the starch granular arrangement within the flour matrix, which can be attributed to variation in genotype, climatic conditions as well as processing variability. SEM micrograph depicted in Figure 1A shows closely packed starch granules of distinct shapes with fused smaller and larger starch granules in rice flour. Intact starch granules with some rough surfaces were evident in the SEM micrograph of rice flour. These intact starch granules reflect the crystalline and ordered molecular arrangement of rice flour. Reddy and Bhotmange (2013) also reported the presence of intact crystalline starch granules in basmati rice flour. The microstructure of wheat flour shown in Figure 1B depicts a compact structure of irregularly shaped particles of different sizes. Massive starch arrangement embedded within the gluten matrix was evident in Figure 1B, wherein gluten possibly acted as a cementing material in forming a compact and dense structure. Sakhare *et al.* (2014) also reported the highly compact packed structure of wheat kernels. The micrograph shown in Figure 1C indicates that somewhat spherical shaped large and small starch granules are present in corn flour. Loosely packed starch arrangement within protein and lipid matrix was also observed in Figure 1C. A large part of the shapeless cracked surface observed in corn flour can be attributed to the presence of soluble starch remnants (Haros *et al.*, 2006). Some crater-like depressions and eroded starch surfaces were seen in Figure 1C, which indicates kernel breakage due to milling. Hall and Sayre (1970) also reported the presence of crater-like small indentations on polygonal starch structures in pearl corn. The scanning electron micrograph depicted in Figure 1D demonstrates that barley flour consists of numerous round and polygonal shaped edged starch granules. The small and large starch granules with smooth surfaces in Figure 1D confirm the presence of both A- and B-type starch granules in barley flour. Densely packed clusters of starch embedded in flour matrix and a small amount of protein adhered to densely packed starch granules were also observed in Figure 1D. Nair *et al.* (2011) also reported the presence of large (A-type) and small (B-type) starch granules surrounded by the protein matrix in barley flour. Sullivan *et al.* (2010) also reported bimodal distribution of starch granules in barley flour. The SEM micrograph depicted in Figure 1E indicated the presence of oval and polygonal starch granules in potato flour. The small and immature starch granules were seen adhered to the large starch granules (Figure 1E). Similar observations were reported by Horovitz *et al.* (2011) for potato starch granules. The SEM micrograph depicted in Figure 1F indicates that green banana flour consists of elongated, round, and oval-shaped starch granules. A large number of smooth, small, and intact starch granules without any rupture were evident in Figure 1F. Babu *et al.* (2014) also reported the presence of oval and elongated smooth starch structures in green banana flour. The micrograph depicted in Figure 1G demonstrates that in water chestnut flour starch granules are somewhat irregular and asymmetric in shape with a rough surface. Rough granular structures indicated that starch was highly damaged, which can be attributed mainly to hydrothermal pre-conditioning of water chestnuts before flour preparation. The fissures seen on the surface of granules were probably due to the drying of water chestnut kernels before milling (Figure 1G).

Effect of different raw materials on system parameter of extruded snacks

Specific mechanical energy

SME, the mechanical energy delivered to the unit mass of the material by motor drive in the extruder, measures the work done by the motor per unit mass in the extrusion system (Prabhakar *et al.*, 2017). The mechanical energy facilitates the starch conversion and correlates well with the physical attributes of extrudates such as expansion, density, and texture characteristics (Altan *et al.*, 2008). Thus, the higher is the SME, the higher is the degree of starch gelatinization and thus the extrudate expansion (Hussain *et al.*, 2017). Table 3 depicts that SME values of extrudates developed from different samples were found in the range of 50.86–85.46 Wh/kg (Table 3). The highest SME (85.46Wh/kg) recorded for potato-flour-based extrudates was statistically at par with that of corn flour–based extrudates (83 Wh/kg), and green banana flour–based extrudates (82.39 Wh/kg) while the lowest SME (50.86 Wh/kg) was recorded for wheat-based extrudates, which were statistically at par with that of barley-based extrudates (52.16 Wh/kg). Meuser *et al.* (1990) reported that SME increases with the increase in starch content of the feeding material. Thus, the higher starch content (78.20%) of potato flour was the possible reason for its higher SME. Gropper *et al.* (2002) reported that protein and fat content affect the SME inversely by forming thermoplastic complexes with water, which restricts the fragmentation of starch granules. However, the nonsignificant difference in SME of wheat-based and barley-based snacks viz-a-viz that of potato-, corn-, and green-banana-based snacks demonstrate the nonsignificant effect of protein and fat content on SME in the present study. An almost similar range of SME has also been reported by Singh *et al.* (2019) for corn-based snacks, and by Pansawat *et al.* (2008) for rice-based extrudates.

Effect of different raw material on product characteristics of developed extrudates

Bulk density and hardness

BD is a measure of the degree of expansion undergone by the melt as it exits the extruder (Meng *et al.*, 2010). BD and ER are important parameters of extruded snacks as far as consumer acceptability is concerned. Lightweight and puffed snacks are preferred by the consumers. Table 3 shows that the BD of different extrudates ranged from 51.79 to 79.68 kg/m^3. The highest BD was recorded in barley-based snacks (79.68kg/m^3), while the lowest BD (51.79 kg/m^3) was recorded in the case of corn-based snacks followed by rice-based snacks (55.11 kg/m^3) (Table 3). These findings demonstrate that out of all types of snacks, barley-based snacks were the most dense, whereas corn-based snacks were lighter followed by rice-based snacks. The higher fiber content of barley flour (5.54%) (Table 1) could be the possible reason behind the higher BD of barley-based extrudates and lower BD of corn- and rice-based extrudates. Similar results have been reported by Kirjoranta *et al.* (2015) for barley-based extrudates and Reddy *et al.* (2014) for corn-based extrudates.

Hardness is associated with the expansion and cell structure of the extrudates. The more is the force needed by the probe to penetrate into the extrudate, the higher is the hardness of extrudates (Meng *et al.*, 2010). Hardness values of different extrudates were significantly ($P < 0.05$) different and were found in the range of 17.05–51.55 N (Table 3). Among all types of snacks, the highest hardness value (51.55 N) was recorded in the case of barley-based snacks followed by wheat-based snacks (43.24 N), whereas the least hardness value (17.05N) was recorded for corn-based snacks. Several studies reported a highly positive correlation between BD and hardness (Altan *et al.*, 2008; Bhattacharya, 1997; Hussain *et al.*, 2017);

Table 3. System and product responses of extrudates prepared from different flour samples.

Flour samples \ Parameters	SME (Wh/kg)	Bulk Density (kg/m^3)	Expansion ratio	Hardness (N)	WAI (g/g)	WSI (%)
Rice-based snacks	80.45^{a} ± 0.12	55.11^{a} ± 0.11	4.82^{a} ± 0.02	21.72^{a} ± 0.21	4.24^{a} ± 0.09	29.84^{a} ± 0.05
Wheat-based snacks	50.86^{b} ± 0.12	73.20^{b} ± 0.10	2.84^{b} ± 0.05	43.24^{b} ± 0.36	3.47^{b} ± 0.07	21.70^{b} ± 0.08
Corn-based snacks	83.00^{ca} ± 0.32	51.79^{ca} ± 0.09	5.06^{c} ± 0.06	17.05^{c} ± 0.11	5.35^{c} ± 0.05	32.68^{c} ± 0.06
Barley-based snacks	52.16^{db} ± 0.07	79.68^{d} ± 0.07	1.96^{d} ± 0.03	51.55^{d} ± 0.16	3.07^{d} ± 0.11	19.03^{d} ± 0.06
Potato-based snacks	85.46^{ec} ± 0.05	62.51^{e} ± 0.07	3.97^{e} ± 0.01	33.24^{e} ± 0.1	3.73^{e} ± 0.08	27.56^{e} ± 0.08
Green-Banana-based snacks	82.39^{face} ± 0.08	59.29^{f} ± 0.08	4.11^{fe} ± 0.03	27.84^{f} ± 0.24	5.50^{f} ± 0.15	35.07^{f} ± 0.09
Water-chestnut-based snacks	73.25^{g} ± 0.11	68.58^{g} ± 0.08	3.05^{g} ± 0.04	37.61^{g} ± 2.23	3.85^{g} ± 0.05	23.21^{g} ± 0.05

Data are expressed as mean ± SD; values in the same column with different superscripts are statistically different; SME: specific mechanical energy; WAI: water absorption index; WSI: water solubility index.

Meng *et al.*, 2010), thus, low-density products naturally offer low hardness. These results are in agreement with the findings of hardness reported by Kirjoranta *et al.* (2015) for barley-based extrudates; by Singh *et al.* (2016) for corn-based extrudates; and by Ding *et al.* (2006) for wheat-based extrudates.

Expansion ratio

During extrusion cooking, the sudden drop of pressure at the exit die causes a flash off of material moisture (Arhaliass *et al.*, 2009) because of which air pockets are formed within the sample, which leads to the formation of porous and puffed snacks (Yanniotis *et al.*, 2007). As far as consumer acceptability is concerned, high ER is desirable (Hussain *et al.*, 2017). ER of snacks developed from different flour samples ranged from 1.96 to 5.06 (Table 3). Highest ER (5.06) was recorded in the case of corn-based snacks followed by rice-based snacks (4.82) and green-banana-based snacks, whereas the lowest ER was recorded in the case of barley-based snacks (1.96) (Table 3). However, ER of green-banana-based snacks (4.11) was statistically at par with that of potato-based snacks (3.97) (Table 3). Since ER and BD are inversely related (Meng *et al.*, 2010), higher fiber content of barley could be the possible reason behind lower ER of barley-based snacks viz-a-viz lower fiber content of corn, rice, and green banana flour justifies the higher ER of extrudates developed from them. These results were found in accordance with the results of ER reported by Reddy *et al.* (2014) for corn-based snacks; Ding *et al.* (2005) for rice-based snacks; Hernandez-Díaz *et al.* (2007) for wheat-based extrudates; and Gamalth (2008) for banana-based extrudates.

WAI and WSI

WAI is a measure of the water holding capacity of starch and gives the weight and volume occupied by starch gel formed upon interaction with water (Kaur *et al.*, 2015) while WSI indicates the extent of polysaccharides leached from starch granules in the presence of excess water and measures the amount of soluble solids present in the extrudates as a result of starch degradation during extrusion cooking (Ding *et al.*, 2005). Thus, higher WSI and WAI are desirable as far as extrudate quality is concerned (Anderson, 1982). Both WAI and WSI values of different flour-based extrudates were significantly different ($P < 0.05$) and were found in the range of 3.07–5.50 g/g and 19.03–35.07%, respectively. Highest WAI (5.50 g/g) as well as WSI (35.07%) was recorded in the case of green-banana-flour-based extrudates, while least WAI (3.07g/g) and WSI (19.03%) were recorded for barley-based extrudates. Delgado-Nieblas *et al.* (2014) reported that the higher is the starch content of the feed material, the higher will be the WAI of extrudates due to greater exposure of hydrophilic groups of starch to water molecules, thereby allowing better moisture penetration into the porous extrudate structure. At the same time, higher protein and fiber content are known to reduce WAI due to their dilution effect on starch (Singh *et al.*, 2007). Jones *et al.* (2000) reported that fiber, starch, and protein have a conjugation effect on WSI. Lower starch and higher protein and fiber content affect the extent of gelatinization and dextrinization, which reduces WAI and WSI. The highest starch content recorded in the case of potato flour (78.2%) was found statistically at par with that of green banana flour (76.61%), whereas protein content and crude fiber content of potato flour were significantly ($P < 0.05$) higher than that of green banana flour (Table 1), which justifies the highest WAI and WSI of green-banana-flour-based extrudates compared to potato-flour-based extrudates as well as other extrudates. Likewise, the least WAI and WSI of barley-flour-based extrudates were possibly due to the lowest starch content (62.40%), highest protein content (11.83%), and crude fiber content (5.54%) of barley flour compared to other flour samples. Similar WAI and WSI values were reported by Reddy *et al.* (2014) for corn-based extrudates; Ding *et al.* (2005) for rice-based extrudates; Hernandez-Díaz *et al.* (2007) for wheat-based extrudates; and Gamalth (2008) for banana-based extrudates.

Sensory evaluation of different flour-based extrudates

Sensory characteristics of different flour-based extrudates are presented in Figure 2. Mouthfeel, described as a sensation recognized by the nervous system in the cavity of the mouth (Singh *et al.*, 2019), was found in a range of 3.00–4.35. Green-banana-based snacks recorded the highest mouthfeel score (4.35) followed by corn-based snacks (4.10) while the least mouthfeel scores were recorded for rice- and barley-based extrudates. The highest mouthfeel score of green-banana-based snacks was possibly due to their fruity taste while the presence of an appreciable amount of soluble sugars in corn (Zilic *et al.*, 2011) was the possible reason for the high mouthfeel score of corn-based extrudates. At same the same, the presence of tannic acids in barley (Niffenegger, 1964) possibly had a negative effect on the taste of the snacks developed from it, while the bland taste of rice could be the possible reason for the lower mouthfeel score of rice-based extrudates. Sharma *et al.* (2012) also reported that a bitter taste was noticed in barley-based muffins due to the presence of phenolics.

The highest visual color score was recorded for rice-based extrudates (4.66) followed by corn-based extrudates (4.20), while green-banana-based snacks recorded the

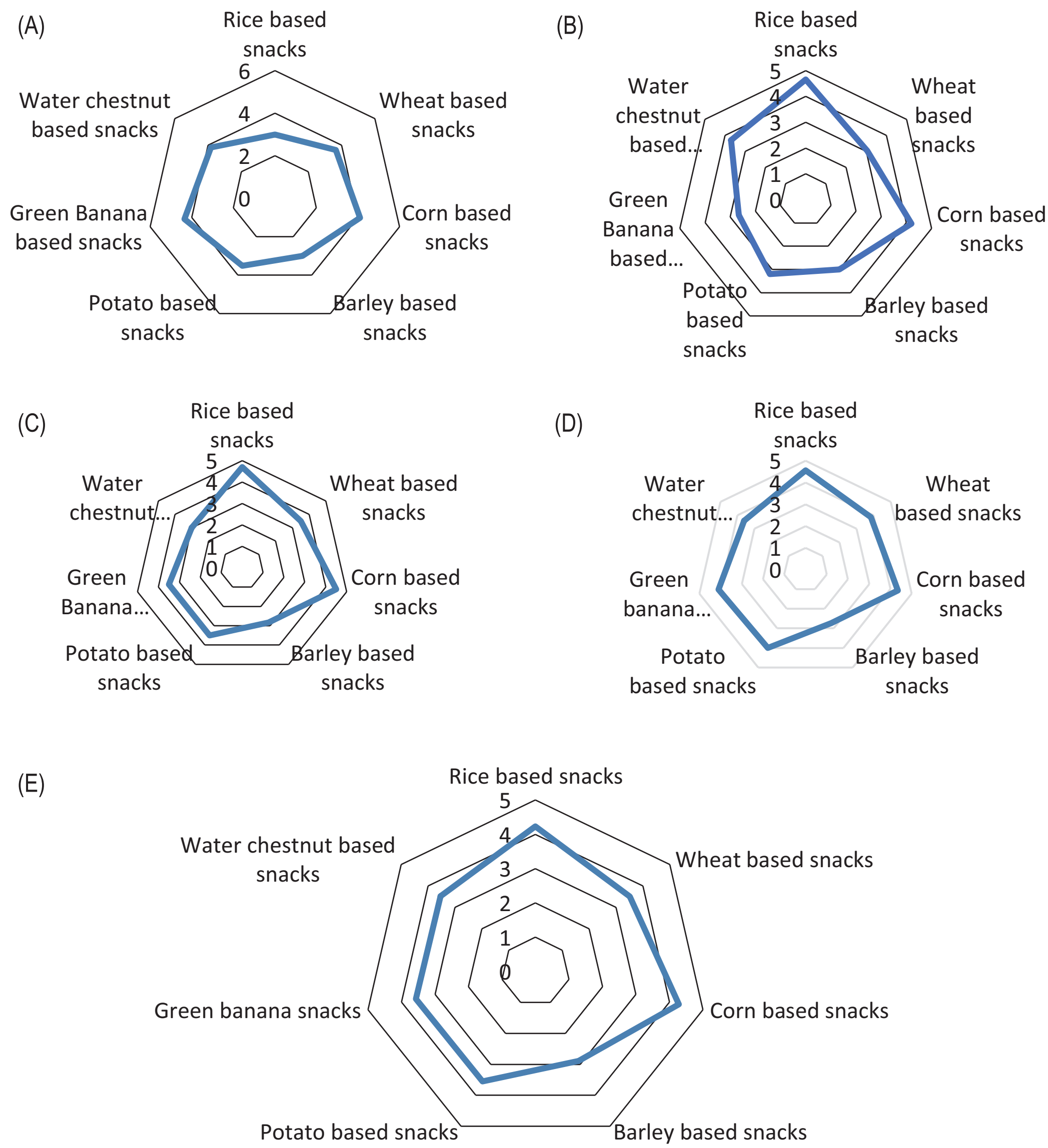

Figure 2. Sensory evaluation of extrudates prepared from different flour samples. (A) Mouthfeel, (B) Color, (C) Appearance, (D) Texture, and (E) Overall acceptability.

lowest color scores (2.66) (Figure 2B). The comparatively bright and white color of rice-based snacks and the desirable yellow color of corn-based extrudates could be the possible reasons for their high visual scores. A low color score of green banana snacks can be ascribed to their inordinate sugar content (Li *et al.*, 2018), which leads to the formation of brown pigments through the caramelization of sugars during extrusion cooking (Adubofuor *et al.*, 2016). Gomes *et al.* (2016) also reported an increase in the darker color of bread when the level of green banana flour in the formulation was increased. The scores for appearance and texture of different extrudates varied from 2.83 to 4.70 and 2.73 to 4.56, respectively. Appearance implies the visual characteristics of the extruded product including its size as well as texture and shape (Singh *et al.*, 2019). The highest score for appearance as well as for texture was recorded by rice-based snacks followed by corn-based extrudates while the least scores were attained by barley-based snacks for both the sensorial parameters. Due to the relatively higher starch content and the lower crude fiber content (Table 1) of rice and corn flour, the expansion (Table 2) was maximum in snacks developed from them compared to other snacks, which could be the reason behind their maximum textural and appearance scores. Likewise, the low starch content and the high percentage of crude fiber in barley flour (Table 1) limited the expansion of the barley-based snacks, which led to harder snacks with undesirable appearance. Overall acceptability of different snacks varied from 2.89 to 4.28 (Figure 2E). Corn-based snacks were found to be highly acceptable with an overall acceptability score of 4.28 followed by rice (4.23) while the least overall acceptability score was recorded for barley-based snacks (2.89). Overall acceptability was determined as the average value of all the sensory characteristics (Singh *et al.*, 2019). Based on the sensory scale used (1-represents poor, 2-fair, 3-good, 4-very good, and 5-excellent), the inference drawn out of sensory evaluation was that corn- and rice-based snacks were rated in the scale of very good to excellent; wheat-, potato-, green-banana-, and water-chestnut-based snacks in the scale of good to very good; and barley-based snacks were rated on the scale of fair to good.

Conclusion

Evaluation of viscous behavior of starch through Rapid Visco Analyzer (RVA) as well as understanding its structure through SEM was deemed essential to predict the extrusion behavior of starch-rich materials. The different starch-rich materials selected in the present study showed diverse pasting profiles, starch structures as well as extrusion behavior. The highest starch content (78.2%), as well as carbohydrate content (82.04%), was recorded in potato flour, which was statistically at par with that of green banana flour. However, the lowest starch content (62.40%) as well as carbohydrate content (67.39%) was recorded in the case of barley flour. The highest peak viscosity (6025 cp), TV (2968 cp), breakdown viscosity (3057 cp), PT (92°C), and minimum peak time (4.67 min) were recorded in the case of banana flour, which was in conformity with its elongated, round, and oval-shaped starch granules revealed through SEM (Figure 1F) as well as higher values of extrusion characteristics such as WAI and WSI. In addition to starch content, it was observed that crude fiber also had a major influence on the physical characteristics of snacks. Despite the lower starch content of corn and rice flour than potato and green banana flour, the highest ERER, overall acceptability, and lower BD and hardness were recorded in the case of corn-based snacks followed by rice-based snacks, which was possibly due to lower crude fiber content of corn and rice flour. The irregularity in the pasting profile of water chestnut flour (Table 2) compared to other flour samples was possibly due to hydrothermal pre-conditioning of water chestnuts before flour preparation, which was well supported by its damaged starch structure observed in its SEM micrograph (Figure 1G). Based on pasting, morphological, physical characteristics (i.e. ER, BD, and hardness), and sensory attributes, it can be concluded that corn flour proved to be the best raw material for the development of extruded snacks, followed by rice flour, green banana flour, potato flour, water chestnut flour, wheat flour, and barley flour. For the development of quality snacks, it is necessary for food designers to relate the viscous behavior of starch and its structure to the mechanism of extrusion involved in the production of snacks. The outcome of the present study will provide a basic guideline for food processors and researchers in the selection of suitable base materials for the development of extruded snacks.

References

AACC (American Association of Cereal Chemists), 2000. International approved methods of analysis. 11th ed. AACC International, St. Paul, MN.

Adubofuor, J., Amoah, I. and Osei-Bonsu, I., 2016. Sensory and physicochemical properties of pasteurized coconut water from two varieties of coconut. Food Science and Quality Management 54: 26–32.

Altan, A., McCarthy, K.L. and Maskan, M., 2008. Extrusion cooking of barley flour and process parameter optimization by using response surface methodology. Journal of Science of Food and Agriculture 88(9): 1648–1659. https://doi.org/10.1002/jsfa.3262

Anderson, R.A. (1982). Water absorption and solubility and amylograph characteristics of roll-cooked small grain products. Cereal Chemistry 59: 265–269.

AOAC, 1995. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA, pp. 114–320.

AOAC, 2005. Official method of analysis of the Association of Official Analytical chemists. 10th ed. Scientific Research Publishing, Washington, DC.

Arhaliass, A., Legrand, J., Vauchel, P., Fodil-Pacha, F., Lamer, T. and Bouvier, J.M., 2009. The effect of wheat and maize flours properties on the expansion mechanism during extrusion cooking. Food Bioprocess Technology 2(2): 186–193. https://doi.org/10.1007/s11947-007-0038-6

Babu, A.S., Mahalakshmi, M. and Parimalavalli, R., 2014. Comparative study on properties of banana flour, starch and autoclaved starch. Trends in Carbohydrate Research 6(1): 38–44.

Bhattacharya, M. and Corke, H., 1996. Selection of desirable starch pasting properties in wheat for use in white salted or yellow alkaline noodles. Cereal Chemistry. 721–728.

Bhattacharya, S., 1997. Twin-screw extrusion of rice-green gram blend: extrusion and extrudate characteristics. Journal of Food Engineering 32: 83–99. https://doi.org/10.1016/S0260-8774(97)00004-6

Danbaba, N., Ukwungwu, M.N., Maji, A.T., Ndindeng, S.A., Jiya, A.G., Danfulani S. and Onyeneke, E.N., 2014. End-use quality of Upland Nerica Rice (*Oryza sativa* L) as affected by the addition of Sweet Cassava (Low cyanide, Manihotesculenta) flour. International Journal of Agriculture Forest 4(3): 237–245.

Delgado-Nieblas, C.I., Zazueta-Morales, J.J., Gallegos-Infante, J.A., Aguilar-Palazuelos, E., Camacho-Hernández, I.L., Ordorica-Falomir, C.A., … and Carrillo-López, A., 2014. Elaboration of functional snack foods using raw materials rich in carotenoids and dietary fiber: effects of extrusion processing. CyTA – Journal of Food 13(1): 69–79. https://doi.org/10.1080/19476337.2014.915892

Ding, Q., Ainsworth, P., Tucker, G. and Marson, H., 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. Journal of Food Engineering 66: 283–289. https://doi.org/10.1016/j.jfoodeng.2004.03.019

Ding, Q.B., Ainsworth, P., Plunkett, A., Tucker, G. and Marson, H., 2006. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. Journal of Food Engineering 73(2): 142–148. https://doi.org/10.1016/j.jfoodeng.2005.01.013

FAO, 2017. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy

Gomes, A.A.B., Ferreira, M.E. and Pimentel, T.C., 2016. Bread with flour obtained from green banana with its peel as partial substitute for wheat flour: physical, chemical and microbiological characteristics and acceptance. International Food Research Journal 23(5): 2214–2222.

Gropper, M., Moraru C.I. and Kokini, J.L., 2002. Effect of specific mechanical energy on properties of extruded protein-starch mixtures. Cereal Chemistry 79(3): 429–433. https://doi.org/10.1094/CCHEM.2002.79.3.429

Hall, D.M. and Sayre, J.G., 1970. A scanning electron-microscope study of starches. Textile Research Journal 40(3): 256–266. https://doi.org/10.1177/004051757004000309

Haros, M., Blaszczak, W., Perez, O.E., Sadowska, J. and Rosell, C.M., 2006. Effect of ground corn steeping on starch properties. European Food Research and Technology 222(1–2): 194–200. https://doi.org/10.1007/s00217-005-0102-2

Hernandez-Díaz, J.R., Quintero-Ramos, A., Barnard, J. and Balandrán-Quintana, P.R., 2007. Functional properties of extrudates prepared with blends of wheat flour/pinto bean meal with added wheat bran. Food Science and Technology International 13(4): 301–308. https://doi.org/10.1177/1082013207082463

Horovitz, O., Cioica, N., Jumate, N., Pojar-FeneŞan, M., Balea, A., Liteanu, V., Mocanu, A. and Tomoaia-CotiŞel, M., 2011. Sem characterization of starch granules. Chemia 211: 200–219.

Hussain, S.Z., Afshana, B. and Amin, T., 2017. Utilization of broken rice and walnut kernels for development of nutritious snacks using extrusion technology. Pharma Innovation Journal 6(10): 91–101.

Hussain, S.Z., Beigh, M.A., Qadri, T., Naseer, B. and Zargar, I., 2019. Development of low glycemic index muffins using water chestnut and barley flour. Journal of Food Processing and Preservation, 1–9. https://doi.org/10.1111/jfpp.14049

Hussain, S.Z., Singh, B. and Naik, H.R., 2014. Viscous and thermal behaviour of vitamin A and iron-fortified reconstituted rice. International Journal of Food Science and Technology 49(5): 1324–1329. https://doi.org/10.1111/ijfs.12430

Jones, D., Chinnaswamy, R., Tan Y. and Hanna, M., 2000. Physicochemical properties of ready-to-eat breakfast cereals. Cereal Foods World 45: 164–168.

Jyothi, A.N., Sheriff, J.T. and Sanjeev, M.S., 2009. Physical and functional properties of arrowroot starch extrudates. Journal of Food Science 74(2): 97–104. https://doi.org/10.1111/j.1750-3841.2008.01038.x

Kaur, A., Kaur, S., Singh, M., Singh, N., Shevkani, K. and Singh, B., 2015. Effect of banana flour, screw speed and temperature on extrusion behavior of corn extrudates. Journal of Food Science and Technology 52: 4276–4285. https://doi.org/10.1007/s13197-014-1524-2

Kirjoranta, S., Tenkanen, M. and Jouppila, K., 2015. Effects of process parameters on the properties of barley containing snacks enriched with brewer's spent grain. Journal of Food Science and Technology 53(1): 775–783. https://doi.org/10.1007/s13197-015-2079-6

Li, Z., Guo, L., Lin, W., He, L., Zhang, L. and Wei, C., 2018. Comparison of physicochemical properties of starches from flesh and peel of green banana fruit. Molecules 23: 2312–2327. https://doi.org/10.3390/molecules23092312

Liu, K.S. and Hsieh, F., 2008. Protein-protein interactions during high-moisture extrusion for fibrous meat analogues and comparison of protein solubility methods using different solvent systems. Journal of Agriculture and Food Chemistry 56(8), 268–287. https://doi.org/10.1021/jf073343q

Meng, X., Threinen, D., Hansen, M. and Driedger, D., 2010. Effect of extrusion conditions on system parameters and physical properties of a chick-pea flour-based snack. Food Research International 43: 650–658. https://doi.org/10.1016/j.foodres.2009.07.016

Meuser, F., Gimmler, N. and Oeding, J., 1990. Starch. International Food Studies 42: 330–336. https://doi.org/10.1002/star.19900420903

Mota, R.V., Lajolo, F.M., Cordenunsi, B.R. and Ciacco, C., 2000. Composition and functional properties of banana flour from different varieties. Starch-Stärke 52(2–3): 63–68. https://doi.org/10.1002/(SICI)1521-379X(200004)52:2/3%3C63::AID-STAR63%3E3.0.CO;2-V

Nair, S., Knoblauch, M., Ullrich, S. and Baik, B.K., 2011. Microstructure of hard and soft kernels of barley. Journal of Cereal Science 54(3): 354–362. https://doi.org/10.1016/j.jcs.2011.06.014

Naseer, B., Naik, H.R., Hussain, S.Z., Zargar, I., Bhat, T.A. and Nazir, N., 2021. Effect of carboxymethyl cellulose and baking conditions on in-vitro starch digestibility and physico-textural characteristics of low Glycemic Index gluten-free rice cookies. LWT-Food Science and Technology 141: 110885. https://doi.org/10.1016/j.lwt.2021.110885

Niffenegger, E.V., 1964. Chemical and physical characteristics of barley flour as related to its use in baked products. A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Home Economics, Montana State College Bozeman, Montana.

Onwuka, G.I., Onyemachi, A.D. and David-Chukwu, N.P., 2015. Comparative evaluation of proximate composition and functional properties of two varieties of cooking banana. Journal of Environmental Science, Toxicology and Food Technology 9(1): 1–4.

Pansawat, N., Jangchud, K., Jangchud, A., Wuttijumnong, P., Saalia, F.K., Eitenmiller, R.R. and Phillips, R.D., 2008. Effects of extrusion conditions on secondary extrusion variables and physical properties of fish, rice-based snacks. LWT – Food Science and Technology 41(4): 632–641. https://doi.org/10.1016/j.lwt.2007.05.010

Prabhakar, H.S., Sharma, P.S., Ranote, B., Singh, B. and Sharma, S., 2017. Concoct citrus waste based extruded snacks: optimizing process conditions using response surface methodology

(RSM) and delving extrudate attributes. International Journal of Current Microbiology and Applied Science 6(11): 189–204. https://doi.org/10.20546/ijcmas.2017.611.024

Qamar, S., Aslam, M., Huyop, F. and Javed, M.A., 2017. Comparative study for the determination of nutritional composition in commercial and noncommercial maize flours. Pakistan Journal of Botany 49(2): 519–523.

Reddy, D.K. and Bhotmange, M.G., 2013. Isolation of starch from rice (Oryza sativa L.) and its morphological study using scanning electron microscopy. International Journal of Agriculture, Food Science and Technology 4(9): 859–866. https://doi.org/10.1007/s13197-013-1251-0

Reddy, M.K., Kuna, A., Devi, N.L., Krishnaiah, N., Kaur, C. and Nagamalleswari, Y., 2014. Development of extruded ready-to-eat (RTE) snacks using corn, black gram, roots and tuber flour blends. Journal of Food Science and Technology 51(9): 1929–1937.

Sakhare, S.D., Inamdar, A.A., Soumya, C., Indrani, D. and Rao, G.V., 2014. Effect of flour particle size on microstructural, rheological and physico-sensory characteristics of bread and south Indian parotta. Journal of Food Science and Technology 51(12): 4108–4113. https://doi.org/10.1007/s13197-013-0939-5

Sharma, P., Gujral, H.S. and Singh, B., 2012. Anti-oxidant activity of barley as affected by extrusion cooking. Food Chemistry 131: 1406–1413. https://doi.org/10.1016/j.foodchem.2011.10.009

Singh, J.P., Kaur, A., Shevkani, K., Singh, N. and Singh, B., 2016. Physicochemical characterization of corn extrudates prepared with varying levels of beetroot (Beta vulgaris) at different extrusion temperatures. International Journal of Food Science and Technology 51: 911–919. https://doi.org/10.1111/ijfs.13051

Singh, J.P., Kaur, A., Singh, B., Singh, N. and Singh, B., 2019. Physicochemical evaluation of corn extrudates containing varying buckwheat flour levels prepared at various extrusion temperatures. Journal of Food Science and Technology 56(4): 2205–2212. https://doi.org/10.1007/s13197-019-03703-y

Singh, S., Gamlath, S. and Wakeling, L., 2007. Nutritional aspects of food extrusion: a review. International Journal of Food Science and Technology 42(8): 916–929. https://doi.org/10.1111/j.1365-2621.2006.01309.x

Sullivan, P., O'Flaherty, J., Brunton, N., Gee, V.L., Arendt E. and Gallagher, E., 2010. Chemical composition and microstructure of milled barley fractions. European Food Research and Technology 230(4): 579–595. https://doi.org/10.1007/s00217-009-1196-8

Yanniotis, S., Petraki, A. and Soumpasi, E., 2007. Effect of pectin and wheat fibers on quality attributes of extruded corn starch. Journal of Food Engineering 80(2): 594–599. https://doi.org/10.1016/j.jfoodeng.2006.06.018

Zilic, S., Milasinovic, M., Terzic, D. and Barac, M., 2011. Grain characteristics and composition of maize specialty hybrids. Spanish Journal of Agricultural Research 9(1): 230–241. https://doi.org/10.5424/sjar/20110901-053-10