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Comparative study of physicochemical and functional properties of pan and microwave cooked underutilized millets (proso and little)

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ABSTRACT

Physiochemical properties such as colour, water absorption index (WAI), water solubility index (WSI) bulk density and the functional properties such as water absorption capacity (WAC), oil absorption capacity, least gelation concentration, foaming capacity, foaming stability, pasting properties, in vitro starch digestibility and microstructure of underutilized millet (proso and little) flours were evaluated. The millets flour exhibited considerable amounts of carbohydrates (78.37–81.69 g/100 g) and proteins (4.48–10.32 g/100 g). Microwave cooked little millet (MWLM) (10.32 g/100 g), and pan-cooked proso millet (PCPM) (9.07 g/100 g) flour contained a significantly higher amount of proteins than the raw millets. WAI (4.48 g/g) and WSI(4.17 g/g) of MWLM were significantly higher than the other flours. The functional properties of MWPM such as WAC (3.23 g/g) and OAC (0.90 g/g) were higher than the other flour samples. The microstructure of flour samples revealed that the starch granules of raw flours were smooth, oval and granular structure whereas cooked flours have deshaped starch granules. The under-utilized millets can further be used as an essential source of nutrients and functional ingredients in various food formulations, including for functional foods.

1. Introduction

Millets are small-seeded grasses from the family Poaceae, cultivated on marginal drylands in subtropical and tropical regions. Millets are rich in carbohydrates, protein, fat, dietary fibres, minerals, flavonoids and some of the vitamins (Chandrasekara & Shahidi, 2010). Most of these millets are used as a staple food, and as one of the main ingredients in the preparation of various traditional foods such as *porridges,* idli, dosa*, bread, chakli, papads* etc (Sarita & Singh, 2016). Proso millet (Panicum miliaceum L.), and little millet (*Panicum sumatrense*) both are widely cultivated throughout Asia, Australia, North America, Europe, and Africa (Yang et al., 2018). Little millet contains proteins (9.80–12.49 g/100 g), fat (2.87–5.09 g/100 g), ash (0.98–4.78 g/100 g), crude fibre (0.49–8.72 g/100 g), carbohydrates (62.25–76.59 g/100 g) with various other essential minerals and phytochemicals and does not contain gluten (Tiwari, Tiwari, & Tripathi, 2018). Proso millet contains proteins (9.4–9.9 g/100 g), fat (1.2–3.8 g/100 g), ash (0.6–3.3 g/100 g) and carbohydrates (70.0–74.0 g/100 g) with various other essential minerals and phytochemicals (Devisetti, Yadahally, & Bhattacharya, 2014). Although millets are nutritionally superior, lack of refined and processed millets limit their extensive use and acceptability.

Millets are traditionally consumed as a food which is prepared by various processing methods such as boiling, roasting and pressure cooking (Annor, Tyl, Marcone, Ragaee, & Marti, 2017). There are many factors which affect the characteristics of cooked grain such as the pre-processing applied, size of the grain, water/grain ratio, cooking time, cooking method and temperature (Dias-Martins et al., 2019). Microwave is an electro-heat technique which converts electrical energy into thermal energy on a frequency range of 300 MHz to 300 GHz, and food application are in the range of 915 MHz and 2.45 GHz (Gavahian et al., 2019). Due to the elctro-heat technique effect, the microwave method is a more efficient energy saver and short process than conventional such as open pan boiling, which uses an indirect heat transfer mechanism (Ekezie, Sun, Han, & Cheng, 2017). Microwave cooking is considered as a quick household cooking method as compared to conventional pan cooking. Liu, Zheng, Wang, and Chen (2019) reported that microwave cooking resulted in a least loss of vitamins in rice as compared to high pressure and conventional pan cooking techniques. In comparison to conventional cooking techniques, microwave facilitates to achieve high temperature in short time by rapid vibrations of polar molecules, uniform heating, high heating rates and safe handling (Guo, Sun, Cheng, & Han, 2017).

This study aimed to explain the effects of different cooking

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protocols, including open cooking, and microwave cooking on little and proso millet. The in vitro digestibility physiochemical and functional properties of proso millet and little millet were also evaluated after pan and microwave cooking. None of the reports has yet been reported in details on the variations in physicochemical and functional properties of underutilized millets after treating with different cooking methods.

2. Materials and methods

Proso millet (BR-7) and little millet (OLM-203) were purchased from the local market of Bihar, India, harvested in May 2017. Samples were physically examined to ensure disease-free and stored in the cold (5 °C) temperature until further use. All chemicals and reagents used were analytical grades.

2.1. Microwave and pan cooking

Millet samples were cooked by microwave and open pan cooking to find the optimum cooking time by following Dias-Martins et al. (2019), the millets were considered cooked when atleast 95% of the grains were not opaque. For pan cooking, grains were added after the water temperature reached 98 °C with a ratio of 1:7 grain/water respectively. The pan cooking processes were carried out for optimum cooking time (predetermined); 5 min and 36 min for little millet and proso millet respectively, under the same temperature profiles (98 °C ± 2 °C). For microwave cooking millet samples were added to water with a 1:7 grain/water respectively at 25 °C. The microwave cooking processes were carried at 600 W for 6 min and 30 min (predetermined optimum microwave cooking times) for little millet and proso millet respectively. Samples were cooked inside the microwave (Sharp-R-3801, Japan) by placing microwave-safe borosil bowl (diameter = 20.5 cm) at the centre. After microwave and conventional pan cooking, the samples were dried overnight at 50 °C in a hot air oven followed by milling and finally passed through a 70 mesh sieve (USA Standard Testing Sieve No. 70). The samples were stored at 10 °C for further analysis.

2.2. Chemical composition of flours

Flour samples of raw and processed proso millet and little millet were estimated for their moisture, ash, fat and protein contents by using the standard methods of analysis given by Association of Official Analytical Chemists (https://www.sciencedirect.com/science/article/pii/S0023643812001065Association of Official Analytical Chemists, 2005). Carbohydrate content was calculated by subtracting the sum of the moisture, fat, protein and ash contents from 100 as outlined in Association of Official Analytical Chemists (2005). Gross energy was determined using bomb calorimeter.

2.3. In vitro starch digestibility

In vitro starch digestibility (IVSD) of millet flours were evaluated by the method of Rathod and Annapure (2017) with slight modifications. Sample (50 mg/mL of 0.2 M phosphate buffer, pH 6.9) was mixed with 0.5 mL of pancreatic amylase (35.7 U/mg) suspension (1.42 mg/mL of 0.2 M phosphate buffer, pH 6.9) followed by incubation at 25 °C for 2 h. 3, 5-dini-trosalicylic acid (2 mL) was further added in the mixture, maintaining the volume to 25 mL by adding distilled water and boiled for 5 min. The mixture solution was filtered. The optical density of the solution was measured at 550 nm by using (UNICAM UV/Vis spectrophotometer, UK). Maltose was used as a reference standard, and IVSD was expressed as mg of maltose released per gram of sample on a dry weight basis.

2.4. Physical properties of flours

2.4.1. Color characteristics

The colour of the samples was analyzed by Hunter Lab Spectrocolorimeter (Model TC-P III-A, Tokyo Denshoku Co., Ltd., Japan) by following the method of Medhe, Jain, and Anal (2019). The colorimeter was calibrated by using Hunter lab color standard white plate (L* = 93.33, a* = −0.91 and b* = 1.46) and black plate. Sample (10 g) flour was kept in the glass container of the instrument and placed over the slit of the equipment. CIE lab system was used to measure the color parameters, where L^* (L^* = null means black and L^* = 100 means white), a^* ($-a^*$ = greenness and + a^* = redness) and b^* ($-b^*$ = blueness and + b^* = yellowness). The total color difference (ΔE) was calculated by using the following equation 1

$$\Delta E = \sqrt{(L^* - L_i^*)^2 + (a^* - a_i^*)^2 + (b^* - b_i^*)^2} \quad (1)$$

2.4.2. 2.4.2 Water absorption index (WAI) and water solubility index (WSI)

Water absorption index (WAI) and water solubility index (WSI) of all flours were determined following the method of Maninder, Sandhu, and Singh (2007) with slight modification. The samples (0.83 g) was dispersed in 10 mL of distilled water and cooked at 90 °C for 15 min in a water bath. The cooked flour paste was cooled at room temperature (25 °C) and centrifuged (model EBA 8S, Hettich, Germany) at 3000 rpm for 10 min. The supernatant was transferred into an evaporating dish, and the weight of sediment was taken. The sediment was dried at 110 °C and weighed again. Water absorption index and water solubility index were calculated following equations (2) and (3), respectively:

$$\text{WAI (g/g)} = \frac{\textit{weight of sediment}}{\textit{weight of flour sample}} \quad (2)$$

$$\text{WSI (g/100g)} = \frac{\textit{Weight of dissolved in supernatant}}{\textit{weight of flour sample}} \times 100 \quad (3)$$

2.4.3. 2.4.3 Bulk density

The bulk density of flours was determined by the method described by Medhe et al. (2019) with slight modification. Samples were gently filled into 10 mL graduated cylinders. The bottom of each cylinder was gently tapped several times until there was no further diminution of the sample level after filling up to the 10 mL mark. Bulk density was calculated as the weight of the sample per unit volume of sample (g/mL).

2.5. Functional properties of flours

2.5.1. Water absorption capacity and oil absorption capacity

Water absorption and oil absorption capacity of flour samples were determined following the method described by Chandra, Singh, and Kumari (2015) with slight modification. For water absorption, sample (0.83 g) was dispersed in 10 mL of distilled water and placed in centrifuge tubes. The dispersion was further stirred occasionally, held for 30 min, followed by centrifugation (model EBA 8S, Hettich, Germany) at 3000 rpm for 25 min. The supernatant was poured in petriplate, and the excess water was removed from centrifuge tubes. The sediment was placed in a hot air oven at 50 °C for 25 min, and the sample was re-weighed. For the determination of oil absorption capacity, sample (0.5 g) was mixed with 6 mL of soybean oil and centrifuged at 3000 rpm for 25 min. After centrifugation, separated oil was removed with the help of pipette, and the tubes were inverted for 25 min to drain the oil before reweighing. The water and oil absorption capacities were expressed as a gram of water or oil bound per gram of the sample on a dry basis. Water absorption capacity and oil absorption capacity were calculated following equations (4) and (5), respectively:

$$\text{WAC (g/g)} = \frac{(\textit{Weight of centrifuge tube after drying} - \textit{weight of centrifuge tube}) - \textit{weight of sample}}{\textit{weight of sample}} \quad (4)$$

$$\text{OAC (g/g)} = \frac{\textit{weight of centrifuge tube after drawing oil} - (\textit{centrifuge tube weight} + \textit{weight of sample})}{\textit{weight of sample}} \quad (5)$$

2.5.2. Least gelation concentration of flour samples

Least gelation concentration of samples was determined by following the method of Kaushal, Kumar, and Sharma (2012) with slight modification. The sample (5 mL) prepared in different concentrations of (2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 g/100 mL) was placed in test tubes and heated for an hour at 98 °C in water bath followed by rapid cooling under running tap water. The tubes were further cooled at 4 °C for 2 h. Least gelation concentration was expressed as the concentration above which the sample did not fall or slip when the test tubes were inverted.

2.5.3. Foaming capacity and foaming stability

Foaming properties of flours were determined by the method described by Maninder et al. (2007) with slight modification. The sample (1.5 g) was dispersed in 50 mL of distilled water and homogenised, using the homogeniser (Servodyne, Model 50000-25) at 960 rpm for 3 min. The blended mixture was further transferred into a graduated cylinder, and the homogeniser cup was rinsed with 10 mL of distilled water and added to the graduated cylinder. The volume was recorded before and after whipping. Foaming capacity (FC) and foaming stability (FS) were calculated by equation (6):

$$\text{FC} = \frac{\textit{Increase in volume after homogenization} - \textit{initial volume}}{\textit{Initial Volume}} \quad (6)$$

FS = Foam volume changes in the graduated cylinder recorded at an interval of 20, 40, 60 and 120 min of storage.

2.6. Pasting properties of millet flours

Pasting properties of flours were tested according to the method of Nasrin, Noomhorm, and Anal (2015) by using rapid visco analyzer (RVA) (Model 4, Newport Scientific Pvt., Ltd. Australia). Sample (2.5 g) was placed into the canister and mixed thoroughly with 25 mL of distilled water. The flour suspensions was heated at 50 °C for 1 min, and then the temperature was slowly increased to 95 °C for 3.2 min and finally, the temperature was again decreased to 50 °C. All the flour samples were mixed and homogenised at 960 rpm throughout the test, and the total test time was 13 min.

2.7. Thermal properties

Thermal properties of flour samples were determined by using differential scanning calorimeter (DSC) (SHIMADZU/DSC-60A Plus) according to the method described by Falade and Christopher (2015) with slight modifications. The flour sample (1 mg) was weighed into pierced DSC aluminium pans and distilled water was added to make the flour: water ratio of 1:3. The pans were hermetically sealed, and samples were left to stand for an hour at 25 °C for moisture equilibration. The sealed pans were heated from 20 °C to 130 °C under nitrogen gas at a heating rate of 10 °C min^{-1} to gelatinize the flour samples. An empty aluminium pan was used as a reference, and the calorimeter was calibrated with indium. From the DSC thermograms, the onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and enthalpy of gelatinisation (ΔHG) were determined.

2.8. FTIR of millet flours

Infrared spectra (500–4000 cm^{-1}) of the raw and cooked millet flours were obtained by attenuated total reflectance (ATR) Fourier transform infrared (FT-IR) spectrometer (Nicolet Avatar 36). Infrared spectra of raw and cooked millet samples were observed by following Nasrin et al. (2015). Powdered millet samples were used for direct measurement of the spectra in the range of 500–4000 cm^{-1} wavenumbers.

2.9. Scanning electron micrographs of millet flours

Microstructure images of millet flours were observed by scanning electron microscope (SEM) (Hitachi SU8230, Japan), as described by Ramashia, Gwata, Meddows-Taylor, Anyasi, and Jideani (2018). The sample particles were sprayed with gold over carbon tape splattered, and then examinations were observed at an accelerated voltage of 5.000 kV using SEM.

2.10. Statistical analysis

The data were subjected to analysis of variance (ANOVA) by using SPSS version 23 (SPSS, IBM, Chicago USA) significant differences ($p < 0.05$) among mean observations were evaluated by Tukey's HSD test.

3. Results and discussion

3.1. Nutritional composition of millet flours

The compositions of different flour samples are presented in Table 1. The carbohydrate content varied from 78.37 to 81.69 g/100 g among different flours. The increasing order of carbohydrate content was RLM (78.37 g/100g) < RPM (78.57 g/100 g) < PCPM (78.91 g/100 g) < MWLM (79.40 g/100 g) < PCLM (81.57 g/

Table 1
Nutritional analysis of millets after cooking treatments.

Sample	Ash (g/100 g)	Moisture (g/100 g)	Fat (g/100 g)	Protein (g/100 g)	Carbohydrate (g/100 g)	Energy (Cal/g)	Starch digestibility %
RPM	1.25 ± 0.08^{bc}	8.71 ± 0.01^{a}	3.24 ± 0.12^{c}	8.28 ± 1.12^{b}	78.51 ± 1.15^{a}	4037	57.18 ± 1.00^{c}
PCPM	1.5 ± 0.21^{c}	8.13 ± 0.04^{b}	2.3 ± 0.11^{b}	9.07 ± 0.71^{bc}	78.91 ± 0.91^{a}	4067	42.20 ± 0.28^{b}
MWPM	1.32 ± 0.13^{bc}	8.93 ± 0.05^{b}	3.05 ± 0.34^{c}	4.48 ± 0.50^{a}	81.69 ± 0.41^{b}	4293.2	43.73 ± 1.08^{bc}
RLM	1.9 ± 0.06^{d}	8.65 ± 0.02^{c}	1.91 ± 0.41^{ab}	9.16 ± 0.61^{bc}	78.37 ± 0.28^{a}	4004	41.96 ± 0.22^{b}
PCPM	0.51 ± 0.04^{a}	7.27 ± 0.17^{c}	1.56 ± 0.24^{a}	9.07 ± 0.71^{bc}	81.57 ± 0.69^{b}	4116	29.71 ± 2.71^{a}
MWLM	0.45 ± 0.08^{a}	8.02 ± 0.14^{d}	1.79 ± 0.03^{ab}	10.32 ± 0.72^{c}	79.40 ± 0.52^{a}	4049	30.09 ± 0.66^{a}

Each value is a mean of triplicates ± SD of triplicates. Means with no common letters within a column significantly differ ($p < 0.05$). RPM = raw proso millet, PCPM = pan-cooked proso millet, MWPM = microwave cooked proso millet, RLM = raw little millet, PCLM = pan-cooked little millet, MWLM = microwave cooked little millet.

100 g) < MWPM (81.69 g/100 g. The highest amount of ash content was observed in RLM (1.9 g/100 g), and lowest in MWLM (0.45 g/100 g).

Devisetti et al. (2014) also reported similar contents, including the carbohydrate (70% w/w) and ash (1.3 g/100 g) in raw brown porso millet. Wani, Hamid, Hamdani, Gani, and Ashwar (2017) observed the increased amount of carbohydrate content after cooking. The high ash and high carbohydrate content of the flour indicated that these millets could serve as a significant source of minerals and energy for consumers (Kaushal et al., 2012).

The protein content was in the range of 4.48–9.16 g/100 g for different flours. The protein contents of RLM, PCLM, RPM and PCPM were not significantly different ($p > 0.05$), whereas protein content of MWPM (4.48 g/100g) was significantly lower than other millets. MWLM (10.32 g/100 g) showed a significantly high amount of protein content, and the variation in the protein contents of cooked and raw millets might be due to variation in the nitrogen content after exposure to different cooking techniques (Wani et al., 2017).

The fat content varied from 1.56 to 3.24 g/100 g and followed the increasing order as: PCLM (1.56 g/100 g) < MWLM (1.79 g/100 g) < RLM (1.91 g/100 g) < PCPM (2.3 g/100 g) < MWPM (3.05 g/100 g) < RPM (3.24 g/100 g). The moisture content varied from 7.27 to 8.65 g/100 g among different flour samples. The cooking treatments decreased the moisture content in millet flours due to removal of water content in response to heat treatment (Wani et al., 2017).

Devisetti et al. (2014) reported protein content of 14.8 g/100 g, fat content of 4.3 g/100 g in raw brown proso millet. Saleh, Zhang, Chen, and Shen (2013) reported protein content of 9.7 g/100 g, fat content of 5.2 g/100 g in raw little millet. The nutritional value of millet flours varies due to difference in geographical regions, varieties and growth conditions (Maninder et al., 2007). The energy value in flour samples ranged from 4004 to 4293.2 cal/g. Saleh et al. (2013) also reported gross energy of 329 kcal/100g in little millet.

3.2. In vitro starch digestibility of millet flours

Starch is a predominant component of cereals classified as rapid digestive starch, slow digestive starch and resistant starch. Table 1 summarises the starch digestibility of flours. The starch digestibility ranged from 57% to 29%. In RPM and RLM, digestibility of starch observed higher comparare to cook one.

In vitro digestibility of starch depends on many factors such as amylose content, degree of crystallinity, amylose -lipid complexes and the molecular structure of amylopectin (Ying et al., 2017tibility found a decrease in parboiled millets can be related to the formation of more undigested or resistant starch. Annor et al. (2017) also observed finger millet starches are resistance to digestive enzymes because of rigid starch granule structure compared to rice. Digestibility of millet starch depends upon many factors such as starch morphology, amylose/amylopectin ratio, lipids, proteins, fibre and presence of antinutrients.

3.3. Physical properties of flours

3.3.1. Color

Hunter colour values (L*, a*,b*) of different flours are presented in Table 2. The lightness "L" values of RPM, RLM, PCPM, PCLM, MWPM and MWLM were observed as 79.37, 78.18, 81.46, 90.35, 80.73 and 89.81 respectively. PCLM flour was more white (high value of L*) whereas RLM flour showed the lowest L* value. The L* value of all the samples was significantly different from each other. The value of "a*" is significantly different in millet flours. Kaushal et al. (2012) reported the colour attributes; L* (94.37), a* (−0.02) and b* (4.22) respectively in rice. The total color difference values (ΔE) were significantly higher ($P < 0.05$) for little millet as compared to compared to proso millet after cooking treatments.

The colour of flours depends on the presence of flavonoids, anthocyanins and tannin (Medhe et al., 2019). Sandhu and Siroha (2017) reported L* (75.5–83.5), a* (0.07–0.96) and b* (9.2–12) respectively in six species of pearl millet. After cooking treatments the increase in lightness of millet flours was due to protein denaturation and attachment of fat droplets to the denatured protein matrix (Kahyaoglu & Kaya, 2006; Sharanagat et al., 2019). After cooking the increase in "a" (redness) and "b" (yellowness) values of flours indicated the formation of brown pigments in the Maillard reactions and thermal oxidation of polyphenols (Bagheri, Kashaninejad, Ziaiifar, & Aalami, 2016).

3.3.2. 3.3.2 Water absorption index (WAI) and water solubility index (WSI)

The WAI of different kinds of flours was in the range of 4.48 g/g to 3.68 g/g, whereas the highest value was observed for MWLM (4.48 g/g) and lowest value for PCPM (3.68 g/g). The WAI values of RPM, RLM, PCLM and MWPM were not significantly different ($p > 0.05$).WAI is interconnected with hydrophilicity and gelation capacity of biomacromolecules, such as starch and protein in flour (Maninder et al., 2007). Dias-Martins et al. (2019) reported WAI and WSI in pan-cooked pearl millet after conventional cooking treatment as 3.74 g/g and 3.45 g/100 g, respectively. Furthermore, there was no significant effect of cooking on WAI and WSI of pearl millet.

WSI value was in the range of 1.41 g/100 g–4.17 g/100 g for different flour samples, whereas the highest value was observed in MWLM (4.17 g/100 g) and the lowest value observed in RLM (1.41 g/100 g).

3.3.3. 3.3.3 Bulk density

Significant differences were observed among the bulk densities of the flours (Table 2). The bulk density of flours was varied from 0.72 g/mL to 0.85 g/mL, whereas the highest value and lowest value were obtained for RLM (0.85 g/mL) and PCPM (0.72 g/mL) flour respectively. The bulk densities of pan and microwave cooked proso millet flours were not significantly different, whereas the bulk density of RLM and RPM was significantly different ($p < 0.05$).

The bulk density of several millet flours depends on grain moisture content (Subramanian & Viswanathan, 2007). The higher bulk density of millet flour suggests having denser in structure than other flours (Du, Jiang, Yu, X. and Jane, 2014). Flour with low bulk density is used in the preparation of weaning food formulations (Devisetti et al., 2014). Higher bulk density depends on the presence of lipids which act as adhevises in agglomeration of carbohydrate and protein molecules (Joshi, Liu, & Sathe, 2015).

3.4. Functional properties of flours

3.4.1. Water and oil absorption capacity

The WACs of the flours were ranged from 1.50 to 3.23 g/g, whereas the WAC of MWLM (3.23 g/g) flour was the highest, and RLM (1.50 g/g) exhibited the lowest WAC (Table 3). The WAC of raw proso and little millet were found statistically similar, whereas pan and microwave cooked proso and little millet showed significantly different ($p < 0.05$) from other flours.

The water absorption capacity (WAC) plays a vital role in food preparation because it affects other functional and sensory properties of food products (Kaushal et al., 2012). Partial denaturation or dissociation of proteins and gelatinisation of carbohydrates after heat treatment increases the binding sites in roasted flours compared to raw samples (Wani et al., 2017). The polar amino acids residues of the proteins have an affinity for water molecules and causing differences in WACs of different flours. The composition of carbohydrate being hydrophilic in majority is another factor affecting the WAC of the flours. Additionally, WAC is a vital property of protein and other components of flours in various foods, e.g. soups, dough, custards, and baked products because these are assumed to imbibe water without dissolution of protein which provides body, thickening and viscosity (Devisetti et al., 2014).

Table 2
Physical properties of millet flours.

Parameter	RPM	PCPM	MWPM	RLM	PCLM	MWLM
L*	79.37 ± 0.43^{b}	81.46 ± 0.10^{d}	80.73 ± 0.25^{c}	78.18 ± 0.14^{a}	90.35 ± 0.50^{f}	89.81 ± 0.18^{e}
A*	0.93 ± 0.02^{a}	1.42 ± 0.03^{c}	1.86 ± 0.03^{d}	1.36 ± 0.13^{c}	0.16 ± 0.02^{a}	0.21 ± 0.01^{a}
B*	10.78 ± 0.22^{a}	17.40 ± 0.02^{e}	18.95 ± 0.19^{f}	13.12 ± 0.04^{b}	14.90 ± 0.10^{c}	15.45 ± 0.04^{d}
ΔE	–	6.96 ± 0.29^{a}	8.33 ± 0.44^{b}	–	12.36 ± 0.11^{c}	11.92 ± 0.28^{c}
WAI (g/g)	3.99 ± 0.23^{a}	3.68 ± 0.07^{a}	3.90 ± 0.05^{a}	3.99 ± 0.22^{a}	4.35 ± 0.83^{a}	4.48 ± 0.09^{a}
WSI (g/100g)	1.42 ± 0.59^{a}	2.61 ± 0.24^{ab}	2.93 ± 0.48^{ab}	1.41 ± 1.02^{a}	3.57 ± 0.24^{b}	4.17 ± 1.00^{b}
BD (g/ml)	0.83 ± 0.01^{c}	0.72 ± 0.02^{a}	0.72 ± 0.01^{a}	0.85 ± 0.01^{d}	0.74 ± 0.02^{c}	0.73 ± 0.02^{ab}

L*, a*,b* are colour values, ΔE indicates the total color difference. WAI: Water absorption index, WSI: Water solubility index, BD: Bulk density. Each value is a mean of triplicates ± SD of triplicates. Means with no common letters within a row significantly differ ($p < 0.05$). RPM = raw proso millet, PCPM = pan-cooked proso millet, MWPM = microwave cooked proso millet, RLM = raw little millet, PCLM = pan-cooked little millet, MWLM = microwave cooked little millet. Where, - indicates not estimated.

The OAC of different flours was in the range of 0.63 g/g to 0.92 g/g. The higher OAC was observed for MWLM (0.92 g/g) and the lowest for RPM and RLM (0.63 g/g). The OAC of RPM and RLM millets were significantly different ($p < 0.05$) from other samples, whereas PCPM, MWPM, PCLM and MWLM were significantly similar ($p < 0.05$). After cooking OAC increased because of the variations of non-polar sides of proteins subunit generated, which possibly bind with the hydrocarbon side chains of oil (Wani et al., 2017). The high OAC indicates that the flours are suitable for enhancing the flavour and mouthfeel while using in food preparations. Additionally, due to these properties, flours can be used as a functional ingredient in food such as whipped toppings, sausages, chiffon deserts and sponge cakes (Kaushal et al., 2012).

Oil absorption capacity (OAC) is the capacity of the flour protein to bind fat by capillary attraction physically (Kaushal et al., 2012). Oil absorption gives specifically physical entrapment of oil within the protein isolates, and non-covalent bonds such as hydrophobic, electrostatic and hydrogen bondings are the forces involved in lipid-protein interaction reported by Falade and Christopher (2015). The binding capacity between oil and water depends on the intrinsic factor such as amino acid composition, the conformation of protein and their hydrophobicity (Kaushal et al., 2012).

3.4.2. Foaming capacity and foaming stability

The highest foaming capacity was observed in RPM and lowest in PCLM and MWLM (Table 3). The foaming capacity were ranged from 0.20 mL/100 mL–0.18 mL/100 mL. It was observed that the foaming capacity decreased after cooking. However, it was not significantly different among cooked and control samples. Wani et al. (2017) observed a decrease in foaming capacity in sweet chestnut after roasting. Denaturation of several proteins occurred while cooking, which reduced the protein solubility that is expected the cause of lower foaming capacity. Foaming stability was not observed in any flour samples. FC and FS depend on the composition of carbohydrates and proteins present in the sample (Bhat, Wani, Hamdani, Gani, & Masoodi, 2016). The stability and the formation of foams are dependent on interfacial film produced by proteins, that maintains the air bubbles in suspensions and reduce the rate of coalescence, whereas, the presence of carbohydrates increase the viscosity of suspending medium (Devisetti et al., 2014). Therefore, stable foams are formed due to lower surface tension and high viscosity at interface. Du, Jiang, Yu, and Jane (2014) reported a protein content of 13.6 g/100 g and presence of FS by proso millet. In current study FS was not observed in proso millet, which might be due the difference in varieties of proso millet and lower protein content.

3.4.3. Least gelation concentration

The least gelation concentration (LGC) of different flours was in the range of 6–12% (Table 4). RLM and RPM formed gel at lower concentration (6–8% w/v) whereas, other flours formed a gel at a higher concentration (12% w/v). PCPM and PCLM formed a gel relatively at a lower concentration. Gel formation depends mainly on swelling and hydration of predominatly amorphous region of starch and starch granules. The lower value of LGC indicates the better gelation ability of the protein ingredient and the swelling ability of the flour (Chandra et al., 2015). The gel strength depends on the intragranular binding force of swollen starch granules due to heat, moisture treatment and annealing of amylose and amylopectin (Devisetti et al., 2014).

3.5. Pasting properties

Table 5 summarises the pasting properties of different flour samples. Highest peak temperature was observed in MWPM (94 °C) and lowest in RLM (53 °C). The peak temperature of little millet flours was similar, whereas for proso millet flours it was found significantly different. The peak viscosities of different flours were ranged from 2152 RVU to 2165 RVU. Final viscosities and setbacks in the flour samples ranged from 2125 RVU to 2145 RVU and 0.82 RVU to 4.75 RVU, respectively. The breakdown of flour samples ranged from 21.63 RUV to 33.14 RUV. The breakdowns observed in RLM, PCLM and MWLM were significantly similar ($p < 0.05$) whereas RPM, PCPM and MWPM flours exhibited significantly different breakdowns.

Table 3
Functional properties of millet flours.

Parameter	RPM	PCPM	MWPM	RLM	PCLM	MWLM
WAC (g/g)	1.96 ± 0.01^{a}	2.64 ± 0.40^{b}	3.23 ± 0.01^{b}	1.52 ± 0.15^{a}	2.8 ± 0.10^{b}	2.8 ± 0.45^{b}
OAC (g/g)	0.63 ± 0.01^{a}	0.87 ± 0.05^{b}	0.90 ± 0.10^{b}	0.68 ± 0.01^{a}	0.85 ± 0.05^{b}	0.92 ± 0.05^{b}
FC (ml/100 ml)	0.20 ± 0.02^{a}	0.19 ± 0.01^{a}	0.18 ± 0.01^{a}	0.19 ± 0.01^{a}	0.18 ± 0.02^{a}	0.18 ± 0.03^{a}
FS(ml/100 ml)	-	–	–	–	-	–
20 min						
40 min	-	–	–	–	-	-
60 min	-	–	–	–	-	-
120 min	–	–	–	–	-	–

WAC: Water absorption capacity, OAC: Oil absorption capacity, FC: Foaming capacity, FS: Foaming stability. Each value is a mean of triplicates ± SD of triplicates. Means with no common letters within a row significantly differ ($p < 0.05$). RPM = raw proso millet, PCPM = pan-cooked proso millet, MWPM = microwave cooked proso millet, RLM = raw little millet, PCLM = pan-cooked little millet, MWLM = microwave cooked little millet.

Table 4
Least gelation concentration of flours.

Concentrations (% w/v)	RPM	PCPM	MWPM	RLM	PCLM	MWLM-
2	–	–	–	–	–	–
4	–	–	–	–	–	–
6	–	–	–	+	–	–
8	+	+	–	+	+	–
10	+ +	+	+	+	+	+
12	+ +	+	+	+	+	+
14	+ +	+	+	+ +	+ +	+
16	+ +	+ +	+	+ +	+ +	+ +
18	+ +	+ +	+ +	+ +	+ +	+ +
20	+ +	+ +	+ +	+ +	+ +	+ +

- = No gelation, + = gel, + + = firm gel RPM = raw proso millet, PCPM = pan-cooked proso millet, MWPM = microwave cooked proso millet, RLM = raw little millet, PCLM = pan-cooked little millet, MWLM = microwave cooked little millet.

Pasting property plays an essential role in the selection of food thickener and binder. Pasting properties dependent on the rigidity of starch granules that are affecting granule swelling potential and leaching amount of amylose in the solution (Medhe et al., 2019). Furthermore, the increase in pasting temperature was observed with increase in heating treatment time. This prolonged heating treatment might influence the structure and arrangement of starch molecules (Qu, Wang, Liu, Wang, & Liu, 2017). Low breakdown of flour, indicates that flour exhibits good paste stability and strong shearing (Du, Jiang, Yu, X. and Jane, 2014). Yang et al. (2018) reported pasting properties of non-waxy cooked proso millet (pasting temperature, peak viscosity, through viscosity, breakdown, setback, and final viscosity) as 79.93 °C, 2111.00, 1112.50, 998.50, 3263.50, 4376 cP respectively.

3.6. Thermal properties

Whole flours are composite systems of the starch molecule, fibres, proteins, lipids and other components that can overall affect the heat capacity of the flour (Chávez-Murillo, Veyna-Torres, Cavazos-Tamez, de la Rosa-Millán, & Serna-Saldívar, 2018). The onset temperature ranged from 63.56 to 108.56 °C for flour samples, as shown in Table 5 and Figs. S1–S6 (supplementary material). The highest onset temperature was observed in PCPM and lowest in RPM flour. The increase in To found because of the transformation of inter-crystalline amorphous form and structural changes of the starch granules (Sharanagat et al., 2019). The peak gelatinisation temperature ranged from 72.68 to 118.69 °C, whereas the highest in MWLM, and the lowest one was observed in RPM. The gealatization temperatures found different among the flours due to size, form and internal distribution of starch granules (Maninder et al., 2007). Wani et al. (2017) observed higher gelatinisation temperatures in pan-roasted and microwave chestnut flours due to the exposure of high temperatures while roasting. Conclusion temperature ranged from 80 to 123.91 °C whereas the highest one was observed in MWLM and the lowest one in RPM. Wani et al. (2017) also reported in pan-roasted and microwave chestnut onset temperature (93.40–92.98 °C), peak temperature (106.19–103.96 °C), conclusion temperature (121.26–123.94 °C) and enthalpy (12.63–11.94 J/g) respectively.

3.7. FTIR of millet flours

FT-IR spectra of RLM, PCLM, MWLM, RPM, PCPM and MWPM millet illustrated are in Figs. 1 and 2. The peaks were observed in the range of specific spectral regions in raw, pan-cooked and microwave samples. The major peaks were observed at 3427, 1654, 1541, 1379, 1245, 1159, 766 and 707 cm^{-1}. These peaks showed the occurrence of hydroxyl (-OH), amine groups (–NH) and carbonyl group (= C = O) bonds, respectively (Wani et al., 2017). There was a difference observed in raw millet flours and cooked millet flours. PCLM and MWLM millet flours had a difference in carbohydrate region (1200- 900 cm^{-1}) compare to RLM but did not show any variation in protein region (1700-1600 and 1570 -1534 cm^{-1}). There were not much difference observed in raw and cooked proso millet in carbohydrate region (1200-900 cm^{-1}) and in protein, region (1700-1600 and 1570 -1534 cm^{-1}). Spectral changes in amide I and II regions are related to the protein backbone conformation due to high temperature, high pressure.

3.8. Scanning electron micrographs of millet flours

Fig. 3 illustrates the morphological micrographs of different flour samples. The flours of RPM and RLM were granular, spherical, oval and smooth close together with no gaps. Some granules were damaged and irregular in shape. Ramashia et al. (2018) reported that the whole finger, millet flour starch granules had a different shape like oval, polygonal with a smooth surface. After cooking significantly changes occurred in starch, granules are entirely damaged. Compared with raw samples, the cooked one showed many branching structures that connected to form a network in little millet but in proso millet not affected much after cooking. Shrestha, Sadiq, and Anal (2018) also observed changes in starch such as irregular shapes and an amorphous mass of cohesive structure in culled banana starch after heat treatment.

4. Conclusion

In this study, differences have been observed among the aesthetic properties, pasting properties, FTIR, and in vitro digestibility of millets

Table 5
Pasting properties of millet flours.

Parameters	RPM	PCPM	MWPM	RLM	PCLM	MWLM
Peak viscosity (RVU)	2153.64 ± 0.79^{ab}	2165.02 ± 2.89^{c}	2156 ± 1.01^{ab}	2154.38 ± 1.2^{ab}	2152 ± 1.37^{a}	2157 ± 0.41^{b}
Trough viscosity (RVU)	2131.67 ± 1.09^{b}	2134.36 ± 3.78^{b}	2124.63 ± 2.60^{a}	2123.21 ± 0.55^{a}	2134.72 ± 2.00^{b}	2129.74 ± 1.05^{b}
Break down (RVU)	21.63 ± 0.47^{a}	24.36 ± 0.47^{b}	31.58 ± 0.36^{c}	31.74 ± 1.37^{c}	33.14 ± 0.58^{c}	31.70 ± 0.93^{c}
Final viscosity (RVU)	2125.83 ± 0.79^{a}	2139.56 ± 0.92^{c}	2150.47 ± 1.27^{e}	2129.03 ± 1.96^{b}	2145.44 ± 1.41^{d}	2131.20 ± 0.54^{b}
Set back (RVU)	4.75 ± 0.28^{e}	1.27 ± 0.02^{b}	1.56 ± 0.01^{c}	3.57 ± 0.01^{d}	0.82 ± 0.03^{a}	0.84 ± 0.02^{a}
Pasting temp (°C)	67.15 ± 1.63^{b}	73.83 ± 0.62^{c}	94.65 ± 0.39^{d}	53.97 ± 1.14^{a}	54.43 ± 1.07^{a}	55.73 ± 1.21^{a}
Thermal properties						
T_O (°C)	64.56	108.56	82.37	71.26	97.73	99.5
T_P (°C)	72.68	112.8	102.72	78.44	117.53	118.69
T_C (°C)	80.09	123.91	124.37	82.28	123.71	123.91
H (J/g)	0.98	0.24	3.27	1.69	4.65	5.34
$T_C - T_O$ (°C)	15.53	7.83	21.65	11.02	8.24	5.22

To: onset gelatinisation temperature, Tp: peak gelatinisation, Tc: conclusion, H: enthalpy.. Each value is a mean of triplicates ± SD of triplicates. Means with no common letters within a row significantly differ ($p < 0.05$). RPM = raw proso millet, PCPM = pan-cooked proso millet, MWPM = microwave cooked proso millet, RLM = raw little millet, PCLM = pan-cooked little millet, MWLM = microwave cooked little millet. RVU = rapid visco units.

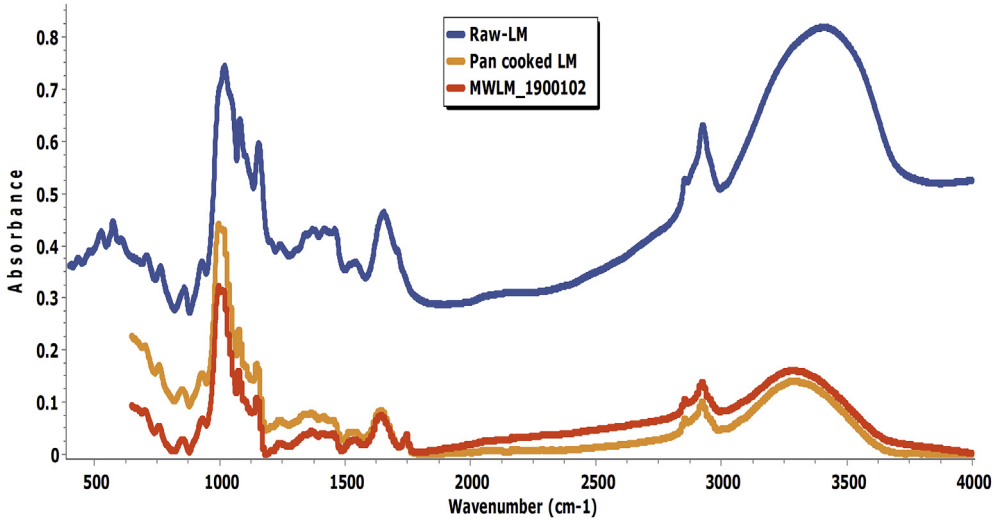

Fig. 1. FTIR spectra of raw, pan cooked and microwaved cooked little millet.

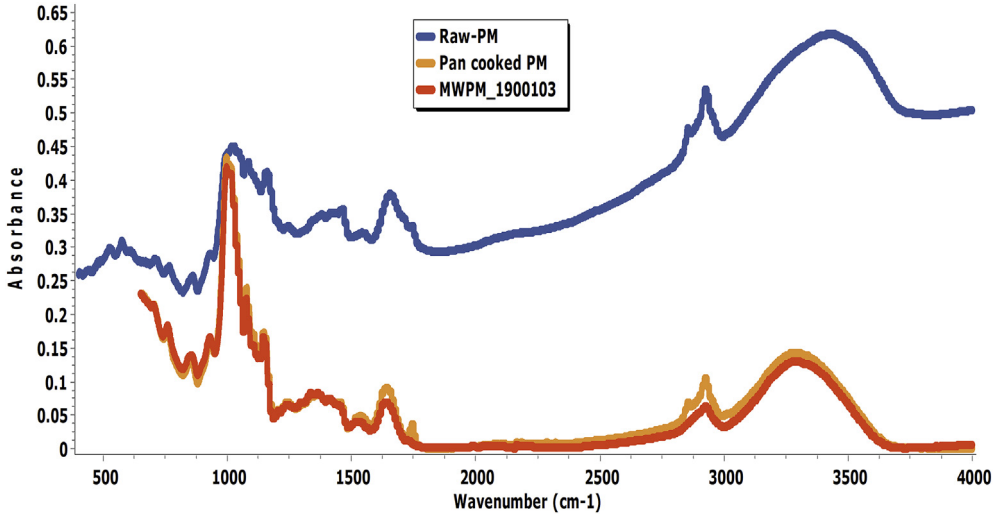

Fig. 2. FTIR spectra of raw, pan cooked and microwave cooked proso millet.

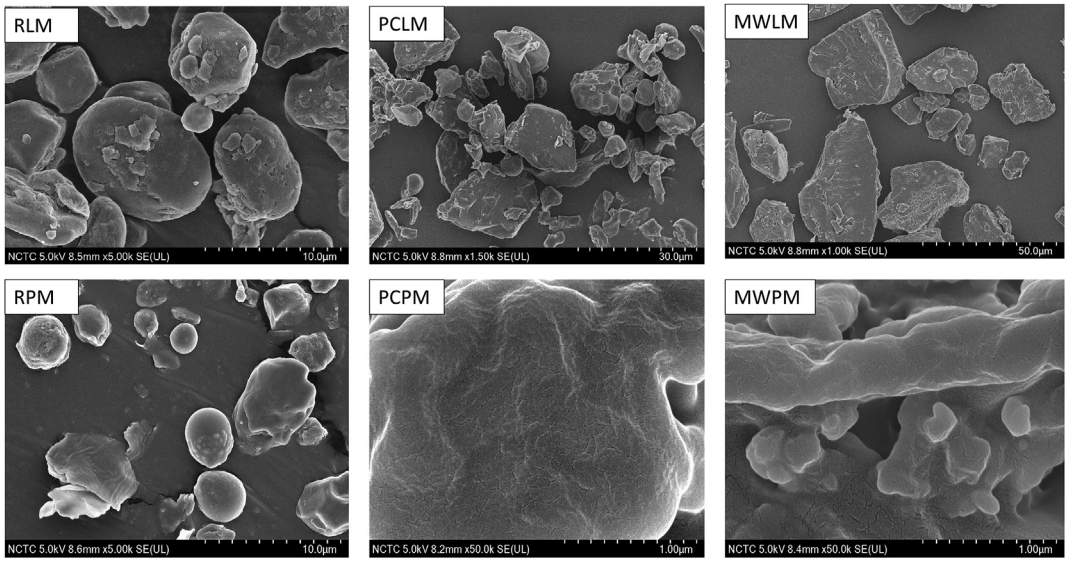

Fig. 3. Scanning electron microscopic structures of RPM = raw proso millet, PCPM = pan-cooked proso millet, MWPM = microwave cooked proso millet, RLM = raw little millet, PCLM = pan-cooked little millet, MWLM = microwave cooked little millet.

pan and microwave cooked millets. From Nutritional aspects, the carbohydrate composition and calorific value have also been increased by both cooking methods. Both methods of cooking do not have any effect on physiochemical properties such as WAI, but it has been observed that WSI has increased. Increase in WAC and OAC has enhanced the functional properties, which can be further used in the food industries for the formulation of healthy gluten-free products. However, the present study reports in-depth analysis of nutritional, physio-chemical and functional properties of pan and microwave cooked millets (Proso and little), these under-utilized millets have great potential to be used in the food industry for the formulation of new products or as a replacement in food products due to their improved nutritional physiochemical and functional properties.

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CRediT authorship contribution statement

Simmi Ranjan Kumar: Data curation, Formal analysis. **Muhammad Bilal Sadiq:** Formal analysis, Conceptualization, Writing - original draft. **Anil Kumar Anal:** Formal analysis, Writing - original draft, Conceptualization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2020.109465.

References

Annor, G. A., Tyl, C., Marcone, M., Ragaee, S., & Marti, A. (2017). Why do millets have slower starch and protein digestibility than other cereals? *Trends in Food Science & Technology, 66*, 73–83.

Association of Official Analytical Chemists (2005). *Official methods of analysis of the association of analytical Chemists.* Association of Official Analytical Chemists.

Bagheri, H., Kashaninejad, M., Ziaiifar, A. M., & Aalami, M. (2016). Novel hybridized infrared-hot air method for roasting of peanut kernels. *Innovative Food Science & Emerging Technologies, 37*, 106–114.

Bhat, N. A., Wani, I. A., Hamdani, A. M., Gani, A., & Masoodi, F. A. (2016). Physicochemical properties of whole wheat flour as affected by gamma irradiation. *LWT - Food Sci. Technol. 71*, 175–183.

Chandrasekara, A., & Shahidi, F. (2010). Content of insoluble bound phenolics in millets and their contribution to antioxidant capacity. *Journal of Agricultural and Food Chemistry, 58*(11), 6706–6714.

Chandra, S., Singh, S., & Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Journal of Food Science and Technology, 52*(6), 3681–3688.

Chávez-Murillo, C. E., Veyna-Torres, J. I., Cavazos-Tamez, L. M., de la Rosa-Millán, J., & Serna-Saldívar, S. O. (2018). Physicochemical characteristics, ATR-FTIR molecular interactions and in vitro starch and protein digestion of thermally treated whole pulse flours. *Food Research International, 105*, 371–383.

Devisetti, R., Yadahally, S. N., & Bhattacharya, S. (2014). Nutrients and antinutrients in foxtail and proso millet milled fractions: Evaluation of their flour functionality. *LWT - Food Sci. Technol. 59*(2), 889–895.

Dias-Martins, A. M., Cappato, L. P., da Costa Mattos, M., Rodrigues, F. N., Pacheco, S., & Carvalho, C. W. (2019). Impacts of ohmic heating on decorticated and whole pearl millet grains compared to open-pan cooking. *Journal of Cereal Science, 85*, 120–129.

Du, S. K., Jiang, H., Yu, X., & Jane, J. L. (2014). Physicochemical and functional properties of whole legume flour. *LWT - Food Sci. Technol. 55*(1), 308–313.

Ekezie, F. G. C., Sun, D. W., Han, Z., & Cheng, J. H. (2017). Microwave-assisted food processing technologies for enhancing product quality and process efficiency: A review of recent developments. *Trends in Food Science & Technology, 67*, 58–69.

Falade, K. O., & Christopher, A. S. (2015). Physical, functional, pasting and thermal properties of flours and starches of six Nigerian rice cultivars. *Food Hydrocolloids, 44*, 478–490.

Gavahian, M., Chu, Y. H., & Farahnaky, A. (2019). Effects of ohmic and microwave cooking on textural softening and physical properties of rice. *Journal of Food Engineering, 243*, 114–124.

Guo, Q., Sun, D. W., Cheng, J. H., & Han, Z. (2017). Microwave processing techniques and their recent applications in the food industry. *Trends in Food Science & Technology, 67*, 236–247.

Joshi, A. U., Liu, C., & Sathe, S. K. (2015). Functional properties of select seed flours. *LWT - Food Sci. Technol. 60*(1), 325–331.

Kaushal, P., Kumar, V., & Sharma, H. K. (2012). Comparative study of physicochemical, functional, antinutritional and pasting properties of taro (*Colocasia esculenta*), rice (*Oryza sativa*) flour, pigeon pea (*Cajanus cajan*) flour and their blends. *LWT - Food Sci. Technol. 48*(1), 59–68.

Liu, K., Zheng, J., Wang, X., & Chen, F. (2019). Effects of household cooking processes on mineral, vitamin B, and phytic acid contents and mineral bioaccessibility in rice. *Food Chemistry, 280*, 59–64.

Maninder, K., Sandhu, K. S., & Singh, N. (2007). Comparative study of the functional, thermal and pasting properties of flours from different field pea (*Pisum sativum* L.) and pigeon pea (*Cajanus cajan* L.) cultivars. *Food Chemistry, 104*(1), 259–267.

Medhe, S., Jain, S., & Anal, A. K. (2019). Effects of sprouting and cooking processes on physicochemical and functional properties of moth bean (*Vigna aconitifolia*) seed and flour. *Journal of Food Science and Technology, 56*(4), 2115–2125.

Nasrin, T. A. A., Noomhorm, A., & Anal, A. K. (2015). Physico-chemical characterization of culled plantain pulp starch, peel starch, and flour. *International Journal of Food Properties, 18*(1), 165–177.

Qu, C., Wang, H., Liu, S., Wang, F., & Liu, C. (2017). Effects of microwave heating of wheat on its functional properties and accelerated storage. *Journal of Food Science and Technology, 54*(11), 3699–3706.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S., Anyasi, T. A., & Jideani, A. I. O. (2018). Some physical and functional properties of finger millet (Eleusine coracana) obtained in sub-Saharan Africa. *Food Research International, 104*, 110–118.

Rathod, R. P., & Annapure, U. S. (2017). Physicochemical properties, protein and starch digestibility of lentil based noodle prepared by using extrusion processing. *LWT, 80*, 121–130.

Saleh, A. S., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains: Nutritional quality, processing, and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety, 12*(3), 281–295.

Sandhu, K. S., & Siroha, A. K. (2017). Relationships between physicochemical, thermal, rheological and in vitro digestibility properties of starches from pearl millet cultivars. *LWT - Food Sci. Technol. 83*, 213–224.

Sarita, E. S., & Singh, E. (2016). Potential of millets: Nutrients composition and health benefits. *J. Scient. Innovat. Res. 5*(2), 46–50.

Sharanagat, V. S., Suhag, R., Anand, P., Deswal, G., Kumar, R., Chaudhary, A., et al. (2019). Physico-functional, thermo-pasting and antioxidant properties of microwave roasted sorghum [Sorghum bicolor (L.) Moench]. *Journal of Cereal Science, 85*, 111–119.

Shrestha, S., Sadiq, M. B., & Anal, A. K. (2018). Culled banana resistant starch-soy protein isolate conjugate based emulsion enriched with astaxanthin to enhance its stability. *International Journal of Biological Macromolecules, 120*, 449–459.

Subramanian, S., & Viswanathan, R. (2007). Bulk density and friction coefficients of selected minor millet grains and flours. *Journal of Food Engineering, 81*(1), 118–126.

Tiwari, N., Tiwari, S., & Tripathi, N. (2018). Genetic characterization of Indian little millet (Panicum sumatrense) genotypes using random amplified polymorphic DNA markers. *Agric. Nat. Resour. 52*(4), 347–353.

Wani, I. A., Hamid, H., Hamdani, A. M., Gani, A., & Ashwar, B. A. (2017). Physico-chemical, rheological and antioxidant properties of sweet chestnut (Castanea sativa Mill.) as affected by pan and microwave roasting. *Journal of Advanced Research, 8*(4), 399–405.

Yang, Q., Zhang, P., Qu, Y., Gao, X., Liang, J., Yang, P., et al. (2018). Comparison of physicochemical properties and cooking edibility of waxy and non-waxy proso millet (Panicum miliaceum L.). *Food Chemistry, 257*, 271–278.

Ying, D., Hlaing, M. M., Lerisson, J., Pitts, K., Cheng, L., Sanguansri, L., et al. (2017). Physical properties and FTIR analysis of rice-oat flour and maize-oat flour based extruded food products containing olive pomace. *Food Research International, 100*, 665–673.