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ORIGINAL ARTICLE

Characterization of pea processing by-product for possible food industry applications

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Abstract Pea pods are by-products of the pea processing industries which are often disposed improperly but are rich reserves of nutrients. In this work, pea pod powder (PPP) was prepared and analysed for its nutritional, physical, functional and structural characteristics for food applications. Results showed that PPP contained 6.3% moisture, 5.2% ash, 3.5% crude fat, 13.3% crude protein, and 35.3% dietary fiber. Further, PPP exhibited 0.47 g/ml bulk density, 0.50 g/ml aerated bulk density, 0.62 g/ml tapped bulk density and had fair flowability as determined by Hausner's ratio and Carr's index. PPP also showed good functional characteristics with 3.24 g/g water absorption index, 7.9% water solubility index, 1.25 g/g oil absorption capacity, and 4.65% swelling power. Based on its excellent qualities, PPP was used to prepare cookies which were analyzed for its structural and spectral characteristics. The X-ray diffraction pattern of PPP and cookies revealed that the crystalline region in the latter remained intact. The FTIR spectra showed the presence of different functional groups in PPP and cookies. The study showed that PPP could be utilized as a beneficial ingredient in dietetic products such as baked goods due to its good water-holding capacity, oil-holding capacity and dietary fiber content.

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Introduction

Peas (*Pisum sativum* L.) are the second most widely planted legume in the world. Peas are consumed both in their green and dried forms all around the world. Around 5.7 million tonnes of peas were produced in India in the year 2020 (Nasir et al. 2022). Since peas are mostly processed into multiple food formats such as frozen, dried, and canned form, the outermost pod is often unused. This outer seed coat, makes up 35–40% of the fresh weight of peas and if not properly utilized or disposed, can attract pathogens, posing a threat to human and animal life. These pea pods are rich reserves of fibre, carbohydrates, and crude proteins and may have numerous food applications. In addition, they are also rich in many macronutrients such as potassium, magnesium, iron and zinc and exhibit a low calorific value of 210 kcal/100 g, primarily because of their limited fat content (Nasir et al. 2022). Pea pods have also been reported to contain phenolic acids such as cinnamic acids (5-cafeoylquinic acid, rosmarinic acid and quinic acid) and benzoic acids (eg., gallic acid). Other polyphenols that occur in pea pods include flavonoids that consist of favanones (naringenin and hesperidin), favanols (epicatechin and catechin), favonols (quercetin, quercetin 3-galattoside, and rutin), favones (luteolin, diosmin, apigenin and kaemferol 3-glucoside) and isofavones (genistein and myricetin) (Castaldo et al. 2022). Considering the rich constituent of pea pods, it is conclusive that it has tremendous potential for the development of value-added foods especially for the bakery sector.

Recent strides in bakery processing has majorly been focused for the development of products which are more digestible and are also suitable for consumers with diabetic, digestive or cardiovascular complications. Millets are now being intensively utilized for the production of such bakery items. Amongst the millet family, Barnyard millet has been shown to contain appreciable amounts of protein, with high absoption capability in the human gut and with excellent dietary fiber content. The major unsaturated fats present in barnyard millet are oleic acid and linoleic acid. Consequently, it has been recommended for patients with diabetes mellitus and cardiovascular diseases (Dayakar Rao et al. 2017). Hence, the conjugation of pea pod and barnyard millet could be a possible combination for formulating a nutrient rich and high fibre bakery product which can be made available to consumers on a global scale.

Among the major bakery products, cookies have grown in popularity among the global consumers due to their extended shelf life at room temperature, simplicity and ease of handling and transportation, and their availability at reasonable prices. Cookies come in a range of packaging options, with unique organoleptic features, variety of sizes, shapes, and flavours. If correctly modified, cookies are arguably the best way to satisfy the dietary demands of average customers. Usually cookies are prepared with wheat flour which can be replaced with better sources such as barnyard millets and fortified using pea pod powder. Studies have demonstrated that pea pods can provide pharmacological benefits including anti-diabetic, anti-reproprotective, antibacterial, hepatoprotective, and α-amylase inhibitory action. The nutritional, textural, and organoleptic qualities of a variety of functional foods, including cakes, biscuits, bread, mayonnaise, and soup powder, have been reported to have enhanced by pea pod powder (Nasir et al. 2022).

Although intensive investigations on the characteristics of pea pod powder has been done by various researchers, the data of its physical characteristics, crystallinity, morphology and infrared spectra is limited and further investigations are needed in this avenue which could be of industrial importance. Therefore, the current investigation aims to characterize the pea pod powder for the said parameters followed by its application in food product formulation. The developed product was also subsequently characterized to evaluate the retention or stability of the pea pod characteristics with processing.

Material and methods

Procurement and preparation of pea pod powder

Peas of 'karishma' variety were procured from a local vegetable vendor in Kichha, Uttarakhand (India). Peas were deshelled manually and the obtained pea pods were washed under running water. The parchment layer was removed manually. In an industrial setting, the pea pods may be subjected to blanching at 100 °C for 2 min followed by shelling to remove the parchment layer (Rudra et al. 2020). The pea pods were dried in a tray drier (MSW206, Delhi, India) at 60 °C for 24 h and then grounded in a lab-scale grinder (Model: FX 11 Food factory, Bajaj, India) at 18,000 rpm so as to obtain pea pod powder. The obtained powder was subsequently passed through a 60 mesh sieve to obtain a fine powder. The sieved powder was stored in aluminium pouches at 0 °C for further analysis.

Preparation of pea pod powder based cookies

Cookies were manufactured by the procedure mentioned by Nasir et al. (2020) with slight modifications. Cookies were prepared using pea pod powder, barnyard millet flour and wheat flour as principal ingredients. Powdered sugar was replaced with stevia powder to develop low calorie cookies. Butter, stevia powder, milk, baking powder, baking soda, lecithin, vanilla essence and salt were the other ingredients used in the cookie preparation and were procured from a local shop. The detailed composition of the prepared cookies is shown in Table 1 and the quantity of each ingredient was selected as per the results of trials on the basis of sensory evaluation. For baking, the microwave (MC2149BB, LG, South Korea) was preheated at 180 °C for 2 min, and the cookies were baked at 180 °C for 29 min followed by air-drying.

Proximate analysis of pea pod powder

The moisture content, protein, crude fat, ash and dietary fibre content of pea pod powder was determined according to AOAC protocols (AOAC, 2000).

Table 1 Composition of pea pod powder based cookies

Ingredients	Quantity (g)
Pea pod powder	10
Barnyard millet flour	20
Wheat flour	30
Lecithin	0.3
Stevia powder	1.5
Baking powder	1.5
Baking soda	0.5
Vanilla essence	0.3
Butter	25
Milk	10
Salt	0.3

Physical characteristics of pea pod powder

Bulk density

Bulk density was calculated by the technique used by Jan et al. (2017a). Briefly, a 100 ml graduated cylinder was filled with the flour sample. The bottom of the cylinder was then gently tapped several times on a foam-covered lab bench. The volume of the flour mix was measured and the bulk density was expressed in g/ml as shown in Eq. (1).

$$\text{Bulk density}\ \left(g/cm^3\right) = \frac{\text{weight of the flour (g)}}{\text{Volume after tapping}\ \left(cm^2\right)} \tag{1}$$

Aerated bulk density

The aerated bulk density of pea pod powder was measured by the method described by Jan et al. (2017b). Sample was carefully poured into a 100 ml standard graduated cylinder of Vankle's design obtained from the Standard Instrument Corporation in Patiala, India. The sample was initially poured into the cylinder to the 100 ml mark. The graduated cylinder with the sample was then weighed in order to determine the aerated bulk density. The aerated bulk density was calculated using Eq. (2)

$$\rho_l = \frac{W_l}{V_l} \tag{2}$$

where, ρ_l is the aerated bulk density ($g.cm^{-3}$), w_l and v_l are the mass and the volume (cm^3) of pea pod powder in aerated condition, respectively.

Tapped bulk density

After measuring the bulk density for the pea pod powder (PPP), the cylinders filled with the powder, were tapped on a hard wooden surface to determine the materials' settling behaviour under shaking or vibration during transit. The pea pod powder was stabilised and settled after ten taps at a tap height of about 20 mm using tap density tester. PPP was added again to the cylinder in order to get the capacity up to 100 ml (Jan et al. 2017a). The material was weighed again, and the tapped density was determined using Eq. (3).

$$\rho_t = \frac{W_t}{V_t} \tag{3}$$

where, ρ_t is the tapped bulk density (gcm^{-3}), w_t and v_t are the mass and the volume (cm^3) of pea pod powder in tapped condition.

Carr's Index

The compressibility index (CI), commonly referred to as Carr's index or Carr's Compressibility Index, is a measure of a powder's hand compressibility. A compressibility index higher than 25 is seen as a sign of poor flowability and a value less than 15 as a sign of good flowability. The compressibility index (CI) was determined using the aerated and tapped bulk densities (Jan et al. 2015) as:

$$CI = \left[(\rho t - \rho l) / \rho t\right] \times 100 \tag{4}$$

where, ρ and ρt are the aerated and tapped bulk densities (gcm^{-3}), respectively, and CI is the compressibility index (%).

Hausner's ratio

Hausner's ratio (HR) signifies how easily a granular material or a powder flows. A sign of poor flowability is a Hausner ratio larger than 1.25. It is defined as the proportion of tapped to aerated bulk density (Jan et al. 2017a).

$$HR = \frac{\rho_t}{\rho_l} \tag{5}$$

Functional characteristics of pea pod powder

Water absorption index and water solubility index

The water absorption index (WAI) and water solubility index (WSI) was measured by the method proposed by Padma et al. (2022) with minor modifications. Briefly, the PPP was suspended in water and gently swirled for 30 min. The mixture was then centrifuged at 3000 rpm for 15 min. The WAI was expressed as the weight of the wet/hydrated residue produced after the supernatant was drained off (Eq. 6). The drained supernatant was collected and dried in a hot air oven at 103 °C overnight. The weight of the dissolved solids in supernatant was then used to calculate the WSI as shown in Eq. (7).

$$WAI\ (g/g) = \frac{\text{weight of absorption in hydrated residue}}{\text{weight of sample}} \tag{6}$$

$$WSI\ (g/100g) = \frac{\text{weight of dissolved solids in suparnatant} \times 100}{\text{weight of sample}} \tag{7}$$

Swelling power

The swelling power of the PPP was measured by the method given by Jan et al. (2017a) and was calculated as:

$$\text{Swelling power (\%)} = \frac{\text{Wt. of wet residue}}{\text{Wt. of sample (100} - \text{WSI)}} \times 100 \quad (8)$$

Oil absorption capacity

In pre-weighed centrifuge tubes, 0.5 g of pea pod powder was dissolved in 6 ml of mustard oil. After vortexing the sample in oil, the sample was held in a vertical position for 30 min followed by centrifugation for 15 min at 3000 rpm. The oil was then drained off before being weighed again. The increase in weight was calculated as one gram of oil absorbed for every one gram of powder (Jan et al. 2017a).

$$\text{Oil binding capacity (\%)} = \frac{\text{Wt. of residual powder}}{\text{Wt. of sample taken}} \times 100 \quad (9)$$

Colour

The samples' colours were assessed using a Hunter Lab Colorimeter (USA, model number 45/0). After standardisation with a white calibration plate, measurements were collected immediately at three distinct sites. Hunter Lab units L*, a*, and b* were used to express the colour wherein L* stands for lightness, a* for hue on a green (−) to red (+) axis, and b* for hue on a blue (−) to yellow (+) axis.

Structural characterization of pea pod powder

Scanning electron microscopy

A scanning electron microscope (SEM) (VEGA 3, SBH, TESCAN Brno S. R. O., Czech Republic) was used to unravel the structural and morphological characteristics of PPP and its product. An accelerating voltage between 5 and 20 kV was selected, and the PPP and ground cookie sample were adhered to the copper stubs using double-sided tape.

X- ray diffraction

Diffraction pattern analysis of PPP and ground cookie was done by XRD (RigakuMiniflex 600 Rigaku corporation, Japan) equipped with Cu radiation at a wavelength of 1.541 Å. Observations were made at room temperature with a scanning speed of 10°/min and a scan range of 10–90°. The diffraction patterns were analysed using Miniflex Guidance software.

Fourier transform infrared (FTIR) spectroscopy

The FTIR spectra were analyzed for the PPP and cookie by a Fourier transform infrared spectrophotometer (ALPHA Bruker, USA) operating at 25 °C. The powdered samples were blended with KBr and converted into tablets by a mechanical press. Initially, the blank sample was used as part of the calibration of the instrument and then the different spectra were evaluated in the range of 600–4000 cm^{-1}. An average of 38 scans per sample were gathered at a resolution of 4 cm^{-1}.

Results and discussion

Proximate analysis of pea pod powder

The proximate composition of PPP is illustrated in Table 2. The moisture content of PPP was observed to be low (6.3%) and within the prescribed limits (< 14%) for safe storage. The quantity of moisture in a material affects its physical

Table 2 Physical characteristics, Functional characteristics, Proximate analysis and color parameters of the pea pod powder (dry weight)

Parameters	Value
Proximate analysis	
Moisture (%)	6.30 ± 0.13
Ash (%)	5.2 ± 0.1
Crude fat (%)	3.46 ± 0.1
Crude protein (%)	13.27 ± 0.22
Dietary fiber (%)	35.33 ± 0.87
Physical characteristics	
Bulk density (g/ml)	0.47 ± 0.8
Aerated bulk density (g/ml)	0.50 ± 0.2
Tapped density (g/ml)	0.62 ± 0.6
Carr's index	18.33 ± 7.6
Hausner's ratio	1.23 ± 0.11
Functional characteristics	
Water absorption index (g/g)	3.24 ± 0.33
Water solubility index (%)	7.9 ± 0.3
Oil absorption capacity (g/g)	1.25 ± 0.07
Swelling power (%)	4.65 ± 0.39
Color	
L*	60.26 ± 0.84
a*	−4.25 ± 0.15
b*	23.01 ± 0.15

characteristics including weight, density, viscosity, powder storage capacity, microbiological stability, flow characteristics, and dry substance content. The PPP had a low moisture content that fell within the safe storage range, indicating a prolonged shelf life. The measured moisture content was greater than that reported for carrot pomace and orange waste but lower than banana peel (9.8%), potato peel powder (8.9%), orange peel (7.9%), jackfruit peel (6.5%) and citrus peel (7.5%) (Pathak et al. 2017; Jan et al. 2017a). Cookies prepared using the PPP exhibited a moisture content of 7.7% which was 23% higher than control (cookies without PPP). However, it should be noted that the incorporation of PPP will result in more bound water than free and unbound water in the cookie matrix which may restrict microbial growth.

Ash content was also analyzed for the PPP. Generally, an ash content in the range of 5–6% is considered a good source of minerals and micronutrients. The PPP ash content was found to be 5.2% that signifies its appreciable mineral content. The obtained values were higher than banana peel powder (5.0%) and citrus peel powder (4.32%) as determined by Pathak et al. (2017) but lower than potato peel powder which has been reported to be 6.64% (Jan et al. 2017a). The mineral content of PPP contains appreciable amounts of iron, zinc, potassium and magnesium (Nasir et al. 2022). Cookies incorporated with PPP showed 3.2% ash content which was 4.4% higher than control showing slight improvement over traditional cookies in terms of minerals.

Fat is one of the main ingredients that affects the overall texture of cookies from a sensory perspective. Several researchers have highlighted that reducing the fat level or replacing fat with other ingredients significantly affects the textural features of biscuit (Nasir et al. 2020). The fat content of PPP was found to be 3.46%, which is higher than potato peel powder (1.44%) and banana peel powder (1.25%) (Jan et al. 2017a), but less than pear pomace (Bchir et al. 2014). This shows that PPP has potential for utilization in biscuits and cookies over other available peels. Moreover, as a desirable source of fatty acids like linoleic, linolenic, stearic, and palmitic acid, pea pod waste has greater potential for application in the production of functional food products. Increased fat content has been observed to make softer cookies while cookies with less fat have a stronger breaking point (Pareyt et al. 2009). Cookies prepared using PPP showed 4.50% fat content which was 7.3% lower than control. The PPP incorporated cookies may therefore require a slightly higher breaking force than traditional cookies.

Amino acids play a crucial role in maintaining human physiological functions and are an essential component for a healthy diet (Nasir et al. 2022). The value of protein content in PPP was found to be 13.27% which was higher than that observed for banana peel, orange peel and lemon peel (Pathak et al. 2017). Mousa et al. (2021) reported that pea peels showed lower values for the essential amino acids but had high quantities of aspartic and glutamic acid. These amino acids are responsible for boosting the immune system and improving athletic performance indicating the health promoting benefits of PPP. Cookies prepared using PPP showed 8.08% protein content which was comparable to control but the quality of protein was improved considering the presence of additional amino acids such as aspartic and glutamic acid in PPP.

Dietary fibre is made up of indigestible polysaccharides that are present in plants, including gums, cellulose, pectins, hemicelluloses, oligosaccharides, and different lignified compounds. Dietary fibre aids in a number of processes such as in enhancing faecal bulking effectiveness, regulating insulin levels, lowering levels of preprandial cholesterol, and enhancing colonic fermentation in addition to avoiding digestion, hydrolysis and assimilation in the small intestine (Nasir et al. 2022). The amount of dietary fiber in PPP was observed to be 35.33% of which, soluble dietary fiber was 11.04% and insoluble dietary fiber was found to be 24.27% which was almost similar to that observed by Hanan et al. (2020). These observed values of dietary fiber content for PPP were higher than that investigated in orange peel powder and passion fruit peel powder (Dias et al. 2020). Since dietary fibre consumption is linked to health, maintenance and the prevention of several diseases such as colon cancer, obesity, cardiovascular disease, and diabetes, PPP may have positive health implications in humans (Mokhtar et al. 2018). Cookies prepared with PPP showed 38.46% dietary fibre which was 28.64% higher than control.

As per the results, it is evident that PPP is an appreciable source of protein, fat, ash, and dietary fibre and can therefore be included in baked goods and ready-to-eat foods.

Physical characteristics of pea pod powder

Bulk density is a crucial factor in determining a product's need for packaging. (Chandi and Sogi 2007). To optimise various operations, such as powder handling, storage, and the creation of various products as a dependent of particle size and other associated qualities, it is crucial to ascertain the bulk (loose and tap) density of the particles. Bulk density is another significant factor that determines whether a flour is suitable for use in food compositions.

Results of this investigation showed that that pea pod powder has a low bulk density of 0.47 g/ml. In the creation of complementary foods and the preparation of infant food, a flour's low bulk density is a desired property (Nelson-Quartey et al. 2007). The value obtained for bulk density was greater than those reported by Dias et al. (2020) for pineapple peel, orange peel, yellow passion fruit peel and avocado peel but lower than goldenberry (*Physalis peruviana*) waste powder (Mokhtar et al. 2018). Further, PPP's aerated bulk density was found to be 0.50 g/ml. Bulk density (BD) depends on particle size and initial moisture content. Low bulk density is advantageous in the formulation of complementary foods (Sunil et al. 2019). The tapped bulk density of PPP was found to be 0.62 g/ml which was almost similar to that of potato peel powder (Azizi et al. 2020). After tapping, the PPP's density increased as the air that had been trapped in the vacuum spaces was released.

Carr's index is used to measure the compressibility of powder particles; higher the compressibility, lower the flowability. The internal friction is measured using Hausner's ratio. The PPP appears to have a decent degree of flowability based on the Carr's index and Hausner's ratio. Smaller particles have more contact sites with their neighbors which makes it more challenging for them to reorganize and create a dense packing. Large gaps develop in an aerated condition as a result of particles arching which further collapse upon tapping. As a result, the Hausner ratio and Carr's index rose due to the significant disparity between the tapped and aerated densities. Additionally, stronger cohesiveness between particles due to higher interparticle interactions or mechanical interlocking, lowered the flowability by raising the HR and CI (Jan et al. 2015). The CI and HR of PPP was found to be 18.33 and 1.23, respectively that indicates its fair flowability. Easy flowability of the PPP enables its use in baking operations (kneading, mixing etc.). Particles with lower flowability would require more energy-intennsive operations and could be uneconomical.

Functional characteristics of pea pod powder

The water-absorption index (WAI) measures how much water a wet substance can hold when compressed or exposed to external centrifugal gravity stress. It is made up mostly of physically imprisoned water and the sum of hydrodynamic water and bound water (Alfredo et al. 2009). The values of WAI in PPP was determined as 3.24 g/g. This result is similar to the water absorption capacity of goldenberry waste products (Mokhtar et al. 2018). Due to the high concentration of hydrophilic groups that may bind water and the high concentration of soluble fibres that have a high capacity to absorb water, the WAI of PPP is notable. High WAI indicates that the sample tested may become moderately viscous, can form gels and retains freshness which has possible application in baked goods. Moreover, the WAI of the fiber strongly indicates its physiological role in proper functioning of intestines and control of blood sugar level (Fung et al. 2010). However, the WAI of PPP was observed to be less than that of potato peel powder (4.18 g/g) and banana peel powder (3.64 g/g) (Jan et al. 2017a).

In terms of biodegradability, uniformity, and shelf stability, the water solubility index (WSI) is crucial in determining the overall quality of the finished product. WSI ascertains whether the powders' macromolecules have exposed hydroxyl groups that can establish hydrogen bonds with water molecules. The WSI of PPP was found to be 7.9% which was lower than potato peel powder (12%) and banana peel powder (11%) reported by Jan et al. (2017a).

The swelling power (SP) determines the extent of the water absorption by the powders The SP of PPP was found to be 4.65%. Avocado peel had lesser value of SP than PPP whereas SP of pineapple peel, orange peel and yellow passion fruit peel were found to be higher than PPP (Dias et al. 2020). High SP suggests that the investigated materials may become more gel-like, increase in medium viscosity, have satiety effects, and increase faecal bolus, which would reduce the absorption of glucose, fat, and cholesterol.

One essential characteristic of polysaccharides is their ability to absorb oil which is termed as oil absorption capacity (OAC). It is somewhat influenced by the chemical makeup, but it is more closely correlated with the porosity of the fibre structure as compared with the fibre molecule's affinity for oil (Biswas et al. 2011). The OAC of PPP was observed to be 1.25 g/g which is in line with the studies for goldenberry waste powder by Mokhtar et al. (2018). The high OAC of PPP may be attributed to its high protein content. Protein conformation, surface polarity, and inherent characteristics such as amino acid composition could affect the oil binding ability of biological materials (Sunil et al. 2019). It is evident from the results that PPP had appreciable oil binding ability due to which it can facilitate improved binding with plasticizers during various processing steps.

Color

CIE L*, a*, and b* values for PPP were 60.26, −4.25, and 23.01, respectively (Table 2). Positive value for b* and the negative value for a* indicated that the PPP was greenish yellow in color. This characteristic color of PPP may have been caused by the carotenoid and chlorophyll pigment present in it. However, after drying, there was a degradation of chlorophyll resulting in reduced intensity of the greenish-yellow color of PPP. This reduced intensity could have occurred due to the breakdown of sugars in the lignocellulosic matrix of PPP via the Maillard reaction (Phuon et al. 2022). The cookies prepared using the dried PPP showed a L*, a*, b* value of 46.72, 9.82 and 30.43, respectively. This shows that the color of the cookies were slightly darker (lower L* value) with higher browning as observed from a positive value of a* and higher value of b* than PPP. It was interesting to note that the control showed a L*, a* and b* of 50.41, 11.67 and 30.59 which was comparable to the color values of the cookies incorporated with PPP. This shows that PPP had no detrimental effect on the cookie color that could affect its consumer desirability.

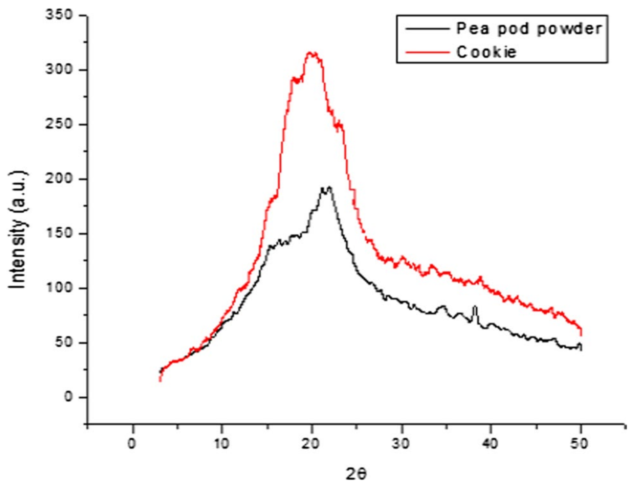

Fig. 1 X Ray Diffraction patterns of pea pod powder and cookie

Structural characterization of pea pod powder and cookie

X ray diffraction

The XRD patterns of the pea pod powder and cookie are shown in Fig. 1. This study examined variations in the crystallinity of cookies using XRD. For assessing the physical attributes of food, crystallinity is a crucial metric. Foods with a broad crystallisation zone have a solid structure and are more resistant to the effects of environmental factors and chemical agents. Crystallinity, meanwhile, regulates the digestibility through influencing the characteristics of foods (Jia et al. 2020). The cookies crystal structure was examined using X-ray diffraction research to determine how pea pod powder and barnyard millet flour affected it. It can be seen from the X-ray diffraction pattern of the pea pod powder that there were obvious peaks at 2θ of 20° and 23°. The diffraction peak for cookie showed the diffraction peaks at 2θ of 20° and 24°. Bangar et al. (2021) reported that barnyard millet shows a A-type crystalline structure at 15°, 17°, 18° and 23.1°. It was evident from the results that there was a shift in the crystallinity peak from 23.1 to 24° indicating a minor expansion in the starch matrix of the cookie. The diffraction peaks indicate that the cookie's crystalline portion was relatively preserved.

Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM) is widely employed in food structure analysis to uncover in-depth a product's internal geometrical structure. The sensory qualities of a product are significantly influenced by structural traits such as cell size, density, and homogeneity.

The Fig. 2a shows the morphological characteristics of PPP. The surface of PPP was found to be rough and porous. SEM images of the interior cross-sectional surface area of cookies has also been shown in Fig. 2b. SEM showed that the starch granules were intact in both the PPP prior to baking and ground cookie after baking. The spherical objects in ground cookie are probably the protein bodies around the starch granules. Butter and gluten both coated the starch granules, and the gluten network was rather homogenous and robust. Coating of protein micelles around layers of fat and carbohyrates was also reported by Verma et al. (2021) for nanoencapsulated curcumin particles. The findings were

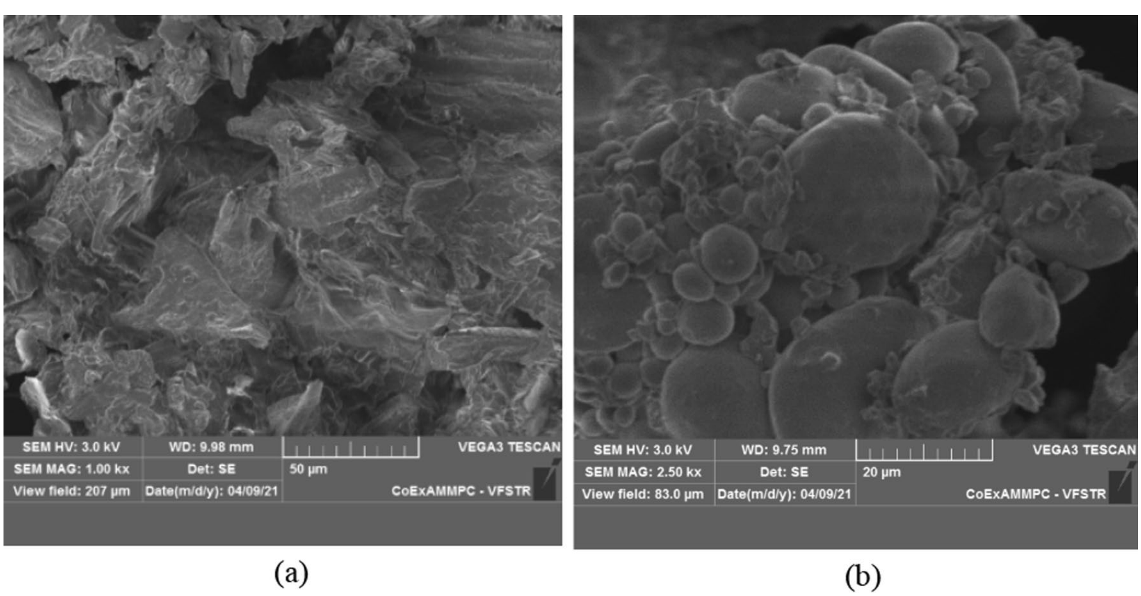

Fig. 2 Scanning electron microscopy images **a** pea pod powder and **b** cookie

similar to Canalis and Ribotta (2018) who studied the morphological characteristics of inulin and oat fibers.

FTIR spectrum analysis

The spectroscopic properties of PPP and cookie were analyzed by FTIR. The FTIR spectra was obtained in order to know the nature of functional groups. The pea pod FTIR spectra revealed several peaks at 3295 cm^{-1}, 2918 cm^{-1}, 1602 cm^{-1}, 1326 cm^{-1}, 1237 cm^{-1}, 1152 cm^{-1}, 1069 cm^{-1}, and 895 cm^{-1} frequency, as shown in Table 3 and Fig. 3a. The spectra of pea pods show a prominent band at 3295 cm^{-1} that is connected to the –OH stretching vibration of either hydrogen bonded hydroxyls or hydroxyl groups in the phenolic (guaiacyl or syringyl monomer unit of lignin) and aliphatic compounds. This association may be brought on by the presence of moisture content in PPP. The (C–H) stretch band of the methyl groups in lignin may be responsible for the vibrational spectra at 2918 cm^{-1}. This is likely because the sample contains a large quantities of hydrocarbons, mostly lipids.

Alpha-keto carbonyl's C=O stretching vibration of cellulose is principally responsible for the peak in the spectra at around 1602 cm^{-1}. The band around 1237 cm^{-1} may be caused by C–O stretching in the acetyl and phenolic groups, whereas the band near 1326 cm^{-1} may be attributed to phenol's syringyl ring breaking C–O stretching. The ground cookie is the baked cookie that is ground using pestle and mortar.

The peaks revealed in case of cookie as shown in Fig. 3b were 3271 cm^{-1} that is similar to pea pod powder, 2917 cm^{-1} that is also similar to pea pod powder (PPP) but transmittance is less. In case of PPP transmittance is 77% but in ground cookie (GC) it decreased to 56%. The other peaks were 2850 cm^{-1} which is extra and was absent in PPP, 1741 cm^{-1} is a slightly different peak but near to a peak which is observed in PPP at band range of 1602 cm^{-1} which is having transmittance of 73% but sharp peak is observed, 1149 cm^{-1} and 1076 cm^{-1} are absent in PPP. Also, peak was observed at 756 cm^{-1} in ground cookie. The band observed at around 1741 cm^{-1} is assigned to stretching vibrations of –C=O groups in carboxylic acid. Peaks observed in ground cookie 1149 cm^{-1} and 1076 cm^{-1} may be assigned to C-O stretch of alcohols and C-O asymmetric stretch of ethers.

Carboxylic acid present in fruit and vegetable peel powders have therapeutic properties. It is useful in treating edema and rheumatic joint problems in addition to ailments including ulcers, jaundice, headache, stomatitis, hemicranias, fever, discomfort in the liver, and wounds in cattle (Nair et al. 2013). It has been reported that glycolic, oxalic, citric and tartaric acids are some of the widely used fruit and vegetable peel-derived carboxylic acids that are used in cosmetics to reduce inflammation and sking ageing (Zakopoulou and Kontochristopoulos 2006). For instance, the carboxylic acids and associated phenlics in carrot, a root vegetable, have been reported to show high antioxidant, antimicrobial and antimutagenic activites (Tlais et al. 2020). The major source of carboxylic acid in pea pod powder is either cellulose or lignin. PPP and

Table 3 FTIR spectrum analysis of pea pod powder and cookie

Position of bands [cm^{-1}]	Origin and kind of vibrations
3295	–OH stretching vibration of either hydroxyl groups in the phenolic (guaiacyl or syringyl monomer unit of lignin) or hydrogen bonded hydroxyls and aliphatic compounds
3253	
3271	
2918	(C–H) stretch band of methyl groups in lignin
2917	
2850	
1741	–C=O stretch vibration of carboxylic acids
1602	C=O stretching vibration of alpha-keto carbonyl for cellulose
1457	$–CH_2$ and $–CH_3$ bend of alkanes
1237	C–O stretching in the acetyl and phenolic groups
1149	
1076	Strong stretching vibrations (C–O) in C–OH group or Strong stretching vibrations (C–C) in the carbohydrate structure, δ (C–H)
1011	
992	
860	anomeric region of carbohydrates or deformation vibrations (C–H) (mainly in the structure of sugar)
756	
704	

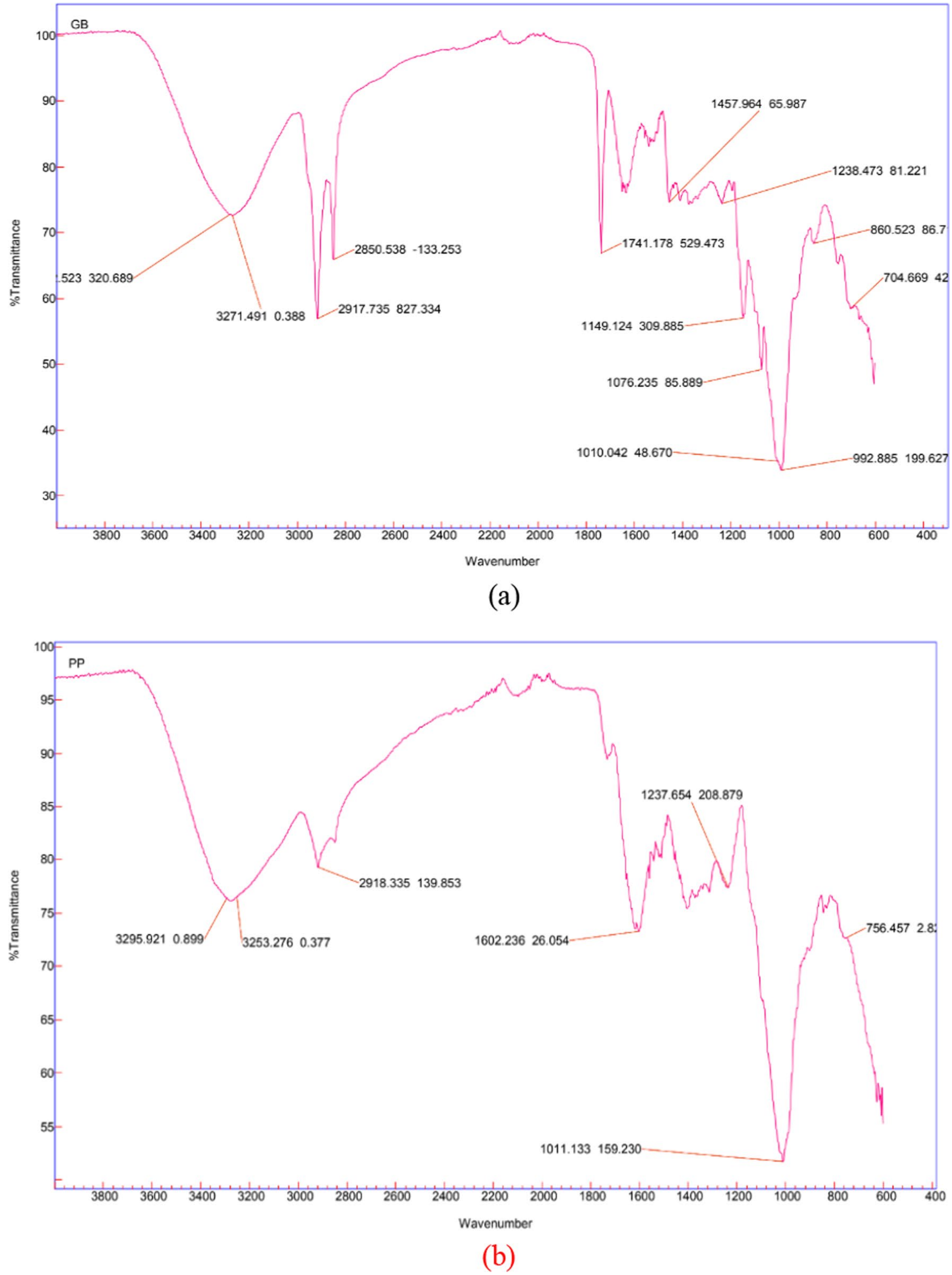

Fig. 3 Fourier transform infrared spectroscopy analysis for **a** pea pod powder and **b** cookie

ground cookie does not reveal any peak between the regions 2220 and 2260 cm^{-1}, which indicates the absence of cyanide groups, validating that PPP and ground cookie do not consists of any toxic materials (Nair et al. 2013).

Conclusion

This work successfully demonstrated the valorization potential of pea pod powder as a potential ingredient for the bakery industry. The proximate analysis of pea pod powder showed appreciable levels of protein, fat, ash, and dietary fibre. Further, the physical characteristics (bulk density, aerated bulk density, tapped density, Hausner's ratio and Carr's index) of pea pod powder revealed its suitability for use in food preparations and exhibited fair flowability. The lower values for water absorption index and water solubility index of PPP, indicated a longer shelf life. PPP also exhibited good oil absorption capacity suggesting its probability in binding with plasticizers as an additive in cereal-based snacks. The colour of PPP was greenish-yellow and its inclusion in cookies was found to be organoleptically appealing. Apart from the appreciable nutritional profile of PPP, the results obtained in this study suggests that PPP exhibited appreciable functional and structural characteristics, which makes it an ideal additive for ready-to-eat products. This research opens up new avenues for possible applications of this ingredient in other food industries.

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Declarations

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