Extraction, characterization, physicochemical and rheological properties of two different varieties of chickpea starch

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Abstract
The variations in physiochemical, rheological, morphological, and thermal properties of extracted starches of two chickpea varieties (PDG-5 and BG-1076) were evaluated. Both the varieties resulted in starch yields 28.2–31.2 g/100 g. Amylose content was 30.2–31.2%. Morphological study by scanning electron microscopy of starches of both the varieties of chickpea revealed the presence of oval, spherical shaped granules with smooth surfaced, with mean granular length of 2 to 30 μm and width of 3 to 10 μm. Rheological properties of extracted starches at selected concentration (1–5%) were evaluated in flow viscometry and dynamic oscillatory mode to assess flow properties in terms of shear stress, shear rate, apparent viscosity, elastic, and viscous modulus. Fourier transform infrared spectroscopy showed the presence of polysaccharides bands. X-ray diffraction patterns showed that extracted starches are mixture of both A- and B-type crystal. Thermal and pasting properties of chickpea starches were determined using differential scanning calorimeter (DSC) and rapid visco analyzer, respectively. Onset (T_o), peak (T_p), end (T_e) temperature, enthalpy of gelatinization (ΔH), peak height index, and gelatinization temperature range were measured by DSC. DSC thermograms revealed that T_o, T_p, and T_e values of chickpeas were ranged from 65.6°C to 66.5°C, 69.6°C to 71.1°C, and 75.6°C to 76.2°C, respectively, whereas the corresponding enthalpy values varied between 14.8 and 15.6 J/g.

The viscosity values at the peak, hold, final, breakdown, and setback viscosity for PDG-5 variety were 2,562, 2,200, 3,646, 852, and 1,456 cP, respectively, and the corresponding values for BG 1076 were 4,848, 3,416, 6,384, 1,452, and 2,978 cP. It was observed that starches from BG-1076 variety with low swelling power had higher solubility and pasting temperature.

Keywords
alkali extraction, chickpea, pasting property, rheology, starch

1 | INTRODUCTION

Pulses are of prime importance for human nutrition due to the presence of high protein content (approximately 20–50%). The protein content of pulses is relatively higher as compared with cereal and other starchy crops and roots. Pulses have been considered as the most imperative component of diet in many parts of the world and are deliberated as the most important plant protein sources for low...
income group. Other than whole grain, pulses nowadays are fractionated into its constituent, that is, starch, protein, and fat. Though incorporation of isolated starch and protein in food is costly due to the additional cost of fractionation but due to its high biological value and bioavailability it is frequently used in food. Among dry legume green peas, dry beans, chickpeas, and lentils are the most common (Singh, Kaur, Sandhu, & Guraya, 2004).

Chickpea (Cicer arietinum L.) is a member of the family fabaceae and is widely grown in tropical, subtropical, and temperate regions (Doddamani et. al., 2014). Chickpea is the second most important pulse crop in the world, chickpea is a cool season pulse crop grown in more than 50 countries of the world. In terms of production, among all the pulse crops chickpea is in third highest position in the world, and India is the highest producer of chickpea. The chickpea production was 7.06 million tons in the world in 2015–2016, and India shares major contribution of chickpea production about 60–70% of world’s total production (Doddamani et. al. 2014, Singh & Ocampo, 1997).

There are three main varieties of chickpea available: desi, bombay, and kabuli. Desi (darker, smaller with rough skin) variety is mainly grown in India, Ethiopia, Mexico, and Iran; bombay (darker, larger than desi in size) is basically an Indian variety and kabuli variety (lighter and bigger size) grown in Southeast Asia, Mediterranean, and South America. Chickpea imparts various health benefits like reduce cholesterol level, protect skin, boost immune system, regulate blood sugar, and build muscles. Chickpea has potential to be a high cholesterol reducing agent. Chickpea seeds are a good source of protein, carbohydrate, fiber, vitamins, and minerals (P, Mg, Ca, Fe, K) and vitamins like niacin, thiamin, riboflavin, B vitamins, and β-carotene (Chavan, Kadam, & Salunkhe, 1989; Sathe, Deshpande, Salunkhe, & Rackis, 1984). Health benefits of chickpea include its use as an aphrodisiac and as an agent to militate against cholera, diarrhea, snakebite, and sunstroke (Singh & Ocampo, 1997). Chickpea are important source of selenium, minerals that support liver enzyme function and detoxify cancer causing compounds from the body. Chickpea is also a great source of folate, which helps in formation of cancer preventing cells in the body. In chickpea seeds antinutritional factors are present such as α-amylase inhibitors, oligosaccharides, phytic acid, saponins, phenolic compounds, and tannins, respectively. Shabaani, Yarmand, Kiani, and Emam-Djomeh (2018) studied gluten-free bread using chickpea protein isolate in combination with transglutaminase. Fernanda, Etienne, and Vanessa (2019) studied the effect of chickpea starch in gluten-free bread along with potato starch powder but they found that blends of chickpea Flour: potato starch (75:25) gluten-free bread with good physical and sensory properties, as well as an enhanced nutritional composition.

After cellulose, starch is the second most plentiful organic compound in the earth. Starch is also the most essential polysaccharide of human diet. Starches from different sources vary its composition in qualitative and quantitative makeup as well as in some of their physicochemical properties. Apart from its dietetic uses in the food industry, starches also have significant nonfood industrial applications (Ashogbon, 2018).

Utilization of starch in food matrices are chiefly controlled by its ease of aqueous solubilization, swelling, gel formation, gelation temperature, flow behavior, viscosity, pasting properties, digestibility, and thermal property. Whereas starch is the most essential constituent of chickpea, comparatively very few methodical studies have been reported. Therefore, our specific objectives were to isolate the starch from chickpea varieties PDG-5 and BG-1076 and its characterization for its appropriate food and nonfood applications. Physiochemical, rheological, X-ray diffraction, Fourier transformation infrared (molecular properties), scanning electron microscopy (morphological properties), and differential scanning calorimeter (DSC; thermal properties) were determined.

2 | MATERIALS AND METHODS

2.1 | Materials

Two different varieties of chickpea (BG-1076 and PDG-5) were procured from Punjab Agriculture University, Ludhiana, Punjab, India. The entire reagent used was of analytical grade and obtained from Loba Chemie laboratory reagents and fine chemicals, Mumbai, India.

2.2 | Methods

Both varieties of chickpea seeds were dried in a tray dryer at 60°C for 16–17 hr to reduce moisture content. Dried sample was then grinded into fine powder for further processing.

2.3 | Proximate analysis of chickpea

Dried powder sample was taken for proximate analysis of chickpea by applying standardized Association of Official Analytical Chemists method (Association of Official Analytical Chemists [AOAC], 2011). Moisture, ash, protein (N × 6.25), fat, and crude fiber were estimated using Association of Official Analytical Chemists method, and carbohydrate was determined by difference. Experiment was done in triplicates.

2.4 | Extraction of starch from chickpea seeds

Two different cultivars of chickpea seeds (BG-1076 and PDG-5) were purchased from the Panjab Agriculture University, Ludhiana, Panjab, India. Starch was extracted from the chickpea seeds using minor modification of alkaline soaking method (Gunaratne et al., 2018). A total of 100-g chickpea seeds were soaked in a 500 ml of 0.05% sodium hydroxide solution at 4°C for 15 hr in a refrigerator to break down the starch–protein matrix. Soaked seeds were hulled and blended with sodium hydroxide solution for 4 min using the laboratory blender. The resulting mixture was screened through 100 mesh sieve or nylon cloth (100 mesh), and supernatant was discarded after 16 hr of precipitation at 4°C. Neutralization of starch precipitates was done with 0.01%
Hydro Chloric Acid (HCL) followed by centrifugation at 3,000 g for 30 min at room temperature. The supernatant was removed and further purified with repeated suspension in distilled water and centrifugation for 3–4 times. The extracted starch was washed 3–4 times with distilled water and purified starch was dried at 40 °C for 12 hr and stored at cool and dark place for further use. Extraction was done in triplicates.

2.5 | Physiochemical properties of chickpea starch

2.5.1 | Amylose content

Amylose content of extracted starch was determined using the method described by Singh, Kaur, et al. (2004). The absorbance was read at 620 nm using ultraviolet-visible spectrophotometer (UVPC 2410, Simudzu, Japan) and calculated using Equation (1). Experiment was done in triplicates.

\[ \text{Amylose content (\%)} = 3.06 \times \text{absorbance} \times 20 \]  

2.5.2 | Swelling power and solubility

Swelling power and solubility of starch was measured according to Singh, Kaur, et al. (2004) using 1% aqueous solution of starch. Experiment was done in triplicates.

2.5.3 | Water binding capacity

Water binding capacity (WBC) of the starches from both chickpea varieties was determined in triplicate using the method described by Singh, Kaur, et al. (2004) with minor modification. A suspension of 4 g of starch (dry weight) in 60-ml distilled water was agitated for 1 hr and centrifuged (3200 x g) for 10 min. The free water was removed from wet starch, drained for 15 min, and wet starch was weighed. Experiment was done in triplicates.

2.5.4 | Turbidity

Turbidity of starches from both the chickpea varieties was measured in triplicate, as described by Singh and Kaur (2017) by measuring absorbance at 640 nm against water in a spectrophotometer (UVPC 2410, Simudzu, Japan).

2.5.5 | Thermal properties

Gelatinization parameters of starch were measured using DSC equipped with thermal analysis data software (Fox Pro Netzsch, Germany) and was analyzed according to Ghoshal and Mehta (2019) with minor modification. A total of 10 mg of sample was taken in the aluminum pan, and 20-μl distilled water was added, sealed hermetically. The scanning temperature range was 10–90 °C, and heating rate was 2 °C/min. An empty pan was used as reference, and gelatinization, onset temperature, peak temperature, end temperature, enthalpy, and specific heat were determined from the thermal properties results. Experiment was done in triplicates.

2.5.6 | Pasting properties

Pasting properties of starch was measured using a rapid visco analyzer (RVA, Pertain Instrument, Australia) according to the method of Gunaratne et al. (2018) with minor modifications. A total of 3 g starch (10% moisture basis) was mixed with distilled water (25 g) in the RVA canister to obtain a total constant sample weight of 28 g (10.7% starch concentration). The slurry was then manually homogenized using the plastic paddle to avoid lump formation before the RVA run. A programmed heating and cooling cycle was set for 24 min, where it was first held at 50 °C for 1 min, heated to 95 °C in 9 min, hold at 95 °C for 2 min, cooled to 50 °C within 9 min, and held at 50 °C for 1 min. Heating and cooling rate was 5 °C/min. All measurements were done in triplicate. Pasting parameters such as pasting temperature, peak viscosity, hot paste viscosity, and cold paste viscosity were directly obtained from the instrumental software. The breakdown viscosity and setback viscosity were calculated by the difference of pasting temperature, peak viscosity, hot paste viscosity, and cold paste viscosity. Experiment was done in triplicates.

2.5.7 | Rheological measurement of extracted starch

Rheological characterization of PDG-5 and BG-1076 was done on a dynamic rheometer (MCR 102, Anton paar, Austria) equipped with plate–plate geometry (PP50), with a plate gap of 1 mm. The sample temperature was controlled by a Peltier system and monitored by platinum resistance thermometer sensors (accuracy of ±0.1 °C). The samples for rheological measurements were prepared by mixing extracted starch with distilled water at five different concentration of starch (1%, 2%, 3%, 4%, and 5% w/v) selecting on the basis of some prior trial and mixed for 20 min with continuous stirring. These starch solutions were then run in flow viscometry mode in the range of 0–100 s⁻¹ shear rate followed by oscillation mode of rheological measurements to study the properties of starch whether shear thickening or shear thinning nature of starch. The measuring gap between the plates was 1 mm during all the measurements. Amplitude sweep in the range 0.01–100% of all chickpea starch varieties were carried out at room temperature to determine the linear viscoelastic region that is further used in frequency sweep and temperature sweep experiments. All the dynamic rheological measurements of amplitude sweep were done in triplicate, and values were used for model fitting and to check adequacy of fitting of experimental data and calculation of model coefficients. G’ is elastic or storage modulus, and G” is viscous or loss
modulus. Frequency dependency of $G'$ and $G''$ was determined by a frequency sweep from 0.1 to 10 Hz frequency and at 0.1% strain value obtained from the amplitude sweep test. Temperature sweep was also done to determine the gelatinization temperature and to check the thermal stability of the sample. The temperature was enhanced from 10 to 90°C at a heating rate of 2°C/min, constant frequency of 1 Hz at 0.1% strain, and $G'$ and $G''$ were determined. The rheological measurements were conducted in triplicate on different days and rheological parameters elastic modulus $G'$ and viscous modulus $G''$, complex viscosity $\eta^*$ were obtained directly from the software attached with the rheometer (MCR 102, Anton paar, Austria) and were analyzed by rheoplus software (Ghoshal, Shivhare, & Banerjee, 2017). Experiment was done in triplicates.

### 2.5.8 Power law modeling

Polymeric solution and molten polymers are characterized by the complex viscoelastic properties. This phenomenon is determined by power law equation.

$$
\tau = K \gamma^n, 
$$

where $\gamma$ is shear rate, $\tau$ is shear stress, $K$ is consistency index, and $n$ is power law exponent (flow behavior index). If $n < 1.0$ corresponds to shear thinning behavior or pseudoplastic behavior, $n > 1.0$ corresponds to shear thickening (Ghoshal & Mehta, 2019).

### 2.6 Fourier transform infrared spectroscopy

The infrared spectra were recorded at room temperature ($28 \pm 2°C$) using a Fourier transform infrared spectroscopy (FTIR) spectrophotometer (Tensor–27 model, Bruker Germany) in the range of 400–4,000 cm$^{-1}$ by accumulating 16 scans of 4 cm$^{-1}$ resolution. About a pinch of powder chickpea starch was placed on ATR for measurement. After that, peak intensity of each samples were measured, and these entire spectra acquisition procedure took 1 min per sample (Ghoshal et al., 2017; Ghoshal & Mehta, 2019).

#### 2.6.1 X-ray diffraction

X-ray diffraction (XRD) of chickpea starch were performed using (X'pert PANalytical) equipped with Cu Kα1 ($\lambda = 1.5406$ Å). The instrument was equipped with graphite monochromator and operated at 40 kV and 30 mA.

The X-rays get scattered from a crystalline solid interfere constructively and produce a diffracted beam of light. $2\theta$ is the angle of scanning for a sample, and its range is different for different samples, and for chickpea starch sample, it was scanned from 10 to 80° ($2\theta$). The $d$ spacing between diffraction planes is calculated using Bragg’s law as

$$
d\lambda = 2dsin\theta, 
$$

where $d$ = inter planar spacing, $\theta$ = diffraction angle, $\lambda$ = wavelength, and $n = 0, 1, 2, 3$ etc. (Ghoshal et al., 2017; Ghoshal & Mehta, 2019).

### 2.6.2 Scanning electron microscope

Scanning electron microscope (SEM) analysis of starch was performed using scanning electron microscope (S-3400N, Hitachi, Japan). Each sample was coated with gold in a sputter coater before scanning. Gold coated samples were visualized and photographed by the SEM machine at an accelerated voltage of 20 kV and magnification in the range of 500–5,000X (Ghoshal et al., 2017; Ghoshal & Mehta, 2019).

#### 2.6.3 Statistical analysis

The data reported in the table were the average of triplicate observation and were analyzed by one-way analysis of variance using Microsoft Excel. Statistical significance was determined taking 95% confidence level and $p < .05$.

### 3 RESULTS AND DISCUSSION

The yield of both varieties of chickpea were in the range of 28.4–30.1 g/100 g for PDG-5 and 29.0–31.2 g/100 g for BG-1076 close to the result reported by Miao, Zhang, & Jiang, 2009. Result of proximate analysis of chickpea and extracted starch are shown in Table 1. Moisture content, ash, and protein of PDG-5 and BG-1076 are in the range varied from 10.4 to 10.7%, 0.05% to 0.06%, and 0.72% to 0.75%, respectively. The ash and protein content of extracted chickpea starch are low, showing its high purity. Ahmed, Thomas, and Arfat (2019) studied the effect of particle size of quinoa starch on proximate analysis and they found that starch, protein, fat, dietary fiber, and moisture loss increased with decreasing particle size.

Amylose content for PDG-5 and BG-1076 are 30.2% and 31.3%, respectively. BG-1076 had higher amylose content than that of PDG-5. Earlier report exhibits the range of chickpea starches was in between 20.7 to 35.5%. Swelling power and solubility of extracted starches are 11.92%, 13.47% and 12.11%, 13.53% for PDG-5 and BG-1076 varieties, similar as reported by Singh et al. (2004). Swelling power of starches was found to be lower might be due to the presence of large number of crystallites formed in association with amylopectin chains also increase stability of starch granules (Tester & Morrison, 1990). BG-1076 has slightly higher swelling power and solubility than PDG-5, and it is directly proportional to amylose content. According to Schoch and Maywald (1968), chickpea has limited swelling power, solubilization, and stability against mechanical shearing due to the presence of large number of long chain amylopectin crystals. Turbidity value was determined at 640 nm in ultraviolet-vis-spectrophotometer, and the absorbance values were 2.367 and 2.432 for...
PDG-5 and BG-1076, respectively. Perera and Hoover (1999) observed increased turbidity during storage of chickpea starch. According to them, leaching of amylose and amyllopectin chain in functional zone occurs consequently and light scattering is enhanced due to the presence of phosphate monoester derivative viscosity and paste clarity improved in chickpea starch gel. The WBC of PDG-5 and BG-1076 were 87.91% and 89.65%, respectively. It can be evident from FTIR result that large proportion of hydroxyl group responsible for making hydrogen bond and covalent bond between starch chains results lower WBC of starch (Singh, Sandhu, et al., 2004).

### 3.1 Pasting property

The pasting properties of both PDG-5 and BG-1076 starch cultivars have been determined by using rapid visco analyzer. Pasting temperature of PDG-5 and BG-1076 were found at 81°C and 76.5°C, respectively. Srivastava, Harse, Gharia, and Mudia (1970) reported that chickpea starches have a high birefringence end point of temperature in the range of 71 to 74°C. The difference in gelatinization temperature may be ascribed to the difference in amylose content, size, form, and distribution of starch granules and to the internal arrangement of starch fractions within the granules. This high value of pasting temperature for chickpea starch showed that both the varieties of chickpea starch are more resistance to swelling and rupture. Miao et al. (2009) reported the similar kind of pasting temperature for kabuli and desi chickpea starch of 73.4°C and 70.7°C, respectively.

The values of viscosities have also been determined for PDG-5 and BG-1076 chickpea starch. The viscosities of starch are also an important factor to study the pasting stability of starch. The value of peak, hold, final, breakdown, and setback viscosity for both varieties of chickpea are 2,562cp, 2,200cp, 3,646cp, 852cp, and 1,456 cp for PDG-5 and 4,848cp, 3,416cp, 6,384cp, 1,452cp, and 2,978 cp for BG-1076, respectively, shown in Figure 1. PDG-5 variety has lower viscosities as compared with BG-1076 variety and has low swelling power; this may be due to the difference in size and shape of starch granules. Singh, Sandhu, et al. (2004) reported the similar observation. Pasting temperature showed significant negative correlation with swelling power, peak viscosity, hold, and setback viscosities, but it showed positive correlation with solubility. Both the variety showed to exhibit type C (restricted swelling) viscosity pattern. PDG-5 variety showed the highest resistant to swelling and rupture. The increase in viscosity with increase in temperature may be attributed to the removal of water from the exudates amylose by the granules as they swell. Both the sample showed increase in viscosity until the end of cooling time that might be due to aggregation of the amylose molecules. Changes in viscosity during the breakdown indicate the paste stability and changes accurately during setback, it might showed the consistency of gel and viscosity of both type of starch increases during cooling time that may have occurred due to aggregation of amylose molecules. Ahmed et al. (2019) explained pasting properties have a significant influence on the composition of starch and amylose content; they found lower pasting parameters due to lower amylose content in quinoa starch.

### 3.2 Thermal analysis of chickpea starch

Thermal properties of chickpea starch were measured using DSC (Fox Pro Netzsch, Germany) equipped with a Proteus software for data analysis. The scanning temperature range was 10–90°C, and

| Chickpea seed | Chickpea starch |
|---------------|----------------|
| Properties (%) | PDG-5 chickpea | BG-1076 chickpea |
| Carbohydrate | 62.6 ± 0.5 | 63.2 ± 0.4 |
| Crude fiber | 10.3 ± 0.4 | 10.8 ± 0.5 |
| Protein | 20.6 ± 0.5 | 19.8 ± 0.2 |
| Ash | 3.2 ± 0.3, | 3.1 ± 0.3 |
| Fat | 3.3 ± 0.3 | 3.1 ± 0.3 |
| Yield | 28.4 ± 30.1 | 29.0 ± 31.2 |
| Moisture | 10.7 ± 0.4 | 10.4 ± 0.3 |
| Ash | 0.06 ± 0.01 | 0.05 ± 0.02 |
| Protein | 0.75 ± 0.03 | 0.72 ± 0.04 |
| Amylose | 30.2 ± 0.4 | 31.3 ± 0.03 |
| Swelling power | 11.92 ± 0.5 | 12.11 ± 0.7 |
| Solubility | 13.47 ± 0.4 | 13.53 ± 0.4 |
| Water binding capacity | 87.91 ± 0.3 | 89.91 ± 0.1 |

**FIGURE 1** Pasting curve of PDG-5 and BG-1076 extracted starch
heating rate was 2°C/min. Gelatinization, onset temperature \( T_o \), peak temperature \( T_p \), and temperature \( T_c \), enthalpy \( \Delta H \), and specific heat were determined from the thermal properties. Correlation between gelatinization temperatures and amyllopectin concentration can be clearly predicted from pasting properties and DSC results with respect to gelatinization endotherm (Table 2). A difference in the transition temperature occurs due to variation in the degree of crystallinity (Bashir & Aggarwal, 2016; Ghoshal et al., 2017). Significant difference \( p \leq 0.05 \) was observed in \( T_o \), \( T_p \), \( T_c \), and \( \Delta H \) values. Our results are matching with Singh, Sandhu, et al. (2004). Here, PDG-5 variety showed higher values of \( T_o \), \( T_p \), \( T_c \), and \( \Delta H \) than BG-1076 variety. Hoover and Ratnayake (2002) postulated that \( \Delta H_{gel} \) replicates the overall crystallinity (degree and feature) of amyllopectin, and it varies for chickpea starches in the range 9.7–12.4 J/g. Our values are little higher than reported. This higher \( \Delta H_{gel} \) value might be due to close association of amyllopectin branches with adjacent native granules and higher energy needed to break the intermolecular bond in starch molecules for gelatinization to be occurred as gelatinization depends on amylase/amyllopectin ratio and crystalline to amorphous ratio.

3.3 | Rheological property of chickpea starch

The flow behavior of extracted starch PDG-5 at different concentrations (1%, 2%, 3%, 4%, and 5% w/v) was shown in Figure 2, it showed pseudoplastic behavior of extracted starch PDG-5, when shear rate was increased, the viscosity of extracted starch show a significant decrease for all the concentration. This study shows that pseudoplastic behavior has been observed for BG-1076 extracted starch at (1%, 2%, 3%, 4%, and 5% w/v) concentration at room temperature. Figure 2a,b represents the combined flow curves of PDG-5 and BG-1076 at (1%, 2%, 3%, 4%, and 5% w/v) concentration of extracted starch in distilled water. The reaction kinetics of food system usually follows isothermal heating. The rate of heating of food material depends on the state/consistency, size, thermal conductivity, viscosity, and moisture content. The thermal behavior of starch is complex compared with other destruction kinetics because of the several physicochemical changes that occur during heating, may involve gelatinization, glass transition, crystallization, change of crystal structure, volume expansion, molecular degradation, and water movement.

At all concentrations of starch such as 1%, 2%, 3%, 4%, and 5% w/v, the value of viscosity increases with increase in concentration, and the viscosity decreases with increase in shear rate at all concentration for both the varieties.

### Table 2

| Cultivar | \( T_o \) (°C) | \( T_p \) (°C) | \( T_c \) (°C) | GI = \( \Delta T \) = \( T_c \) (°C) – \( T_o \) (°C) | \( \Delta H \) (J/g) |
|----------|----------------|----------------|----------------|---------------------------------|-----------------|
| PDG-5    | 66.5 ± 0.3 a   | 71.1 ± 0.8 c   | 76.2 ± 0.6 e   | 9.7                             | 15.6 ± 0.2 g    |
| BG-1076  | 65.6 ± 0.6 b   | 69.6 ± 9.4 d   | 75.6 ± 0.4 f   | 10.0                            | 14.8 ± 0.6 h    |

Note. Different alphabet indicates significant difference in the same column. GI = gelatinization interval, \( T_o \) = Initial, \( T_p \) = peak, \( T_c \) = concluding, and \( \Delta H \) = enthalpy.

### Figure 2

Comparisons of flow curve of 1%, 2%, 3%, 4%, and 5% of (a) PDG-5 and (b) BG 1076
the varieties. Table 3 represents that the value of n and \( R^2 \) are less than 1, showed non-Newtonian pseudoplastic behavior at all concentration. Using the coefficient K and n, the shear stress values were recalculated, and it was found that the values are almost similar and described the adequate fitting of power law model in flow behavior of extracted chickpea starches.

### 3.5 Frequency sweep

Frequency sweep test was done to calculate the gel structure at linear viscoelastic region. As polysaccharides are viscoelastic material, they exhibit solid and liquid characteristics simultaneously, and moduli \( G' \) (storage) and \( G'' \) (loss) refers to elastic and viscous character of a given sample. Frequency sweep were analyzed over a range of 0.1 to 10 Hz at various starch concentration. The \( G' \) was higher than \( G'' \) in the entire range of 0.1 to 10 Hz frequency in each graph. These patterns are evidence of weak gel like behavior of these heterogeneous systems (Ahmed, Ramaswamy, Ayad, & Alli, 2008). Most of the starch gels are dependent on the frequency. It can be evidenced that at all concentration of starch an increase in \( G' \) was observed with increase in frequency as the concentration of starch increases. There is more increase in the \( G' \) with increase in frequency than \( G'' \). If there is small difference between storage modulus and loss modulus, it shows viscoelastic-like weak gel structure. If there is a big difference between storage and loss modulus, it shows strong gel structure. Similar results were reported by Ghoshal et al. (2017) for wheat dough. Gel strength increases with increase in starch concentration; at higher concentration, more difference between \( G' \) and \( G'' \) was observed.

The frequency sweep of PDG-5 (Figure 3a) starch indicates an increase in the value of both \( G' \) and \( G'' \) with increasing frequency from 0.1 to 10 Hz. In all the graphs, the value of \( G' \) is greater than \( G'' \). This indicates that storage modulus is prevailing over loss modulus. Both \( G' \) and \( G'' \) increased with increase in frequency (Singh, Sandhu, et al., 2004). The difference between \( G' \) and \( G'' \) indicates the gel structure. The gel strength increases with increase in sample concentration; the similar results were obtained by Singthong, Cui, Ningsanond, and Goff (2004). Singh and Kaur (2017) reported earlier similar result that \( G' \) and \( G'' \) are frequency dependent.

Figure 3b represents the frequency sweep curve for 1%, 2%, 3%, 4%, and 5% w/v of BG-1076 chickpea starch. At all concentrations (1%, 2%, 3%, 4%, and 5% w/v) the value of \( G' \) and \( G'' \) increased with increase in frequency as well as \( G' \) and \( G'' \) increase with concentration. At all the concentration the value of \( G' \) is higher than \( G'' \). Both \( G' \) and \( G'' \) increased slowly and steadily from 0.1 to 10 Hz except 1% concentration after 10 Hz frequency; the \( G' \) and \( G'' \) both increased sharply. This is very prominent in PDG-5 variety. Ahmed et al. (2008) explained that abrupt increase of \( G' \) might be due to the formation of 3D network structure developed by leached out amylose and reinforced by strong interaction among the swollen starch particles. Until 10 Hz, no crossover was observed. Earlier study on different oat cultivars showed that the value of \( G' \) and \( G'' \) increased with increase in frequency and the values of \( G' \) were much greater than \( G'' \) at all frequency values showing the strong elastic behavior of starch sample (Singh & Kaur, 2017). Liu et al. (2018) reported for wheat dough; they explained that the value of \( G' \) and \( G'' \) increased with increase in frequency. Whereas complex viscosity, \( \eta^* \) values gradually decreased with increasing frequency values from 0.1 to 10 Hz (not shown) indicating frequency dependency of starches. Ahmed et al. (2019) reported with increasing frequency, \( \eta^* \) value decreases, but during heating after gelatinization, \( \eta^* \) values increased with increasing frequency that further decreases with frequency increase due to breakdown of starch structure.

### 3.6 Temperature sweep

Temperature sweep was done to determine gelatinization and to check the thermal stability of both the varieties of starch. For temperature sweep, test temperature was raised from 10°C to 90°C using heating process at different concentration 1%, 2%, 3%, 4%, and 5% w/v with heating rate of 2°C/min. Significant increase in \( G' \) might be a formation of 3D network of the swollen granules (Singh, Sandhu, et al., 2004).

Figure 4a represents the temperature sweep curve of extracted chickpea starch PDG-5 variety. At all the concentration of PDG-5 chickpea starch \( G' \) and \( G'' \), both increased with increase in temperature. Initially 10–50°C values of \( G' \) and \( G'' \) was constant or very slowly increased, might be due to presence of amylose enriched sol-stage. Above 50°C, the \( G' \) value of starch sharply increased, might be due to sol-gel conversion of starch, up to a certain temperature to attain maximum peak and then values started to drop with further heating at all concentration for both the varieties. The reason behind initial increase in \( G' \) can pertain to degree of granules swellings to the full available volume of the system and due to intergranules contract

### Table 3 Power law modeling for flow curves of PDG-5 and BG-1076 chickpea starch

| Sample Concentration | PDG-5 \( n \) | PDG-5 K | PDG-5 \( R^2 \) | BG-1076 \( n \) | BG-1076 K | BG-1076 \( R^2 \) |
|----------------------|-------------|---------|----------------|----------------|-----------|----------------|
| 1%                   | 0.084       | 0.271209| 0.937          | 0.0158         | 0.60672   | 0.946          |
| 2%                   | 0.124       | 0.249036| 0.946          | 0.019          | 0.56278   | 0.954          |
| 3%                   | 0.155       | 0.221334| 0.956          | 0.24           | 0.50778   | 0.963          |
| 4%                   | 0.22        | 0.178114| 0.967          | 0.043          | 0.26246   | 0.972          |
| 5%                   | 0.24        | 0.160585| 0.989          | 0.084          | 0.40574   | 0.983          |
and then formation of 3D network structure. The result shows that if temperature increased further then \( G' \) and \( G'' \) started decreasing. Similar result reported by Gupta, Bawa, and Semwal (2009). In PDG-5 variety, peak temperature is little higher than BG-1076 variety, and it is matching with DSC and pasting results. In both the varieties at lower concentration of starch, the peak value was little lower than at higher concentration, and peak area was also higher at higher concentration than at lower concentration. In both the varieties of chickpea starch, amylose content is higher than other cereal flour, and therefore, hard gel formation occurs and credited to higher modulus value \( G' \) and \( G'' \). Heating beyond peak temperature cause decrease of \( G' \) and \( G'' \) value that might be due to destruction of gel structure and eventually melting of crystalline region remaining in the swollen particles that soften the particles. According to Ahmed et al. (2019), the 3D network disintegrates due to the failure of interaction between particles and network.

### 3.7 | X-rays diffraction study

X-rays diffraction provides detailed information of the crystal structures, grain size, orientations, phases, and chemical composition of materials. The XRD pattern of both chickpea starch PDG-5 and BG-1076 (Figure 5a,A,B) shows sharp peak at scattering angle \( 2\theta \) of 6.5\(^{\circ}\), 15\(^{\circ}\), 18\(^{\circ}\), and 23\(^{\circ}\) that showed presence of crystalline structure of starch for both varieties of chickpea. Peak values exhibit crystalline amylose and amylpectin component of starch. X-ray diffractogram (Figure 5a,A,B) indicates a mixture of A- and B-type crystal (Barichello, Yada, Coffin, & Stanley, 1990; Kaur & Singh, 2016; Kim, Lee, Baik, Joo, & Yoo, 2007; Ratnayake, Hoover, Shahidi, Perera, & Jane, 2001; Ross-Murphy & Shatwell, 1993). PDG-5 starch showed higher intensities than BG-1076 starch; this might be due to difference in amylpectin content. Amylose content is higher in BG-1076 chickpea starch. Similar result was reported earlier by Miao et al. (2009). Hoover, Hughes, Chung, and Liu (2010) exhibited that the relative crystallinity depends on the ratio of total area to amorphous area of X-ray diffractogram; therefore when amorphous area decreases, an increase in relative crystallinity occurs. Crystallite size and number of crystallite are the two factors that control crystallinity difference in legumes starches and are influenced by crystalline array structure, moisture content, and polymeric composition of starch.

### 3.8 | Morphological study (SEM)

The morphological study of both varieties of chickpea starch are shown in SEM micrograph (Figure 5b,A,B) that represent the presence of different size and shape of starch granules. Granules surface of starch was smooth, and no crevices or cracks on the surfaces of the PDG-5 and BG-1076 were observed. Both varieties of chickpea starches showed presence of large oval to small spherical shape granules of 2–30 \( \mu \)m in length with average diameter of 3–10 \( \mu \)m. Variation of size and shape is more prominent in BG 1076, whereas PDG-5 has less variation in size and shape. The result of SEM revealed that the PDG-5 and BG-1076 starch had the almost same smooth surface; no cracks were observed. Hoover and Ratnayake (2002) studied two types of chickpea cultivar and found mean granular length and width in the range of 22–24 \( \mu \)m and 18.5–18.8 \( \mu \)m, respectively. Singh et al. (2004) reported chickpea starch was oval to small spherical in shape, but Miao et al. (2009) reported contradictory results (Singh, Sandhu, et al., 2004; Kim et al., 2007).

### 3.9 | FTIR study

FTIR spectrum of chickpea PDG-5 starch (Figure 5c,A) shows peaks at 3,294.9, 2,932.7, 1,645.2, 1,418.7, 1,357.6, 1,244, 1,149.6, 1,076, 931.1, 861.5, and 765 cm\(^{-1}\), and BG1076 (Figure 5c,B) shows peak at 3,435.0, 2,935.1, 1,640.8, 1,417.2, 1,361.7, 1,205.8, 1,148.0, 1,077.1, 930.0, 861.3, and 765.2 cm\(^{-1}\). It indicates the various functional groups. The wavelength range of 950 to 1,200 cm\(^{-1}\) is considered as a fingerprint region for carbohydrates, and in Figure 5c,A,B,
numerous small peaks are present that indicates presence of various polysaccharides. The band ranged between 3,435 to 3,294.9 cm$^{-1}$ has been attributed to stretching of surface hydroxyl (O─H) group and hydrogen bonding of O─H stretching vibration and a moist material characteristics, chemisorbed water and indicates the presence of alcohol and phenols (Akhtar et al., 2018). We can correlate with shear thinning behavior and pseudoplastic behavior of chickpea starch solution. Also in variety BG1076, peak height is smaller than PDG-5 in Figure 5c, and it has low swelling power but higher solubility and pasting temperature eventually higher viscosity than PDG-5 variety. The range 2,932.7–2,935.1 cm$^{-1}$ has been attributed to ─CH$_2$ stretching the peak observed at 1,640.8 to 1,645.2 cm$^{-1}$ is due to bending of water molecules (H─O─H) and at 1,417.2–1,418.7 cm$^{-1}$ is due to ─CH$_2$ bending and C─O─O stretching of carboxyl group (Shabaani et al., 2018; Dankar, Haddarah, Omar, Pujolà, & Sepulcre, 2018). The peak range between 1,357.6 and 1,361.7 cm$^{-1}$ is observed due to C─H (asymmetric) bending of CH$_3$. Peak at 1,244 cm$^{-1}$ is indicating CH$_2$OH (side chain) related mode. FTIR peak at 1,149.6 cm$^{-1}$ shows C─O and C─C stretching. The peak at 1,076 is the characteristic of the crystalline region. The peak present at 930.0 to 931.1 cm$^{-1}$ attributed to skeletal mode vibration of α-1,4 glycosidic linkage (C─O─C). The peaks

**FIGURE 4** Temperature sweep curve of (A) 1%, (B) 2%, (C) 3%, (D) 4%, and (E) 5% of (a) PDG 5 and (b) BG-1076 chickpea starch
present at 861.5 and 765 cm$^{-1}$ attributed to $\text{CH}_2$ deformation and C–C stretching (Ghoshal & Mehta, 2019; Singh & Kaur, 2017; Ratnayake, Wassinger, & Jackson, 2007; Ratnayake et al., 2001).

4 | CONCLUSION

Starch separated from two varieties of chickpea exhibited considerable difference in physicochemical, morphological, and thermal properties. Both the varieties have high amylose content. Chickpea starches exhibited shear thinning behavior as $n$ values in both varieties are less than 1, therefore pseudoplastic in nature and $G’ > G”$ in both the starches indicating solid like properties. The extracted starch granules are resistant to swelling and rupture during processing and behave as C type starch like other legume starches. Chickpea starches possess large oval to small spherical shape granules and exhibited mixture of A- and B-type crystalline XRD pattern. This study showed that both varieties of chickpea starch were suitable for the food and nonfood applications.

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FIGURE 5 (a) XRD (b) SEM, and (c) FTIR of extracted starch from (A) PDG-5 and (B) BG-1076 varieties

CONFLICT OF INTEREST

The authors do not have any conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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