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Research article

Impact of variety and drying methods on the physicochemical, functional, and thermal properties of Ethiopian potato (*Plectranthus edulis*) tuber flour

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ABSTRACT

This study aimed to analyse the physicochemical, structural, functional, and thermal properties of flour from two indigenous Ethiopian Potato (Plectranthus edulis) varieties, Chanqua and Loffo, and to compare with wheat flour (WF). The study also investigated how oven and sun drying methods affected the physicochemical properties of the flours. The results demonstrated a significant distinction ($p \leq 0.05$) between the flour samples and WF, attributable to variations in both the varieties and the drying methods except that no significant difference in pH was observed due to the varieties, and the fibre and ash content did not vary significantly with the drying methods. The moisture content (MC) of the flours ranged from 5.72 % in oven-dried Chanqua Ethiopian potato flour (OD-CEPF) to 7.53 % in sun-dried Loffo Ethiopian potato flour (SD-LEPF), both of which were lower compared to WF. The protein content varied from 4.47 % (SD-CEPF) to 5.93 % (OD-LEPF). FTIR tests revealed a significant impact on the structural changes, leading to variations in the location and intensity of infrared absorption peaks, particularly in sensitive regions. Whereas, the XRD patterns showed characteristic B-type diffraction, with a relative crystallinity (RC) of 31.97 % in CEPF and 30.53 % in LEPF having a significant difference ($p \leq 0.05$) between them. LEPF had better flow properties than CEPF, with lower Hausner ratio (HR) (1.16 vs. 1.25), Carr's index (CI) (14.51 % vs. 20.26 %), and angle of repose (31.00° vs. 34.67°). It also showed significantly higher ($p \leq 0.05$) water absorption capacity (WAC), oil absorption capacity (OAC) and swelling power (SP) properties than CEPF. The study also indicated notable distinctions in the thermal and paring properties of flours. The oven drying method was found to be superior in enhancing the physicochemical properties, with LEPF showing better physicochemical, functional, structural, and thermal properties than CEPF.

1. Introduction

Roots and tuber crops, second only to cereals, are major staple energy sources in tropical regions. Compared to other tropical food sources, they offer an economical source of dietary energy as carbohydrates. Although their energy content is about one-third that of rice or wheat due to high moisture, their high yields provide more energy per unit of land compared to cereal grains [1]. Rich in starches, and notably high amount of resistant starches compared to other cereals, these crops play a significant role in human diets by

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lowering the risk of diabetes, obesity, and cardiovascular disease, and gluten-related disorders [2].

The Ethiopian potato (*Plectranthus edulis*) is an indigenous tuber crop cultivated in several regions of Ethiopia [3,4] And it is recognized as one of the economically most important species in the *Lamiaceae* family and the genus *Plectranthus* [5]. Traditionally, in some regions of Ethiopia, it is consumed boiling along with a stew made from various spices and hot pepper, and it is highly regarded as a beneficial for individuals recovering from illness due to mild effects on the stomach [6,7]. Recent studies have highlighted the tuber's significant nutritional value, rich in bioactive compounds and antioxidants, suggesting its potential for enhancing overall well-being [5,8].

Fresh tubers, like potatoes, are highly perishable and require prompt consumption or cold storage, a challenge in many developing nations due to insufficient and costly storage facilities, leading to significant postharvest losses. Processing fresh tubers into flour extends shelf life and reduces transportation and storage costs [9,10]. Ethiopian potato flours (EPFs), produced by cleaning, peeling, slicing, drying, and milling tubers, can be stored long and used in various food application. Studies have shown that incorporating unto 10 percent Ethiopian potato flour in to teff-maize composite flour enhance the nutritional profile with notable improvements in fat (2.4–2.8 %), protein (10–10.8 %), carbohydrate (79.1–82.0 %), and energy content (380.7–391.9 kcal/100 g) [7].

Flour, as a fundamental component of diets in various nations, is central in the creation of numerous food products [11]. Recently, flours of roots and tubers have gained significant attention due to their potential applications in substituting wheat flour (WF) in gluten-free products and enhancing nutritional value with their rich content of carbohydrates, dietary fibre, vitamins, and minerals [12].

Researches have revealed that the physicochemical properties of flour and starch are influenced by several factors, including amylose content, processing techniques, environmental conditions, and storage conditions [11]. For instance, Parambil et al. [2] found a significant difference in the physicochemical, morphological, functional, thermal, rheological, and pasting profile of Hausa potato (*Plectranthus rotundifolius)* starch and flour, with the starch showing a higher amylose content (30.44 %) and better pasting properties than the flour (20.57 %).

Different drying methods also significantly impact flour characteristics [13–17]. Bao et al. [13] investigated the impact of three drying methods (ethanol, oven, and freeze drying) on the structural and functional properties of potato flour and reported that freeze-drying disrupted the potato starch granules more than ethanol and oven drying. Similarly, Kasaye Atlaw [14], observed that oven-dried cassava flour (9.67 %, 0.54 and 0.55 g/ml) had higher moisture content (MC), water activity (a_w) and bulk density (BD) than sun-dried flour (9.23 %, 0.48 and 0.49 g/ml) respectively, though sun drying proved more economic and effective in reducing MC, thus inhibiting microbial growth. Desalegn and Kibr [15] examined the impact of sun, solar, and oven drying on the nutritional quality and functional properties of anchote tuber flour, and reported that sun-dried untreated anchote flour had the lowest protein (3.27 %) and fibre content (3.22 %), while oven-dried flour had the lowest ash (4.79 %), fat (0.91 %), and MC (9.04 %). Olatunde et al. [16] also evaluated the effect of sun and oven drying methods on chemical, functional and pasting properties of the sweet potato varieties.

Besides drying methods, the variety could also play significant role in determining the physicochemical, structural and functional properties of the flours [11,16]. Understanding these properties is crucial for optimizing the potential application and ensuring that thermal processes do not compromise the composition, nutritional value, or health benefits of the flour [18].

Despite the promising potential of EPF, there is currently no information on its physicochemical, structural, functional characterization, nor on impact of different varieties and drying methods. This research aims to fill that gap, promoting the utilization of EPF in various food industry applications and providing strategies to reduce postharvest losses.

2. Materials and methods

2.1. Materials

This study involved two Ethiopian potato (EP) varieties, Chanqua and Loffo, sourced from different locations within the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia, with the Chanqua variety obtained from the Ezo area in the Qogota Woreda, and the Loffo variety sourced from the Gembelagesha area in the Chencha Zuriya Woreda, which have distinct environmental

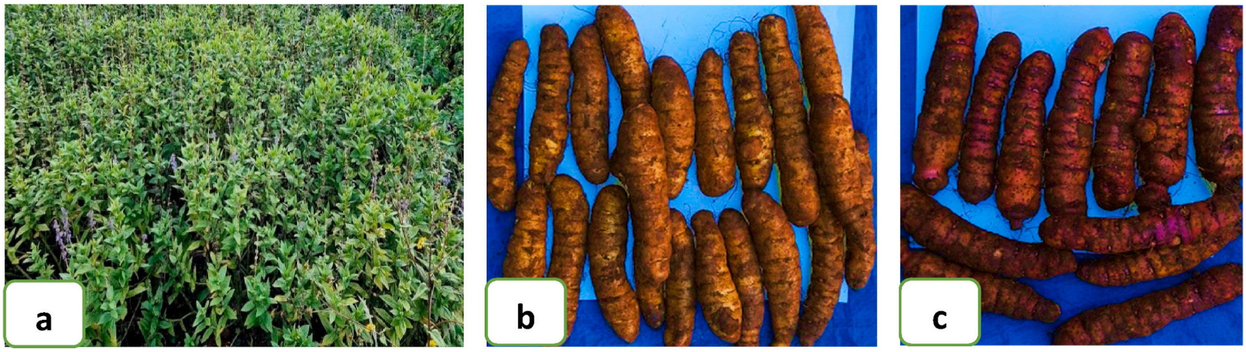

Fig. 1. Ethiopian potato (a) plant, (b) and (c) tubers of Loffo and Chanqua varieties respectively.

conditions. Fresh and mature EP tubers (Fig. 1a–c) were collected from these areas and wheat was purchased from a local market in Addis Ababa, Ethiopia.

2.2. *Ethiopian potato flour (EPF) preparation*

EPF was prepared following the technique used by Kusumayanti et al. [19], Olatunde et al. [16] and Bao et al. [13], with some modifications. Mature and fresh Ethiopian potato tubers were obtained from the aforementioned sources. The tubers were carefully washed in clean water, peeled, and then soaked in tap water for 30 min to prevent enzymatic darkening. Afterward, they were sliced into uniform pieces with a thickness of 2 mm using a domestic plantain slicer. Then two drying methods were employed to process the flour; A portion of the sample slices were oven dried (Model 10-D1391/AD, SCA) at an average temperature at 40 °C for 48 h [13]. Another portion of the slices were sun-dried for three consecutive days until constant weight was recorded. The dried Ethiopian potato samples were then ground in a home blender, and sieved with a 300 μm mesh size screen, named EPF and packaged in an airtight container until additional analysis could be done (see Fig. 2). Commercial wheat flour was used as a control.

2.3. *Physicochemical properties of EPF*

The chemical composition such as MC, protein, fat, crude fibre, total ash and carbohydrate content were determined according to method given by AACC [20]. Carbohydrate content was calculated by subtracting the values of crude protein, fat, and fibre from 100 (Equation (1)).

$$Carbohydrate\ content\ (\%) = 100 - [Moisture\ (\%) + Protien\ (\%) + Lipids\ (\%) + Ashes\ (\%) \tag{1}$$

Energy value was calculated as method described by Klang et al. [21] (Equation (2)).

$$\text{Energy} = (4\ \text{x}\ \%\text{carbohydrate}) + (9\ \text{x}\ \%\text{fat}) + (4\ \text{x}\ \%\ \text{protein}) \tag{2}$$

2.3.1. *Amylose content*

Colorimetric method with iodine affinity was used to determine the amylose content in EPF as proposed by Navaf et al. [22] and Parambil et al. [23]. To perform the analysis, a sample weighing 0.1 g was placed in a 100 ml standard flask. Then, 1 ml of 99 % ethanol and 9 ml of 1 M sodium hydroxide were added to the flask. The resulting suspension was thoroughly mixed and subjected to a boiling

Fig. 2. The preparation of EP flour.

water bath for 10 min. After cooling the flask to room temperature (24 °C), the suspension was adjusted to a total volume of 100 ml using distilled water (DW). From this prepared solution, a 5 ml aliquot was transferred to another 100 ml standard flask. Then, 1 ml of 1 M acetic acid and 2 ml of iodine solution were added to the flask, and the total volume was adjusted to 100 ml with DW. The absorbance of the resulting solution was measured at 620 nm using UV-spectrophotometer (Lambda 950 UV/Vis/NIR, PerkinElmer, UK). The amylose content was obtained by using Equation (3).

$$\text{Amylose content (\%)} = 3.06 \times \text{absorbance} \times 20 \qquad 3$$

2.3.2. Colour

The colour measurements of the EPF were carried out using a Colour Measuring System (Hunter Lab colorimeter, Minolta). The whiteness of EPF was done determined as per method mentioned in Tessema & Admassu [24] where whiteness of flour was calculated by using Equation (4).

$$Whiteness = 100 - \left[(100 - L)^2 + a^2 + b^2\right]^{\frac{1}{2}} \qquad 4$$

where L= (lightness), b = ±(yellowness/blueness) and a = ±(redness/greenness) values.

The treatment with the best physicochemical properties, selected from sun- and oven-dried samples, were chosen for further analysis of structural, thermal, and functional properties. The selection was based on key characteristics, including low moisture content and water activity for better shelf stability, balanced pH, higher fibre, protein, and amylose content for enhanced nutritional benefits, and lower fat content with higher ash, carbohydrate, and whiteness values for improved stability and visual appeal.

2.4. Morphology

The granular structure of EPF was examined using a Scanning Electron Microscope (JCM-6000 plus, Jeol Ltd., Korea). Finely ground EPF samples were sprinkled onto a double-sided tape affixed to a SEM stub. The samples were properly positioned and images were captured at an accelerator potential of 10 kV, following the method described by Bekele & Admasu [25].

2.5. Fourier Transform Infrared (FTIR) analysis

The spectra of EPF samples were captured using a Fourier Transform Infrared (FTIR) spectrometer system (Nicolet is50 ABX, Thermofisher Scientific, Germany) coupled to an attenuated total reflection (ATR) accessory. The analyses were performed at room temperature, and the spectra were recorded within the range of 4000–500 cm^{-1} at a resolution of 4 cm^{-1} as indicated by Wani et al. [26].

2.6. X-ray diffraction (XRD) pattern and relative crystallinity (RC)

The X-ray powder diffractometer (XRD-7000, Drawel, Drawel scientific instrument co., Ltd., Shanghai) with a copper tube was utilized to examine the crystalline structure of EPF and performed as method described in Bekele & Admassu [25]. The instrument operated at a power of 40 kV (40 mA) with a scanning speed of 1°/min. The starting angle for scanning was 5°, and the ending angle was 75°. To evaluate the relative crystallinity, the proportion of the crystalline region within the overall zone between 5° and 75° (2θ) was quantitatively determined following the procedure used by Bao et al. [13], with slight modification.

Equation (5) was used to determine the RC of the powders.

$$RC(\%) = \frac{\text{crystalline area}}{\text{Amorphous area} + \text{crystalline area}} * 100 \qquad 5$$

2.7. Density and flowability properties

The density and flowability of the EPF powder were determined using the technique described by Parambil et al. [23] and Navaf et al. [22]. To measure the bulk volume, 1 g of powder samples was placed in a 10 ml measuring cylinder and the volume was recorded as bulk volume. Then the measuring cylinders containing the samples were tapped 100 times on a flat surface, and the resulting volume was measured as the tapped volume. The bulk density (BD), tapped density (DT), true density (Td), and porosity (P*f*) of the EPF were calculated using Equations (6), (7), (8), and (9) respectively. The flowability properties of the powder were assessed using Hausner's ratio (HR), Carr's Compressibility Index (CI), and the angle of response (tan θ), which were calculated using Equations (10), (11), and (12) based on the methods described by Parambil et al. [23] and Deepika et al. [27]. The true density (Td) of the samples was determined using the displacement technique. Specifically, 1 g of EPF was added to a 10 ml measuring cylinder, and 5 ml of hexane was poured in, and the volume displaced from the measuring cylinder was marked.

$$BD\left(\frac{g}{ml}\right) = \frac{weight\ of\ the\ sample}{Bulk\ volume} \qquad 6$$

$$DT\left(\frac{g}{ml}\right)=\frac{Weight\ of\ sample}{Tapped\ volume} \tag{7}$$

$$Td\left(\frac{g}{ml}\right)=\frac{weight\ of\ sample}{Displaced\ volume} \tag{8}$$

$$Porosity\ Pf(\%)=\left(1-\frac{LBD}{Td}\right)*100 \tag{9}$$

$$HR=\frac{DT}{BD} \tag{10}$$

$$CI(\%)=\left(\frac{DT-BD}{DT}\right)*100 \tag{11}$$

$$\tan\theta=\frac{2h}{d} \tag{12}$$

where ‘d’ is the diameter of the base and ‘h’ is the height of the heap.

2.8. Functional properties

The WAC and OAC of EPF were determined by following the procedure used by Parambil et al. [23] and Bikila et al. [28] with slight modification. 0.5 g of EPF was placed in a 15 ml pre-weighted centrifuge tube to measure WAC. A 10 ml DW was added to the centrifuge tube and vortexed (XH-B, Hinotek, China), followed by 15 min of centrifugation (TGL-16, Sichuan Shoke, China), drained out the excess water, and reweighed the centrifuge tube. The increase in sample weight was calculated as grams of water absorbed per gram of sample. Whereas 0.5 g of the sample was placed in a pre-weighted centrifuge tube and 6 ml of sunflower oil was added, to measure OAC. Excess oil was removed from the samples after they were vortexed and centrifuged. The final weight of the samples was determined, and any weight increase was expressed as grams of oil absorbed per gram of sample (Equations (13) and (14)).

$$WAC\left(\frac{g_{H_2O}}{g}EPF\right)=\frac{M_2-M_1}{M_1} \tag{13}$$

$$OAC\left(\frac{g}{g}\right)=\frac{M_2-M_1}{M_1} \tag{14}$$

where M_1 is the mass of the dry EPF sample and M_2 is samples weight with the absorbed water and oil.

The SP and solubility of EPF were studied by method followed by Bao et al. [13]. 5 g of powdered EPF samples were mixed thoroughly with 100 ml of distilled water (DW). The suspension was then heated in a water bath at 92.5 °C for 30 min, with regular shaking. After heating, the suspension was cooled to 20 °C for 3 min and subjected to centrifugation at 13,000×g for 10 min. The supernatant was collected and dried in a hot air oven (Model 10-D1391/AD, SCA) at 105 °C for 12 h. The dried supernatant was weighed to determine the solubility (Equation (16)), expressed as the percentage of dry flour, and the degree of swelling power (Equation (15)), represented as the grams of water absorbed per gram of dry flour.

$$Swelling\ power\left(\frac{g}{g}\right)=\frac{weight\ of\ the\ wet\ residue\ (swollen\ granules)}{Dry\ weight\ of\ orginal\ flour} \tag{15}$$

$$Solublity\ (\%)=\frac{weight\ of\ the\ dried\ supernatant\ (solutes)}{dry\ weight\ of\ the\ original\ flour} \tag{16}$$

2.9. Thermal properties

The thermal properties of EPF samples were analysed using a differential scanning calorimetry (DSC) (SKZ1052B, Hunan, China) equipped with a thermal analysis data station, following the method mentioned by Bekele & Admassu [25]. 10 mg sample was carefully weighed into an aluminium pan with a capacity of 40 μl. Then, 20 μl of distilled water was added to the sample using a Hamilton micro syringe. To ensure sample equilibrium, the sealed pans were left at room temperature (24 °C) for 1 h before the analysis. The samples were then subjected to heating over a temperature range of 20–180 °C at a rate of 10 °C per minute. Thermal properties such as the onset temperature (To), conclusion temperature (Tc), peak temperature (Tp), and the enthalpy of gelatinization (ΔH), were calculated based on the DSC curves.

2.10. Pasting properties

The pasting characteristics of EPF were evaluated using a Rapid Visco Analyzer (Perten RVA 4800, PerkinElmer, Sweden), in accordance with the method outlined by Fan et al. [29]. 3 g of EPF were weighed into the RVA canisters, and DW was added to achieve a total weight of 28 g. The suspension of EPF (12 % w/w) was initially heated from 50 °C to 95 °C at a rate of 1.5 °C per minute. It was then held at 95 °C for 2.5 min, followed by cooling to 50 °C at a rate of 1.5 °C per minute and holding for 5 min. During the analysis, the paddle speed was set at 160 rpm. Then parameters such as pasting temperature (PT), peak viscosity (PV), trough viscosity (TV), breakdown (BD), setback (SB), final viscosity (FV) and Ptime = peak time were recorded.

2.11. Statistical analysis

The statistical analysis, including Analysis of Variance (ANOVA), was conducted using software packages, namely OriginPro 2019b, MS Excel 2016, and SAS version 9.0. Prior to ANOVA analysis, Normality of the data was assessed using skewness and kurtosis values, calculated by the PROC UNIVARIATE procedure in SAS version 9.0. To assess the differences in the physicochemical properties of the flours, Tukey's multiple comparison test was employed. A 95 % confidence interval was utilized, with a significance level set at $p \leq 0.05$, to determine the statistical significance of the observed variations.

3. Results and discussion

3.1. The physicochemical properties of EPF

The results of the physicochemical properties of EPF are presented in Table 1. The MC of the EPF ranged from 5.72 % (OD-CEPF) to 7.53 % (SD-LEPF) which is lower than the MC of WF (7.63 %). The EPF exhibited lower MC compared to the cassava flour reported by Lu et al. [30] (11.9 %) and the range reported by Kasaye Atlaw [14] (9.23 %–11.45 %). The drying methods had a significant ($p \leq 0.05$) effect on the MC values, with the mean MC of oven-dried EPF being 6.09 % and sun-dried flours 6.74 %, indicating that oven-dried flours had lower moisture content. This result, however, contradicts the findings of Kasaye Atlaw [14], who showed that sun-dried cassava flour had a lower MC compared with oven-dried and try-dried cassava flours. This could be attributed to the differences in the drying conditions used, such as drying temperature, drying time, and the shape and size of the slices, as studied and documented in the works of Pornpraipech et al. [31]. Buzera et al. [10] noted that the drying method, along with factors such as drying time and storage conditions, influences the MC values of flours. Uchechukwu-Agua et al. [32] indicated that lower MC is good indicator of good storage stabilities of flours, as it inhibits microbial growth. The pH value of the EPF ranged from 5.39 to 6.50, with OD-CEPF having lower pH value and SD-CEPF higher pH value. More or less similar ranges of pH (5.7–6.0) have been reported for cassava flours [32]. The pH value is a good indicator of flour quality [14,32]. The drying method had a significant ($p \leq 0.05$) effect on the pH value, with the mean pH values of 5.75 for OD-EPF and 6.47 for SD-EPF, whereas variety had no significant effect on the pH value. A_w is a crucial property of food that determines microbial growth by measuring the energy of unbound water in a sample [14]. The a_w of EPF varied from 0.23 (OD-LEPF) to 0.37 (SD-CEPF), which is lower than the a_w of WF (0.46). Both varieties and drying methods significantly ($p \leq 0.05$) affected the values of a_w. Based on drying methods, the mean a_w values were 0.34 for SD-EPF and 0.25 for OD-EPF, while based on variety, the mean aw values were 0.27 for LEPF and 0.32 for CEPF.

The fat content ranged from 0.77 % to 1.41 % (Table 1), which is lower compared to WF (2.08 %). Both the variety and drying

Table 1
Physicochemical properties of the EPF and WF.

Samples	MC%	pH	a_w	Fat (%)	Fibre (%)	Ash (%)	Protein (%)	Carbohydrate (%)	Energy (Kcal/100 g)	Amylose (%)
SD-CEPF	5.94 ± 0.25^{bc}	6.50 ± 0.22^{a}	0.37 ± 0.00^{b}	1.41 ± 0.04^{b}	2.32 ± 0.18^{c}	3.51 ± 0.06^{b}	4.47 ± 0.19^{d}	84.65 ± 0.34^{a}	369.20 ± 0.85^{a}	14.17 ± 0.07^{b}
OD-CEPF	5.72 ± 0.15^{c}	5.39 ± 0.26^{b}	0.27 ± 0.02^{d}	1.23 ± 0.01^{c}	2.66 ± 0.49^{bc}	3.53 ± 0.02^{b}	5.79 ± 0.09^{bc}	83.73 ± 0.08^{a}	369.18 ± 0.67^{a}	14.33 ± 0.11^{b}
SD-LEPF	7.53 ± 0.35^{a}	6.48 ± 0.14^{a}	0.31 ± 0.01^{c}	0.85 ± 0.08^{d}	3.13 ± 0.26^{b}	4.42 ± 0.66^{a}	5.35 ± 0.19^{c}	81.83 ± 0.99^{b}	356.50 ± 1.18^{b}	14.36 ± 0.29^{b}
OD-LEPF	6.46 ± 0.36^{b}	5.41 ± 0.34^{b}	0.23 ± 0.01^{e}	0.77 ± 0.08^{d}	3.27 ± 0.04^{b}	4.72 ± 0.13^{a}	5.93 ± 0.02^{b}	82.10 ± 0.21^{b}	359.12 ± 1.31^{b}	14.86 ± 0.05^{a}
WF	7.63 ± 0.15^{a}	6.40 ± 0.01^{a}	0.46 ± 0.05^{a}	2.08 ± 0.05^{a}	4.00 ± 0.01^{a}	1.51 ± 0.02^{c}	8.51 ± 0.22^{a}	80.25 ± 0.35^{c}	373.84 ± 0.81^{a}	13.78 ± 0.01^{c}
Analysis of variance and significance (p-values)										
Variety (A)	[a]	NS	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
Method (B)	[a]	[a]	[a]	[a]	NS	NS	[a]	NS	NS	[a]
Interaction (AxB)	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

Values in the same column and variety with different superscript letter are significantly different ($p < 0.05$). SD-CEPF, SD-LEPF and OD-CEPF, OD-LEPF refers Sun-dried and oven dried Chanqua and Loffo Ethiopian potato flour respectively and WF wheat flour.

[a] Significant and NS not significant.

methods had significant ($p \le 0.05$) effect on the fat content of the EPF. The mean fat content of the CEPF (1.32 %) was higher than that of LEPF (0.81 %), whereas the mean fat content of the SD-EPF (1.13 %) was higher than that of OD-EPF (1.00 %).

The fibre content of EPFs ranged from 2.32 % to 3.27 %, with the lowest fibre content found in SD-CEPF and the highest in OD-LEPF. These values were lower compared to the fibre content of WF (4.00 %). The EPFs' ash content ranged from 3.51 % to 4.72 %, with OD-LEPF having the highest ash content and SD-CEPF having the lowest. The ash contents of the EPF are considerably higher than that of WF. The protein content of the EPFs varied between 4.47 % (SD-CEPF) and 5.3 % (OD-LEPF) and was significantly higher ($p \le 0.05$) than that of WF (8.51 %). Both the varieties and drying methods had significant effect on the protein content. The fat, fibre, ash and protein contents of EPFs in this work are higher than those reported by Lu et al. [30] for fat (0.6 %), fibre (2.0 %), ash (2.0 %), and protein (2.8 %) in cassava flour. The carbohydrate content of the EPF's ranged from 81.83 % to 84.65 %, with SD-LEPF having the lowest carbohydrate content and SD-CEPF having the highest. All EPFs had a higher carbohydrate content compared with the value found in WF. Furthermore, the drying procedures did not significantly affect the carbohydrate contents of EPFs. The energy values of the EPFs ranged from 356.50 kcal (SD-LEPF) to 369.20 kcal (SD-CEPF). The drying methods had no effect on the energy values of the EPFs.

The amylose content of EPFs ranged from 14.17 % to 14.86 %, with OD-LEPF having the highest amylose content and SD-CEPF having the lowest (Table 1). The amylose content was significantly influenced by both the drying methods and the variety of flours. Comparing the two drying methods, oven drying had a minimal impact on the amylose content of EPF. Consequently, EPF dried in the oven showed a higher average amylose content (14.32 %) compared to the sun-dried samples (14.10 %). According to Sanful et al. [33], variations in amylose content among the samples, caused by the drying methods, may be attributed to the disruption of the cellular or granular structure within the amorphous and crystalline regions. This disruption potentially promotes the formation of strong bonds and increases the interaction with water molecules, thereby facilitating the release of amylose.

The mean amylose content based on variety was 14.61 % for LEPF and 14.25 % for CEPF, which is comparable with the amylose content of WF (13.78 %).

The amylose content of EPFs (14.17–14.86 %) is lower than Hausa potato flour (20.57 %) [2], aerial yam (*Dioscorea bulbifera*) flour (25–31 %) [33], sweet potato flour (26.8 %) and higher than cassava flour (13.1 %) [34].

3.1.1. Colour

The colour of a food product serves as the consumer's initial impression, and a flour with high whiteness promotes the acceptance of the finished product [18,35]. There were significant variations ($p \le 0.05$) in all colour characteristics caused by the EP varieties and drying methods with the exception of b* values in the drying methods (Table 2). The lightness (L*) values of the EPFs, which varied from 67.89 (SD-CEPF) to 70.41 (OD-LEPF), were within the range of the L* values (57.74–91.43) of flours made from potato and sweet potato tubers reported by Wang et al. [18], but were significantly lower ($p \le 0.05$) than the L* value of WF (92.40). The mean L* values of LEPF (69.21) were substantially higher than those of CEPF (68.23), revealing that colour properties can be influenced by variety. Singh et al. [36] obtained more or less similar L* values for flours ranging from 69.80 to 72.18 for three different potato varieties. Nilusha et al. [35] also reported that flours of five different Sri Lankan cassava varieties had significantly diverse L* values ranging from 95.50 to 97.27.

Based on drying methods, a significant difference was observed in the mean L* and whiteness values of the EPF. OD-EPF (69.48 and 65.37) had a higher L* and whiteness value than SD-EPF (67.95 and 64.05), respectively. Similar trends were observed in the research work of Desalegn and Kibr [15], which found that anchote flour dried in the oven (76.90) had a higher L* value than anchote flour dried in the sun (75.48). They also stated that this could be attributed to the fact that the sun drying requires extended periods of time and direct contact with oxygen, which intensifies the reddish colour.

The redness/greenness (a*/−a*) values of EPF varied between 6.19 (SD-LEPF) and 6.60 (OD-LEPF), whereas the yellowness (b*) values ranged from 14.72 (OD-LEPF) to 15.32 (OD-LEPF), which are higher than a* (−0.70 to −0.23) and b* (4.10–6.30) values reported by Nilusha et al. [35].

Table 2

Colour Parameters of EPF varieties under different drying methods and WF.

Sample	Colour			
	L*	a*	b*	Whiteness
SD-CEPF	67.89 ± 0.88^{c}	6.29 ± 0.25^{b}	14.83 ± 0.39^{ab}	64.07 ± 0.78^{c}
OD-CEPF	68.55 ± 0.41^{c}	6.37 ± 0.10^{ab}	14.72 ± 0.27^{b}	64.70 ± 0.40^{c}
SD-LEPF	68.01 ± 0.99^{c}	6.19 ± 0.13^{b}	15.19 ± 0.56^{ab}	64.03 ± 0.75^{c}
OD-LEPF	70.41 ± 0.46^{b}	6.60 ± 0.08^{a}	15.32 ± 0.17^{a}	66.03 ± 0.39^{b}
WF	92.40 ± 0.26^{a}	1.51 ± 0.15^{c}	8.52 ± 0.20^{c}	88.48 ± 0.28^{a}
Analysis of variance and significance (p-values)				
Variety (A)	a	a	a	a
Method (B)	a	a	NS	*
Interaction (AxB)	a	a	a	a

Values in the same column and variety with different superscript letter are significantly different ($p < 0.05$). Datas are the means ± standard deviation of seven measurements. L* = lightness value, 100 = white and 0 = black, a* = red (+)/green (−), b* = yellow (+)/blue (−). SD-CEPF, SD-LEPF and OD-CEPF, OD-LEPF refers Sun-dried and oven dried Chanqua and Loffo Ethiopian potato flour respectively and WF wheat flour.

[a] Significant and NS not significant.

The variations in flour colour could be explained by differences in anthocyanin and carotene, which are responsible for reddish and yellowish accumulation in flour, respectively [18,37].

Based on the optimal physicochemical properties of EPF, oven-drying was selected, and thermal, structural, and functional aspects were measured using oven-dried samples.

3.2. Morphology of EPF and wheat flour

The shape and surface morphological properties of granules play a significant role in the food and industrial application [3]. They also have a notable impact on functional properties such as WAC, SP, and digestibility [22]. The SEM results for EPF varieties are shown Fig. 3(a–c). These results revealed that starch granules were predominantly spherical and elliptical (oblong) in shape, with the granules integrated into a matrix of lipid, fibre, and protein, leading to the formation of large, granular bundles. A similar pattern was observed in Hausa potato flour with a notable difference in the shape of the starch granules in Hausa potato flour, which were mainly circular with some truncated circular forms, and had a smoother surface compared to the others [2]. The granular shapes of the starch in both CEPF and LEPF were consistent with the findings of Hellemans et al. [5] and Assefa et al. [38]. Circular granule shapes in

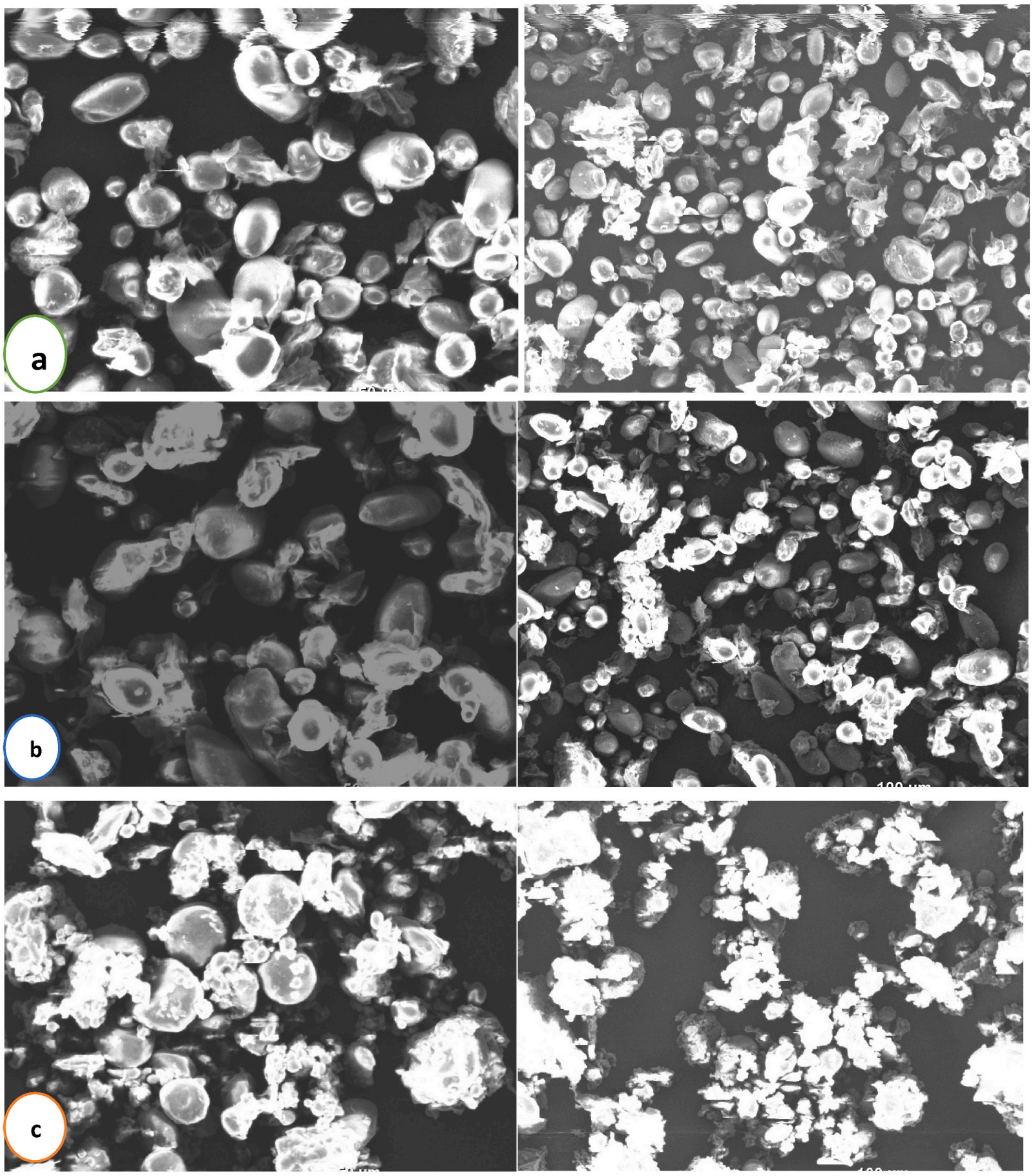

Fig. 3. Morphology of CEPF (a), LEPF (b) and WF; SEM @ 600× and 300× magnification.

cassava starch, round and polygonal granule shapes in sweet potato starch, and circular, oval, and elliptical granule shapes with smooth surfaces in arrowroot starch were reported by Leon et al. [39].

3.3. FTIR analysis

The FTIR structural characterization of EPFs and WF is shown in Fig. 4. Wavenumber and amplitude information in an FTIR graph provide insights into the molecular composition, chemical bonds, and concentration of functional groups in a sample, allowing for identification, characterization, and quantitative analysis of various organic and inorganic compounds [40]. The frequency at which a functional group appears in an FTIR spectrum reveals its characteristics, while the intensity of the corresponding band provides information about the existence of intermolecular hydrogen bonding [2]. CEPF and LEPF exhibited wide bands cantered at 3271.57 cm^{-1} and 3270.37 cm^{-1}, respectively, which were assigned to the stretching vibration of the O-H group. Furthermore, both CEPF and LEPF displayed bands around 2925.33 cm^{-1} and 2925.82 cm^{-1}, corresponding to the stretching modes of the C-H bonds. This is consistent with prior reports stating that the stretching vibration of the O-H group is characterized by a broad and strong absorption band between 3600 cm^{-1} and 3300 cm^{-1}, and bands between 3750 and 2800 cm^{-1} demonstrate the symmetric/asymmetric stretching modes of the C-H [2,41,42]. The bands at 1632.81 cm^{-1} (CEPF) and 1633.55 cm^{-1} (LEPF) were attributed to the C-O bending associated with the O-H group, corroborating the earlier work revealing that bands around 1637 were due to C-O bending with the O-H group [4]. Weak bands were observed at 1408.76 cm^{-1}, 1333.37 cm^{-1}, and1147.74 cm^{-1} for CEPF, and at 1409.84 cm^{-1}, 1248.21 cm^{-1} and 1147.39 cm^{-1} for LEPF. Furthermore, intense bands were observed at 997.97 cm^{-1} for CEPF and at 998.76 cm^{-1} for LEPF, indicating the presence of stretching vibrations involving C-O bonds. According to Donato et al. [41], the CH/CH2 groups' deformational modes are primarily responsible for the weak and partially overlaid bands in the spectral region between 1500 and 1200 cm^{-1}. Previous studies have documented that bands within the wavenumber ranges of 1362–1306 cm^{-1}, 1151-1141 cm^{-1}, 1100-900 cm^{-1}, and 998-983 cm^{-1} correspond to C-H symmetric bending, C-O-C asymmetric stretching, C-O-H bending, and C-O stretching, respectively [4,42].

3.4. XRD and RC analysis

Starch particles in the flour consist of both crystalline and amorphous regions, and X-ray diffraction patterns were used to describe their crystallization properties.

As shown in Fig. 5, the X-ray diffraction patterns of the EPFs obtained in this study exhibited the characteristic B-type diffraction patterns, with distinct peaks observed around 5.6°, 17°, 22°, and 24° (2θ). This phenomenon is similar to the findings reported by Bao et al. [13] regarding potato flours obtained through three different drying methods. On the other hand, wheat flour displayed A-type characteristics due to the presence of additional distinctive peaks at 2θ = 18.3°, 20.3°, 23.15°, and 26.27°, which are indicative of the presence of A-type starch. CEPF exhibited higher (31.97 %) RC value compared to LEPF (30.53 %), but it was lower than that of WF (36.71 %). Bao et al. [13] reported comparable RC values ranging from 31.3 % to 34.2 % for potato flour obtained through different drying methods. In contrast, Zhang et al. [43] reported lower RC values ranging from 15.7 % to 23.4 % for native and heat moisture treated flours of sweet potato. RC of 30 % was reported by Saiah et al. [44] for native wheat flour. Variations in crystal structure and RC were observed among the EPF, which could be attributed to the differences in the variety of EP [45].

3.5. Density and powder flowability properties

The bulk density, tapped density, true density and porosity of EPF and WF are reported in Table 3. The BD obtained in LEPF (0.73 g/

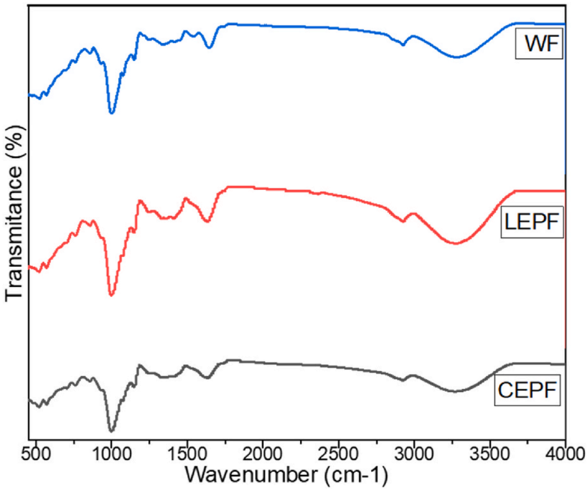

Fig. 4. FT-IR spectra of EPFs and WF.

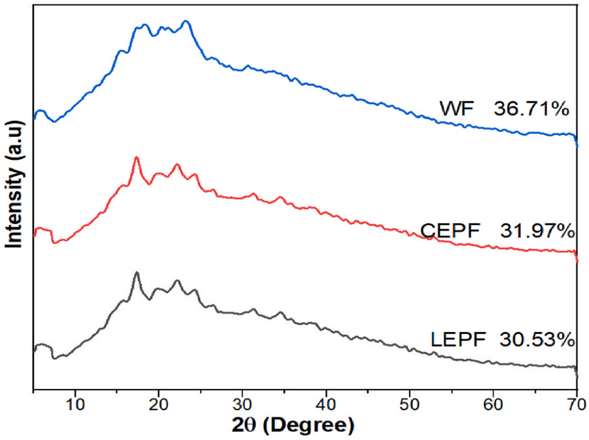

Fig. 5. XRD patterns and RC of EPFs and WF.

Table 3
Densities and flowability properties of EPFs and WF.

Sample	BD (g/ml)	DT (g/ml)	Td (g/ml)	Porosity (%)	HR	CI (%)	Angle of response (°)
CEPF	0.58 ± 0.03^b	0.72 ± 0.03^a	1.15 ± 0.06^b	49.71 ± 0.14^b	1.25 ± 0.02^a	20.26 ± 1.18^a	34.67 ± 0.57^b
LEPF	0.73 ± 0.06^a	0.85 ± 0.06^a	1.27 ± 0.13^b	42.54 ± 0.73^c	1.16 ± 0.02^b	14.51 ± 1.49^b	31.00 ± 1.00^c
WF	0.76 ± 0.05^a	0.87 ± 0.07^a	1.94 ± 0.04^a	60.35 ± 2.29^a	1.14 ± 0.03^b	12.00 ± 2.50^b	40.61 ± 0.62^a

Values in the same column and variety with different superscript letter are significantly different ($p < 0.05$). Datas are the means ± standard deviation of three measurements. CEPF, LEPF and WF refers Chanqua and Loffo Ethiopian potato flour respectively and WF wheat flour. BD, DT, Td, HR and CI refers Bulk density, tapped density, true density, Hausner's ratio and Carry Index respectively.

ml) was significantly ($p \leq 0.05$) higher than that of CEPF (0.73 g/ml) and was comparable with that of WF (0.76 g/ml). Earlier research showed bulk densities of 0.52 g/ml and 0.58 g/ml for Hausa potato flour [2] and Talipot palm flour [22], respectively. Potato flours from different cultivars were reported to have BD ranging from 0.84 to 0.89 g/cm^3 [46]. It was also stated that high BD in flour, resulting from small particle size, affects physicochemical properties like water absorption capacity, and is crucial for determining packaging requirements. The DT of EPFs were 0.72 g/ml (CEPF) and 0.85 g/ml (LEPF), with no significant difference between them and WF (0.87 g/ml). According to Parambil et al. [2], applying external pressure decreases the void spaces within the tapped volume, leading to a higher DT. This increase in density indicates improved expandability and blending characteristics, as well as favourable packaging and storage practices for the component during different unit operations. The Td of LEPF (1.27 g/ml) obtained in this study was higher than that of CEPF (1.15 g/ml) but significantly lower than that of WF (1.94 g/ml). Buzera et al. [9] reported higher TDs (0.70 g/ml-1.03 g/ml) and Tds (1.46 g/ml-1.65 g/ml) of flours from potato varieties under pre-treatment and drying conditions. P*f* investigation revealed that CEPF flour (49.71 %) was considerably higher than LEPF (42.54 %), but lower than WF (60.35 %); this difference was attributed to a difference in Tds and BDs. P*f*, as a characteristic of food, represents the visible structure and unoccupied space within the material, influencing heat transfer, diffusion rates, and sensory attributes [2]. Earlier research revealed P*f* of 50.60 %, and 69.29–73.28 % for Hausa potato flour [2], and starches powder of *Colocasia* tuber [27], respectively. Previous research found the Td (1.96 g/ml) and P*f* (73.22 %) for WF (73.22 %) [47].

This study revealed that HR (1.16), CI (14.51 %) and angle of responses (31.00°) of LEPF were significantly lower ($p \leq 0.05$) than that of CEPF HR (1.25), CI (20.26 %) and angle of response (34.67°) (Table 3). The CI indicates the materials' compressibility, while the HR shows how cohesive the particles are [22]. All the flours in this study had good powder flowability property. Comparable values of HR (1.35), CI (26.15 %) and angle of responses (32.17°) were reported by Parambil et al. [2] for Hausa potato flour. They also stated that the flour powders having HR, CI and angle of response values greater than 1.25, 25 % and 45° respectively, are classified as having poor flowability. Bian et al. [48] reported the HR, CI and angle of response value of (1.06,1.22), (8.20 %,18.33 %) and (40.90°, 41.57°)

Table 4
Functional properties of EPFs and WF.

Sample	WAC (g/g)	OAC (g/g)	SP(g/g)	Solubility (%)
CEPF	2.20 ± 0.03^b	0.91 ± 0.01^b	5.09 ± 0.04^c	15.80 ± 0.06^a
LEPF	2.38 ± 0.03^a	1.03 ± 0.06^a	5.78 ± 0.08^b	13.54 ± 0.09^b
WF	1.06 ± 0.02^c	1.09 ± 0.09^a	6.41 ± 0.01^a	7.97 ± 0.20^c

Values in the same column and variety with different superscript letter are significantly different ($p < 0.05$). Datas are the means ± standard deviation of triplicates. CEPF, LEPF and WF are the flours of Chanqua and, loffo Ethiopian potato and Wheat respectively.

from the hard and soft wheat flours, respectively.

3.6. Functional properties

The WAC and OAC are important parameters used in the characterization of tuber flours. WAC refers to the ability of a flour to absorb water whereas OAC refers to the amount of oil that can be absorbed by a given amount of flour [49]. WAC and OAC of the EPF and WF are listed in Table 4. WAC of LEPF (2.38 g/g) was significantly higher ($P \leq 0.05$) than that of CEPF (2.20 g/g) and WF (1.03 g/g). The OAC of the LEPF (1.03 g/g) was comparable with that of WF (1.09 g/g) in this study. The WAC and OAC results of EPF are consistent with values reported by Parambil et al. [2] for Hausa potato flour (WAC: 2.42 g/g, OAC: 1.15 g/g) and relatively higher compared to Lu et al. [30] for cassava flour (WAC: 1.23 g/g, OAC: 0.85 g/g). The higher WAC and OAC values can be attributed to the elevated levels of starches, fibre, protein, and fat content present in the sample, as these components have the ability to absorb water and oil [2,49].

The SP and solubility percent of EPFs and WF are listed in Table 4. The significant commercial application of starch lies in its capacity to swell and form a thick paste when heated with water, and this swelling power is determined by measuring the ability of starch granules to absorb water [2]. The SP of the LEPF (5.78 g/g) is higher than that of CEPF (5.09 g/g/) and lower that WF. The SP values of the samples investigated in this study fell within the range of the findings of Culetu et al. [49] who reported SP value varying between 3.14 g/g and 7.32 g/g for different gluten-free flours. The solubility percent of the CEPF (15.80 %) is higher than that of LEPF (13.54 %) and WF (7.97 %). Both CEPF and LEPF showed higher SP and solubility compared to cassava (with SP of 13.80 g/g and solubility of 3.02 %) and different coloured sweet potato flours (with SP ranging from 3.40 g/g to 3.67 g/g and solubility ranging from 8.61 % to 9.56 %) as reported by Kusumayanti et al. [19].

3.7. Thermal properties

DSC analysis was conducted to investigate the thermal properties of EPF and wheat flours, and the results are presented in Table 5 and Fig. 6(a–c). The T_o, T_p, T_c and ΔH of CEPF and LEPF are 42.90 °C, 82.33 °C, 112.30 °C and 4.55 J/g and 41.23 °C, 80.53 °C, 109.5 °C and 4.62J/g, respectively. The T_o of LEPF (41.23 °C) was significantly ($p \leq 0.05$) lower than that of CEPF (42.90 °C) and WF (55.01 °C). The T_o indicates the point at which water is absorbed into the amorphous region, causing granular swelling. This leads to gelatinization, hydration of the amorphous region, and the breaking of weak hydrogen bonds [2]. There was no significant difference in T_p values between CEPF and LEPF, yet both were significantly higher than WF. The thermal characteristics of flours could be influenced by factors such as the amylose to amylopectin ratio, the molecular structure of the crystalline region, the chain distribution and the double helix order [2,22]. The T_o, T_p and T_c of EPFs are comparable with those reported in cassava flour (42.8 °C, 81.9 °C and 112.4 °C) [30]; however, they are higher than those reported in sweet potato flour (72.76 °C, 79.91 °C and 84.72 °C) [43]. Nyawose et al. [50] also reported T_o, T_p and T_c values of different cassava variety flours, which varied from 41.55 to 70.03 °C, 88.94–118.92 °C and 133.48–138.41 °C, respectively.

The T_p and T_c values of both EPFs were higher than those reported in potato flours obtained by employing different drying methods (66.8–68.8 °C and 72.5–73.7 °C) [13], potato under different drying conditions (70.00–74.19 °C and 81.50–82.3 °C) [51], potato flour (67.50–69.35 °C and 73.74–73.85 °C) [52], respectively. The T_o, T_p and T_c values of CEPF were higher than of LEPFs and WF, however, ΔH was lower. According to Lu et al. [30], the lower ΔH suggests improved thermal stability, indicating less energy is required to break down the starch structure. Culetu et al. [49] reported Tp and ΔH values of various gluten-free flours ranging from 71.62 to 81.87 °C and 4.85–13.79 J/g, respectively. Earlier research reported T_o, T_p, T_c and ΔH values for untreated wheat flour (57.72 °C, 63.82 °C, 8.00 °C and 7.38 J/g) and treated wheat flours (57.82–94.92 °C, 64.02–70.24 °C, 79.24–80.64 °C and 5.21–7.17 J/g), respectively [53]. According to Wolde et al. [54], the observed variations in thermal properties could potentially be attributed to differences in the amylose content, granule size, and crystalline structure of the samples.

3.8. Pasting properties

The pasting profile of the EPF and WF are presented in Table 6 and Fig. 7. The samples of EPF and WF showed significant difference ($p \leq 0.05$) in almost all Rapid Visco Analysis (RVA) parameters. The PV value of the LEPF (1332.5 mPa s) was considerably higher than that of the CEPF (1144.6 mPa s), but lower than that of the WF (1898.7 mPa s). According to Parambil et al. [2], the maximum PV is reached when the majority of the sample's starch swell due to temperature changes within a specific time frame, causing the material to reach its highest degree of viscosity. The variation in PV values may be attributed to differences in WAC of sample [55], amount and

Table 5
Thermal properties of EPF and WF.

Sample	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
CEPF	42.90 ± 0.40^b	82.33 ± 0.83^a	112.30 ± 0.95^a	4.55 ± 0.02^b
LEPF	41.23 ± 0.70^c	80.53 ± 0.05^a	109.50 ± 0.60^b	4.72 ± 0.05^b
WF	55.01 ± 0.30^a	65.48 ± 0.51^b	82.09 ± 0.40^c	8.73 ± 0.22^a

Values in the same column and variety with different superscript letter are significantly different ($p < 0.05$). Datas are the means ± standard deviation of three measurements. CEPF, LEPF and WF refers Chanqua and Loffo Ethiopian potato flour respectively and WF wheat flour.

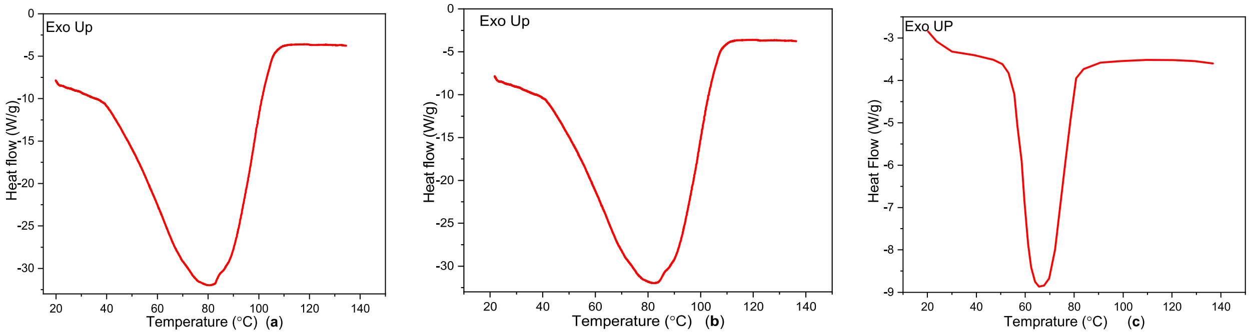

Fig. 6. DSC graph of EPF and WF: (a) Loffo, (b) Chanqua and (c) WF.

Table 6
Pasting properties of EPF and WF.

Sample	PV (mPa.s)	TV (mPa.s)	BV (mPa.s)	FV (mPa.s)	SV (mPa.s)	P_{time} (min)	PT (°C)
CEPF	1144.6 ± 11^{c}	939.3 ± 10^{c}	205.3 ± 11^{c}	1907.2±6^{c}	967.9 ± 16^{b}	5.19 ± 0.08^{b}	78.80 ± 0.17^{b}
LEPF	1332.5 ± 12^{b}	1086.3 ± 10^{b}	246.2 ± 60^{b}	2089.5±9^{a}	1003.2 ± 17^{a}	5.21 ± 0.11^{b}	75.50 ± 0.26^{c}
WF	1898.7 ± 12^{a}	1103.4 ± 09^{ab}	795.3 ± 19^{a}	2006.3±8^{b}	902.9 ± 13^{c}	6.52 ± 0.15^{a}	89.57 ± 0.28^{a}

Values in the same column and variety with different superscript letter are significantly different ($p < 0.05$). Datas are the means ± standard deviation of triplicates. CEPF: Chanqua Ethiopian potato flour; LEPF: Loffo Ethiopian potato flour; WF: Wheat flour; PV: peak viscosity; TV: trough viscosity; BV: breakdown viscosity; SV: setback viscosity; FV: final viscosity; PT: pasting temperature; and Ptime: peak time.

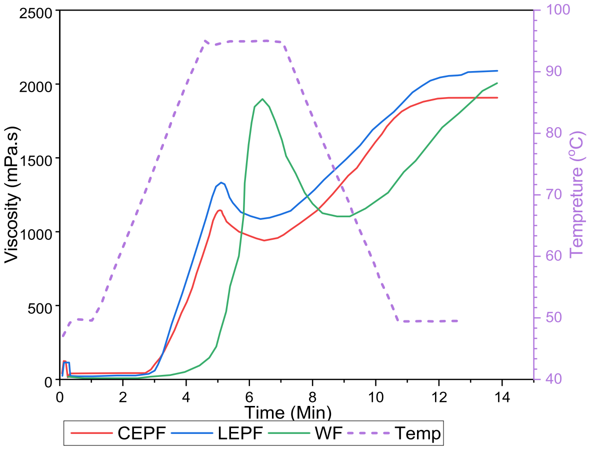

Fig. 7. The pasting profile of the EPFs and WF.

type of starch granules, amylose content and other components like non-starch polysaccharides, lipid and protein [11,56] and other quality properties and processing methods of the sample [2]. There was a significant difference in the TV values of EPFs and WF, with the TV value of LEPF (1086.3 mPa s) being higher than that of CEPF (939.3 mPa s). Wolde et al. [54] mentioned that the TV value is a measure of a material's capacity to withstand heating and shearing, and higher TVs are ideal for industrial applications that require for high starch consistency over extended cooking. The BV values of the EPFs and WF showed a significant ($p \leq 0.05$) difference. The BV values of LEPF (246.2 mPa s) was higher than that of CEPF (205.3 mPa s), but lower compared to BV value of WF (795.3 mPa s). The BV value of a sample determines how well it can withstand heating and shear stress during cooking and samples with lower BV values suggest that starches are more stable in hot condition [11,54]. According to Bao et al. [13] the enhanced order of the amorphous areas, which reduced the disruption of the starch granules, may be responsible for the lower breakdown value. The FV values of EPFs and WF varied as 1907.2 mPa s (CEPF), 2006.3 mPa s (WF) 2089.5 mPa s (LEPF) with considerable difference ($p \leq 0.05$) among them. In comparison to CEPF, LEPF (2089 mPa s) showed significantly higher ($p \leq 0.05$) FV values, indicating that it has the greater potential to gel or paste after cooking or cooling. This could be attributed for the same reason that a high FV has been related to the aggregation of amylose, as described in the study by Dereje et al. [11]. Moreover, according to Shimelis et al. [57], FV values are used to indicate the starch stability of cooked paste.

Significant differences were observed between the SB values of the EPFs and WF, where they ranged as WF (902.9 mPa s < CEPF

(967.6 mPa s) < LEPF (1003.2 mPa s). The higher SB values indicates the higher tendency of the starch samples to retrogradation due to reassociation of granules during cooling [54] and low SB value could be indication of high fat content in the sample [11].

The PT value of the EPF varied as 75.5 °C (LEPF) and 78.50 °C (CEPF) with considerable difference among themselves and WF (89.57 °C). This value is lower than the PT of *D. alata* and *D. rotundata* yam variety flours, which ranged from 83.10 to 90.45 °C [58], but higher than the PT range of potato flour, which was 70.2–73.7 °C [13]. The lower the PT value is preferred due to energy cost [11].

4. Conclusion

This study investigated the physicochemical, structural, functional, and thermal properties of flours from two indigenous Ethiopian potato varieties (Chanqua and Loffo) and compared them with WF. The impact of oven drying and sun drying methods on the physicochemical properties were also assessed. The findings indicated that significant differences ($p \leq 0.05$) were found between EPFs and WF across all examined properties. The MC of EPFs varied depending on the drying method. OD-LEPF showing higher protein and amylose content compared to SD-CEPF, influenced by both variety and drying method.

Significant variations ($p < 0.05$) were observed in all colour characteristics caused by the Ethiopian potato varieties and drying methods with the exception of b* values in the drying methods. The SEM analysis revealed that the starch granules were spherical and elliptical (oblong) in shape, embedded in the fibre, lipid, and protein matrix, resulting in the development of large, granular bundles. FTIR analysis showed significant structural changes, particularly in sensitive regions, leading to variations in the location and intensity of infrared absorption peaks. The X-ray diffraction patterns of the EPFs exhibited the characteristic B-type diffraction.

LEPF had significantly lower values HR, CI, and angle of response and higher WAC, OAC, and SP properties compared to CEPF. The study also highlighted notable differences in the thermal and pasting properties between CEPF and LEPF. Furthermore, the oven drying method positively influenced the physicochemical properties, with LEPF showing superior physicochemical, functional, structural, and thermal properties compared to CEPF.

Data availability statement

Data included in article/supp. Material/referenced in article.

CRediT authorship contribution statement

Misikir Milkias: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shimelis Admassu:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Formal analysis. **Workineh Abebe:** Writing – review & editing, Visualization, Validation, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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