Physicochemical properties of tef starch: morphological, thermal, thermogravimetric, and pasting properties

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\section*{ABSTRACT}
Starches isolated from the tef variety (Quncho) were examined for their physicochemical, morphological, thermal, pasting, and thermogravimetric characteristics. Studies revealed that the Quncho tef and maize starches had moisture, fat, total protein, and ash contents of 8.1, 0.59, 0.02, 0.25, and 5.99, 0.61, 0.01, 0.21 g/100 g, respectively. Quncho tef starch had higher phosphorus content (45.1 mg/100 g sample) than corn starch (40.6 mg/100 g sample). Starch purity of Quncho tef was found to be low (91.6 g/100 g), while corn starch was high (93.6 g/100 g). Amylose contents of Quncho tef starch were observed to be lower (22.2 g/100 g) than those of the corn starch (28.4 g/100 g). Variation of amylose contents significantly affects the physicochemical, morphological, and thermal properties of the starches. Quncho tef starch was low $T_o$, $T_p$, $T_c$, $\Delta T$, and $\Delta H_{gel}$ values of 33.3°C, 78.2°C, 125.1°C, 91.8°C, and 1.72 J/g, respectively, while commercial corn starch was high $T_o$, $T_p$, $T_c$, $\Delta T$, and $\Delta H_{gel}$ values of 34.7°C, 117.9°C, 179.3°C, 144.6°C, and 5.29 J/g, respectively. The initial, peak, and final thermal degradation of Quncho tef and commercial corn starches were 226.58°C, 354.45°C, 384.46°C, and 284.65°C, 417.71°C, 536.01°C, respectively. The maximum weight loss percentages of Quncho tef and corn starches were found to be 80.87% and 89.26%, respectively. The heat degradation of Quncho tef and corn starches was heavily influenced by the ratio of amylose to amylopectin content starch. Corn starch granules appeared oval in shape and irregular in shape under scanning electron microscopy, whereas Quncho tef starch granules appeared polygonal or hexagonal in shape and irregular in shape.

\section*{Introduction}
The principal Ethiopian cereal, Tef [\textit{Eragrostis tef} (Zucc.) Trotter], is farmed on 2.5 million acres annually and is a staple food grain for more than 50 million Ethiopians.\textsuperscript{11} Tef grain size is reported to be exceptionally tiny, with mean lengths ranging from 0.61 to 1.17 mm and mean widths ranging from 0.13 to 0.59 mm, yielding an average thousand kernel weight of 0.264 g.\textsuperscript{2} It has more iron, calcium, and zinc than other cereal grains such as wheat, barley, and sorghum.\textsuperscript{3} It also provides a superb protein balance of key amino acids.\textsuperscript{14} Tef grain is becoming increasingly popular in Western nations since it is gluten-free and has several nutritional benefits.\textsuperscript{5} Tef is utilized in the manufacture of healthful and new foods such as infant meals and gluten-free products.\textsuperscript{6} Tef has just been included in the “Celiac Diseases Foundation” and “Celiac Support Association” lists of gluten-free meals.\textsuperscript{17}
Starch is one of the most plentiful, inexpensive, and renewable biodegradable polymers among carbohydrate polymers, as well as a key source of energy.\textsuperscript{8} It has potential raw materials for industrial goods including functional components that provide texture, stability, and film-forming qualities, as well as non-food sectors such as biofilm, cosmetics, and pharmaceuticals.\textsuperscript{9,10} Cereals like maize and wheat are the primary botanical sources of starch, although they may also be found in roots and tubers.\textsuperscript{11} To date, tef grains are processed into flour and utilized as a component in a variety of products such as injera, pasta, and bread. Tef, on the other hand, has a high starch content (73%) and includes (18–27%) amylose, which is appropriate for starch synthesis.\textsuperscript{17} Bultosa et al. have chosen four different tef varieties and concluded that the starch extracted contains (28.2%) amylose content of the total starch of tef grain.\textsuperscript{12}

A novel tef variety is being researched. Quncho is Ethiopia’s most popular tef variety, and it is a must-have component for creating outstanding injera because of its great yield and highly white seed color when compared to other tef varieties.\textsuperscript{1} The use of starch in the food and non-food sectors is determined by its physicochemical qualities, which include morphology, size, amylose concentration, crystal properties, thermal properties, swelling powers, and hydrolysis capabilities.\textsuperscript{13,14} The knowledge of food properties is most needed to solve the issues in different angles such as preservation of food, processing, efficient storage, packaging, consumption, and marketing. Furthermore, the appropriate analysis on food properties in terms of classification can comprise significant data for avoiding imprecision. Since tef is most superior in Ethiopia for its nutrient composition as a staple food and it is proven that the tef starch is slowly digestible, the knowledge on the studies on starch derived from new tef varieties will be most welcome for the particular applications. In addition, such a study will be more helpful for further research to look for an appropriate modification to obtain the required functional characteristics for a specific end use. Therefore, information on the starch obtained from Quncho tef variety is essential to utilize for starch-based goods. Hence, the major goal of this research was to provide information on the physicochemical, morphological, thermal, and thermogravimetric properties of starches extracted from Quncho tef variety grown in Ethiopia.

**Material and methods**

**Raw materials and chemicals**

*Quncho tef* (Dz-cr-387) was obtained from Debreziet Agricultural Research center located 47 km from Addis Ababa. Commercial corn starch, chemicals, and reagent were purchased from Mexico sub-city Micron PLC Addis Ababa, Ethiopia.

**Isolation of starch**

The starch was extracted isolated according to the method described by Bultosa et al. (2002), with minor modifications (Figure 1).\textsuperscript{12} The tef grain was crushed and sieved by a 600-mesh sieve. Tef powder (around 100 g) was combined with 500 mL distilled water (DW) and agitated for 1 hour at 25°C. Wet milling was used to grind the slurry again, and it was filtered twice through a 200-mesh screen. After that, the filtrate was centrifuged at 4000 rpm for 15 minutes at 20°C (pro-Analytical C2004). The supernatant was discarded, and the gray layer was scraped off with a spatula. After that, the sludge was distributed in DW. The procedures above were repeated until the gray layer could not be seen. The finished product was distributed in DW and dried for 24 hours at 50°C. The separated starch was crushed in a mortar, sieved using a 200-mesh sieve, and kept at 4°C.

**Properties of tef starch**

*Chemical composition*: The chemical composition of tef starches (moisture, ash, fat, and protein content (%)) was determined using AOAC methods (AOAC, 2000).\textsuperscript{15}
Phosphorus content: With a small adjustment, the phosphorus content of Quncho tef and commercial corn starches was determined using the ammonium molybdate and vanadate spectrophotometric technique.\textsuperscript{16} A combination of a starch sample (0.6 g) and 1 mL 10% zinc acetate solution was heated until dry and after that washed for 3 hours at 550°C and cooled down. The ash was mixed with 1 mL (w/v) HNO 3 (29%, w/v), then ashed for another 1 h, cooled, and dissolved in 1 mL 20% HCl, which was well stirred. The volume was adjusted to 10 mL with distilled 165 water after 0.2 mL of supernatant was collected and mixed with 1 mL HNO 3 (29%), 1 mL ammonium vanadate (0.25%), and 1 mL ammonium molybdate (5%). The absorbance was measured at 435 nm against a sample blank after 10 minutes. Potassium dihydrogen phosphate was used to generate a calibration curve (0–20 g phosphorus per mL).

Starch yield: On a dry matter basis, the starch yield was measured as a percentage of the total starch content in flour. The following equation (1) is used to determine the starch yield of Quncho tef starch.

\[
\text{Starch Yield} = \frac{\text{Weight of isolated starch (db)}}{\text{weight of tef flour (db)}} \times 100
\]  

Amylose and amylopectin content: The amylose content of extracted starch was determined.\textsuperscript{17} 0.03 g of starch was prepared and incorporated in 20 ml of 0.1 NaOH. The suspension of starch was continuously stirred and then added to a 250 ml volumetric flask. Further, the solution was diluted using distilled water. 10 ml of an aliquot of the starch suspension was pipetted into a 100 ml volumetric flask. Next to this, 10 ml of 0.1 N HCL was added into a 100 ml volumetric flask with 1 ml of iodine reagent and then, the volume was diluted to 100 ml. The absorbance was calculated at 625 nm. Finally, the amylose content of both starches was determined, and also amylopectin content was calculated by the difference of percentages of amylose content.

Swelling power: The swelling power of the Quncho tef and corn starches was determined by a modified method by Torruco et al.\textsuperscript{18} Starch (2 g) was dispersed in 80 ml distilled water in pre-weighed 50 ml centrifuge tubes and kept in a shaking water bath at 80°C for 30 min. The suspension was then be centrifuged at 3000 \(\times\) g for 25 min. The supernatant was carefully decanted in a petri dish,
evaporated and dried at 130°C for 2 h until a constant weight is achieved and were weighed to calculate the g/100g Solubility. The residue was weighed for swelling power estimation. The experiment was conducted in triplicates. Swelling power is determined using equation (2):

\[
\text{Swelling Power} = \frac{\text{weight of sediment paste (g)}}{\text{weight of sample (dry basis)}}
\]

(Pasting properties)

Pasting properties of Quncho tef and corn starches were determined by using a Rapid Visco Analyzer (RVA 4500, Perten Instrument Ltd., Sweden), according to the method of Bultosa. The dried starch sample was weighed (3.5 g, db) and added in distilled water, then adjusted to a total weight of 25 g. The starch sample was equilibrated at 50°C for 2 min, heated to 90°C in 5 min at a rate of 6°C/min, held at 90°C for 5 min, then cooled to 50°C in 6 min at a rate of 6°C/min. Pasting temperature, peak viscosity (PV), peak time (Pt), peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BV), final viscosity (FV), and Setback viscosity (SBV) was determined from the final pasting curve.

Retrogradation (%): The suspension (1.5%, w/v) of Quncho tef and corn starches was prepared and heated at 85°C for 30 min in a water bath. After that, the sample was removed in a water bath and cooled at room temperature for a few minutes. The starch sample was immediately placed in refrigerated at 4°C for 1, 2, and 3 days. After refrigeration, the starch sample was centrifuged at 4000 rpm for 15 min, and retrogradation was calculated as the percentage of the amount of water removed after centrifugation.

(Thermal properties of starches)

According to Reddy, the thermal properties of the Quncho tef and commercial corn starches were evaluated with slight modification. 1 g of starch sample was mixed with 3.5 ml of distilled water. The starch suspension was stirred by a magnetic stirrer for 30 min until well homogenous and kept for 1 hour before analysis. The thermal analysis was performed by using a differential scanning calorimeter (DSC, SKZ1052B, China). The starch sample was added to the pan or sample holder, then hermetically sealed. An empty pan was used as a reference. Afterward, the sample holder or pan was heated from 20°C to 140°C at a heating rate of 10°C/min, under an inert nitrogen atmosphere at a rate of 50 mL/min. Thermal parameters such as onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and gelatinization temperature (ΔH) were evaluated by using the TA Instruments Software.

(Thermogravimetric analysis starches)

The thermogravimetric properties of Quncho tef and commercial corn starches were determined by thermogravimetric analysis equipment (DSC-TGA) Q600 equipment (TA Instruments, USA). 3.526 mg of starch sample was transferred into the DSC-TGA alumina crucible. The starch sample was heated from room temperature to 710°C at a rate of 15°C/min, and the ramps were under to determine the decomposition of starch. The ramps were adjusted under a nitrogen atmosphere at 200 mL/min. Differential thermogravimetric analysis (DTGA) was used to evaluate the maximum rate of starch degradation, and decomposition and weight loss linked with residual material were evaluated through TA Instruments software.
Table 1. Chemical constitutes of Quncho tef and corn starches.

| Sample          | MC (%) | Fat (%) | TP (%)  | A (%, dry basis) | SY (%) | Am (%, dry basis) | P(mg/100 g) | Ap (%) |
|-----------------|--------|---------|---------|------------------|--------|-------------------|-------------|--------|
| Quncho tef starch | 8.1 ± 0.06 | 0.59 ± 0.01 | 0.02 ± 0.01 | 0.25 ± 0.01 | 70.8 | 22.2 ± 0.78 | 45.1 ± 0.04 | 77.8 ± 0.3 |
| Corn starch      | 5.88 ± 0.09 | 0.61 ± 0.01 | 0.01 ± 0.01 | 0.21 ± 0.01 | -     | 28.4 ± 0.45 | 40.6 ± 0.08 | 71.6 ± 0.55 |

TP: total protein, A: ash, SY: starch yield, SP: starch purity, Am: amylose, P: phosphorus Ap: amylopectin, ± indicates the standard deviations of data represent mean values of three samples.

Scanning electron microscopy (SEM)

A scanning electron microscope was used to take electron micrographs of the starches (Stereo scan 250 Mk3, Cambridge Instruments Limited, Cambridge, Japan). Samples of powdered starch were placed on double-sided sticky tape put on an aluminum stub, and the starch was then covered with gold.

Statistical analysis

The data reported in all of the tables are an average of triplicate observations and were subjected to one-way analysis of variance (ANOVA). Pearson correlation coefficients (r) for the relationships between all properties were also calculated using Minitab Statistical Software version 17 (Minitab Inc., USA).

Results and discussion

Chemical composition starches

Table 1 shows the physicochemical composition of tef starch isolated from Quncho varieties and commercial corn starch. In terms of fat content (0.59% and 0.61%) and total protein content (0.02% and 0.01%), Quncho tef and corn starches had comparable compositions, but Quncho tef starch had higher moisture content (8.1) and ash content (0.25%) than corn starch (5.88%) for moisture content and (0.21%) for ash content. The moisture content of Quncho tef starch was found to be greater than that of commercial maize starch in this investigation. However, it is less than 10%, which is acceptable.21 According to this finding, the moisture content of Quncho tef starch was greater than the moisture content of tef starch previously reported.22 Quncho tef starch has a lower fat level than maize starch reported (0.49%).23 Quncho tef starch has a lower total protein content than previously reported for tef starch.12 A similar result was observed by previous findings.23 According to the data, the reduced protein level of Quncho tef starch suggests good starch purity. As a result, Quncho tef starch is the best material for creating edible films. Granule surface and internal protein make up the protein in starch granules.24

The highest phosphorus level was found in Quncho tef starch (45.1 mg/100 g), whereas commercial maize starch had the lowest (40.6 mg/100 g). The presence of phosphorus in Quncho tef and corn starches is critical for the contribution of swelling of starch granules. This finding was validated by prior research on potato starches.25

The proximate compositions of starches depend on the botanical sources of raw materials and processing conditions of starches. According to this result, we showed that the lower protein content of Quncho tef starch indicates high purity of starches as comparable to the previously reported values.12 The presence of phosphorous content in Quncho tef and corn starches is very important for the contribution of swelling of starch granules. The Quncho tef starch showed the highest phosphorus content (45.1 mg/100 g), while commercial corn starch had the lowest phosphorus content (40.6 mg/100 g). This similar result was confirmed with previously reported potato
starches. The phosphorus concentration of starches varies depending on cultivar, storage, agronomical circumstances, and the amylose/amylopectin content ratio. Starch’s physicochemical and functional characteristics were considerably influenced by the presence of phosphorus.

**Starch yield**

Table 1 shows the starch and yield purity of Quncho tef and commercial corn starches. The starch yield of Quncho tef starch was (70.8%), which was greater than earlier tef starch findings. The variance in this yield is related to the varietal differences in the extraction sources (Jan, Saxena, and Singh 2016). The purity of Quncho tef starch was (91.6%) low as compared to corn starch (93.6%); the variation of these results may be due to the method of extraction of the starch.

**Amylose and amylopectin content**

The amylose content of starches has a considerable impact on the internal quality and properties of the starch. According to these findings, Quncho tef starch has a lower amylose concentration (22.2%) than commercial maize starch (28.4%). The amylose content of Quncho tef starch was lower than tef starch varieties reported by Bultosa et al. Amylose and amylopectin concentrations have a substantial impact on the physicochemical and functional aspects of starches such as swelling power, solubility, pasting, retrogradation, and thermal properties of starches. Amylose concentration of starches varies greatly depending on botanical genotypes, soil type, climatic circumstances, and harvesting period during cultivation. The amylose-to-amylopectin ratio is an important characteristic in the functional qualities of starches. The amylose content of starches is particularly important for the creation and stability of thickening and gelling agents in food industries for the manufacturing of pasta, cakes, and bread, and it is also utilized in the development of biodegradable edible films.

**Thermal properties**

Thermal properties indicate the gelatinization temperature of starches, which means the temperature at which heated starch granules undergo the transition from the crystalline state to a gel. Thermal parameters of starches (onset temperature \(T_o\), peak temperature \(T_p\), conclusion temperature \(T_c\), gelatinization temperature \(\Delta T\), and enthalpy of gelatinization \(\Delta H_{gel}\)) are presented in Table 2. Onset temperature \(T_o\) means the initial peak temperature or at a temperature beginning to swell starch granules. Peak temperature \(T_p\) indicates the point where the gelatinization or swelling of starch granules is complete. The enthalpy of gelatinization \(\Delta H_{gel}\) is a characteristic index that reflects the energy consumption of starch during the gelatinization process. The thermal parameters \(T_o\), \(T_p\), \(T_c\), \(\Delta T\), and \(\Delta H_{gel}\) of Quncho tef and commercial corn starches are significantly different. Quncho tef starch was low \(T_o\), \(T_p\), \(T_c\), \(\Delta T\), and \(\Delta H_{gel}\) values of 33.3°C, 78.2°C, 125.1°C, 91.8°C, and 1.72 J/g, respectively, while commercial corn starch was high \(T_o\), \(T_p\), \(T_c\), \(\Delta T\), and \(\Delta H_{gel}\) values of 34.7°C, 117.9°C, 179.3°C, 144.6°C, and 5.29 J/g, respectively. Transition temperatures \(T_o\), \(T_p\), \(T_c\) of Quncho tef starch were higher than those previously reported by Bultosa et al. Variations in the

### Table 2. Thermal properties of starch obtained from Quncho tef and corn starch.

| Sources          | \((T_o) \, ^\circ C\) | \((T_p) \, ^\circ C\) | \((T_c) \, ^\circ C\) | \((\Delta T) \, ^\circ C\) | \((\Delta H_{gel}) \, J/g\) |
|------------------|------------------------|------------------------|------------------------|----------------------------|----------------------------|
| Quncho tef starch| 33.3 ± 0.24a           | 78.2 ± 0.84a           | 125.1 ± 0.62a          | 91.8 ± 0.41a               | 1.72 ± 0.41a               |
| Corn starch      | 34.7 ± 0.35b           | 117.9 ± 0.51b          | 179.3 ± 0.10b          | 144.6 ± 0.68b              | 5.29 ± 0.68b               |

Values with similar letters in the same column do not differ significantly \((p < 0.05)\).

Onset temperature \((T_o)\), peak temperature \((T_p)\), conclusion temperature \((T_c)\), and gelatinization temperature \((\Delta T)\), enthalpy of gelatinization \((\Delta H_{gel})\).

± indicates the standard deviations of data represent mean values of three samples.
thermal properties of Quncho tef and commercial starches may be attributed to the differences in phosphorus contents, amyllose contents, and degree of crystallinity. The onset, peak, and conclusion temperatures of Quncho tef starch were lower than commercial corn starch and may have been due to their higher phosphorus contents. According to this study, Quncho tef starch showed higher phosphorus contents and a lower degree of crystallinity, while commercial corn starch had a lower phosphorous content and a higher degree of crystallinity. Similar results have been reported in previous findings for potato starches. Higher phosphorus content is thus expected to give rise to lower gelatinization temperatures as monitored by DSC (Figure 2). The phosphate groups may destabilize the crystalline structures in the amyllopectin regions of the starch granules, leading to lowering of the gelatinization and melting temperatures of the starches. The differences in transition temperatures (T<sub>o</sub>, T<sub>p</sub>, T<sub>c</sub>) among Quncho tef and corn starches may also be attributed to differences in the degree of crystallinity. J. Singh et al. (2006) showed that a higher degree of crystallinity of potato starches leads to higher transition temperatures. The transition temperature value of Quncho tef and corn starches has a direct relationship with the crystalline structure shown in the XRD analysis. High transition temperatures have been reported to result from a high degree of crystallinity, which provides structural stability and makes the granules more resistant to gelatinization.

Enthalpy of gelatinization was lower for Quncho tef starch (1.72 J/g), while it was higher for commercial corn starch (5.29 J/g). Enthalpy gelatinization of these starches was higher than that in the previous findings that have been reported by Bultosa et al. The enthalpy of gelatinization for commercial corn starch showed that more energy is consumed to initiate swelling of starch granules. The enthalpy of gelatinization (ΔH<sub>gel</sub>) is a characteristic index that reflects the energy consumption of starch during the gelatinization process. The variations in (ΔH<sub>gel</sub>) could represent differences in bonding forces between the double helices that form the amyllopectin crystallites, which, resulted in different alignment of hydrogen bonds within starch molecules. It is an indicator of the loss of molecular order within the granule that occurs on gelatinization. The gelatinization enthalpy values of starches have been reported to be affected by factors such as granule shape, percentage of large and small granules, degree of crystallinity, and the presence of phosphate esters.

![Figure 2](image-url)

**Figure 2.** DSC curves of Quncho tef and commercial corn starches.
The thermogravimetric analysis (TGA & DTGA) of Quncho tef starch was lower than that of commercial corn starch. The differences in the gelatinization range values among the Quncho tef and commercial corn starches may be due to the presence of small crystallites with slightly different crystal strengths in the crystalline regions of the starch granules. Gelatinization or temperature ranges of Quncho tef starch were higher than the previous findings reported by Bultosa et al.\textsuperscript{12}

\textbf{Thermogravimetric analysis (TGA & DTGA)}

The thermogravimetric analysis is a relevant technique that provides important information about the thermal stability of starches for their industrial application. TGA and Derivative thermogravimetric (DTGA) curves for the thermal degradation process of Quncho tef and commercial corn starches are shown in Figure 3. DTGA curves revealed the rate of weight loss or derivative of thermogravimetric curves. According to TGA/ DTGA curves, there are two main steps in the degradation processes of starches. As seen in Figure 4, The first weight loss of TGA Quncho tef and commercial corn starches occurred between 25°C and 130°C, 20°C, and 100°C, respectively, which was corresponding to the initial vaporization of water.\textsuperscript{134} The second steps of weight loss of the TGA curve for Quncho tef and commercial corn starches have occurred between 200°C and 670°C, 300°C, and 570°C, respectively, which are related to the principal decomposition of starches.\textsuperscript{135} This stage reveals the thermal degradation of starch macromolecules (amylose and amylopectin) and micro-organic components.\textsuperscript{26} The final stages of weight loss of Quncho tef and commercial corn starches are greater than 670°C and 560°C, respectively, during which the slow elimination of more resistant organic compounds occurs, and at 700°C the accumulation of ash or residue occurred.\textsuperscript{126}

The initial thermal degradation of Quncho tef and commercial corn starches was 226.58°C and 284.65°C, respectively. This is due to the energy required for breaking the \(\alpha - 1, 4\) glycosidic bond in commercial corn starch being larger than in Quncho tef starch. Furthermore, the maximum decomposition rate of Quncho tef and commercial corn starches are 354.45°C and 417.71°C, respectively. The degradation rate of corn and cassava starches was the fastest from 316°C to 319°C, respectively.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{TGA & DTGA curves of Quncho tef starch.}
\end{figure}
Figure 4. TGA & DTGA curves of commercial corn starch.

and this may be due to $\alpha - 1,6$ glycosidic bond breaking requiring more energy than the $\alpha - 1,4$ glycosidic bond. Quicho tef and commercial corn starches are completely degraded or decomposed, when the temperature reached above 570°C. Moreover, the maximum weight loss percentages of Quicho tef and corn starches were 80.87% and 89.26%, respectively. This is matched to the thermal decomposition of starch and other macromolecules and minor organic components. The thermal degradation residue or mass loss residue of Quicho tef and commercial corn starches was 18.24% and 10.58%, respectively.

Scanning electron microscopy

The granule morphology of starches was identified by scanning electron microscopy (SEM). Granule morphology is a relevant parameter used to characterize and identify the size and shapes of granule starches or to identify the structural characteristics of starch granules. Scanning electron microscopy of Quicho tef starch was examined at 500 x, 1000 x, and 25000 x, respectively, which are presented in Figure 5. Observations from the scanning electron microscopy of Quicho tef starch showed various shapes of granules. Quicho tef starch granules have varied shapes, a mixture of small and large granule size, and their surface appeared to be compact and some cracked or fractured. Quicho tef starch showed polygonal or hexagonal in shapes, irregular shapes, and its corners are with a few granules round. It was observed to be smooth and compacts the surfaces of starch granules. This result is comparable with the previous report of SEM of rice starches.

From these results, SEM of starch showed the presence of many large-sized granules, but they have different shapes of granules. Variations in amylose contents of both starches exhibited the differences in granule size of Quicho tef starch. This is due to the granular size is directly related to the amylose content of the starch. From the observations, it is well agreed with the previous findings. Morphology of Quicho tef starch has a close agreement with the starches of tef varieties and corn, respectively. The difference in granule morphology may be attributed to the biological origin, biochemistry of the amyloplastic, and physiology of the plant.
Swelling power

Swelling power is a major physical property of starch. It occurred during the heating above gelatinization temperature due to the ability of the starch to swell in excess water. The swelling power of *Quncho tef* and commercial corn starches is shown in Table 3. Significant variation (*P* < 0.05) in the swelling power of starches was observed between *Quncho tef* and corn starches. In this investigation, the swelling power of the *Quncho tef* starch was lower than 6.76 (g) corn starch 11.42(g). This trend is in agreement with the swelling power of DZ-Cr-37, and DZ-01-1681, except for maize starch. However, the corn starch had lower swelling power than the previous report by Sandhu et al.\(^\text{38}\) This is due to the commercial corn starch having lower amylase content than *Quncho tef* starch. Therefore, the lower the amylose content of starch is revealed the higher the swelling power and vice versa. Variation in swelling power is due to the differences in amylose and amylpectin in their starch granules. The ability of starch molecules to retain water determines their swelling power via hydrogen bonding. The starch molecules that are heated in excess water revealed the breaking of crystalline structure, and this might be due to the disruption of hydrogen bonds, and water molecules become connected by hydrogen bonding to the exposed hydroxyl groups of amylose and amylpectin. This causes an increase in the granule swelling power of starches.

Pasting properties

The variations in the pasting parameters (peak viscosity, PV; trough viscosity, TV; breakdown, BD; final viscosity, FV; setback, SB; pasting temperature, PT) directly exhibited the cooking behavior of starches during the heating and cooling cycles. These parameters are very important in industrial application products and provide information about the viscosity and thickening behavior of starch. The pasting parameters and curves of *Quncho tef* starches are presented in Figure 6.

The mean pasting temperature (PT) of *Quncho tef* (70.70°C) and corn starches (70.70°C) were identical in this work. The *Quncho tef* and corn starches exhibited no significant difference (*P* < 0.05) in their pasting temperatures. This trend has coincided with the pasting temperature of different *tef* varieties and maize starches that were reported by Bultosa et al.\(^\text{12}\) However, the pasting temperature of *Quncho tef* and corn starches were lower than the corn starch, Chenopodium starch, normal and waxy rice starch, normal maize starch, sweet potato starch, and corn starch, but higher than the pea starch, maize starch, potato starch, and quinoa starch. Previous authors showed that the low pasting temperature of starch reveals the lower resistance to swell and rupture starch granules.\(^\text{39}\) Pasting temperature is the point to start swelling and begin to increase the viscosity of starch.\(^\text{40}\) The *Quncho tef* and corn starches exhibited a significant difference in their pasting parameters (*P* < 0.05), except Pasting temperature (PT). Peak viscosity designates the water-holding capacity of starch granules, and the maximum viscosity reached by the sample and propensity of starch granules to swell easily before
Table 3. Swelling power and pasting properties of Quncho tef and corn starches.

| Sample          | Swelling power (g) | Pasting temperature (Pt) | Peak time (min) | Peak Viscosity (cP) ± | Breakdown Viscosity (cP) ± | Trough Viscosity (cP) ± | Setback Viscosity (cP) ± | Final Viscosity (cP) ± |
|-----------------|--------------------|--------------------------|-----------------|------------------------|---------------------------|--------------------------|--------------------------|------------------------|
| Quncho Tef starch | 6.76 ± 0.00300a    | 70.70 ± 0.240a           | 7.00 ± 0.0929a  | 8805.00 ±0.04a         | 2048.00 ±0.05a            | 6757.00 ±0.03a           | 2729.00 ±0.03a           | 9486.00 ±0.07a          |
| Corn starch     | 11.42 ± 0.340b     | 70.70 ± 0.509b           | 4.33 ± 0.03b    | 12,058 ± 0.15b         | 4640.00 ±0.04b            | 7418.00 ±0.01b           | 5175.00 ±0.06b           | 12,593.00 ±0.15b        |

Values with similar letters in the same column do not differ significantly (p < 0.05).

± indicates the standard deviations of data represent mean values of three samples.
breakdown viscosity.\textsuperscript{41} Peak viscosity was found to be the lowest for \textit{Quncho tef} starch (11,984.9 cP) and the highest for corn starch (12,061.9 cP). Similar values of peak viscosities for different tef varieties and maize starches have been reported by Bultosa, Taylor, and Trotter.\textsuperscript{12} The peak viscosity of starches can be influenced by granule size, the structure of amyllopectin, crosslinking, moisture content, lipids, and residual proteins. According to Liu, Ramsden, and Corke, cross-linking contributed to a decrease in the peak viscosity of normal rice starch.\textsuperscript{42} Peak viscosity of \textit{Quncho tef} and corn starches were higher than the native and modified normal and waxy rice starch, sweet potato starch, rice starch, maize starch, indica rice starch, and quinoa starch, while lower than the potato starch varieties.\textsuperscript{26}

Figures 4 and 5 exhibited the required time to achieve the peak viscosity of the starch. \textit{Quncho tef} starch (peak time 7.00 min) took the shortest time than corn starch (peak time 4.00 min) to attain their peak viscosity (PV). The peak time of \textit{Quncho tef} starch was no significant difference with different tef varieties that investigated by Bultosa, Taylor, and Trotter except for maize starch.\textsuperscript{12} These trends are in agreement with Pineda-gomez and Gonzalez, who showed that the potato varieties have the shortest time to reach the PV because they have the highest water absorption index measures and lowest amylose content.\textsuperscript{26} The breakdown viscosity is the difference between peak viscosity and trough viscosity and is used to measure the fragmentation of starch granules.

The average breakdown viscosity (BV) for \textit{Quncho tef} starch paste (2048.00 cP) was significantly lower than that of corn starch (4640.00 cP). Similar values of breakdown viscosities for different tef varieties and maize starches have been investigated by Bultosa, Taylor, and Trotter\textsuperscript{12} and for pea starch have been reported by Z. Lu, Donner, and Liu.\textsuperscript{43} The breakdown viscosities of \textit{Quncho tef} and corn starches were higher than the normal rice starch, corn starch, corn starch varieties, Chenopodium starch, rice cultivars starch, and normal maize starch while lower than the indica and japonica rice starch varieties.\textsuperscript{44} The differences in moisture content of corn starch have extremely influenced the breakdown viscosities, this intention may be applied for \textit{Quncho tef} and corn starches. On the other hand, the decrease in breakdown viscosities of starches might be due to incomplete pasting and swelling of starch granules, crosslinking, and greater resistance to shear and heat of starch paste, and a minimum degree of expansion of starch granules.\textsuperscript{45}

Trough or hot paste viscosity contributes to the greater strength of the granule starches and starch consistency during prolonged cooking. Trough viscosity (TV) was found to be the lowest (6757.00cP) for \textit{Quncho tef} starch and the highest (7418.00 cP) for corn starch. This trend corresponds to that of Bultosa, Taylor, and Trotter.\textsuperscript{12} However, trough viscosity of starches is highly influenced by the
following factors such as amylose leaching, amylose lipid complex formation, friction between swollen granules, and granule swelling.\textsuperscript{37} Setback viscosity designates the difference between the final viscosity (FV) and hot paste viscosity value (HPV). SB exhibits the degree of retrogradation of the starch during cooling of the starch paste. The setback viscosity of \textit{Quncho tef} starch (2729.00 cP) was considerably lower than that of the corn starch (5175.00 cP). Similar values of cooling paste viscosity of different \textit{tef} varieties and maize starches have been reported by Bultosa, Taylor, and Trotter except for corn starch.\textsuperscript{12} However, SB of these trends is higher than corn starch and corn varieties starch, while lower than the pea starch. Higher setback viscosity of starches exhibited the higher retrogradation tendency and vice versa. Similar results of SB of potato starches have been reported by Abegunde et al.\textsuperscript{46} On the other hand, setback viscosities varied from the difference in moisture content of starches.

The final viscosity reveals the tendency of starch to form a viscous paste after cooling. The \textit{Quncho tef} and corn starches had significantly differed ($P < 0.05$) in their final viscosity. The final viscosities of \textit{Quncho tef} starch (9486.00 cP) were considerably lower than that of the corn starch (12,593.00 cP). The \textit{Quncho tef} and corn starches had higher final viscosity than the different \textit{tef} and maize starches and this might be due to the accumulation of amylose molecules.\textsuperscript{12} The final or cold paste viscosity of the present work was higher than rice cultivars starch, and corn variety starches, while lower than the pea starch and native corn starch.\textsuperscript{52} Higher CPV is due to the persistence of the swollen granule starch paste after cooling.\textsuperscript{[47,48]}

**Conclusion**

The starch of a novel \textit{tef} variety (\textit{Quncho}) was isolated and studied for its physicochemical, morphological, thermal, and thermal stability characteristics. The correlations between these qualities in \textit{Quncho tef} and maize starches were investigated. The amylose concentration of \textit{Quncho tef} and corn starches varies greatly. The chemical compositions of quinoa \textit{tef} starch and maize starch were equivalents. The contents of amylose and amylopectin have had a considerable impact on the physicochemical, morphological, and thermal characteristics of starches. Variances in thermal characteristics between \textit{Quncho tef} and commercial starches can be related to differences in phosphorus concentration, amylose content, and crystallinity. The phosphorus content of starch is inversely related to its thermal properties. \textit{Quncho tef} starch degraded more slowly than maize starch. Because more energy is required to destroy the amylopectin structure of starches, the ratio of amylose to amylopectin concentrations has a substantial effect on the thermal decomposition of starches. The thermal stability of starch is an essential factor to consider when heating food items. SEM analysis of \textit{Quncho tef} and corn starch granules revealed a variety of shapes and sizes, with a combination of small and big granules. The variations in granule size of \textit{Quncho tef} and corn starches were revealed by variances in amylose contents of both starches. \textit{Quncho tef} starch had polygonal or hexagonal forms, as well as irregular shapes, whereas maize starch granules had oval shapes, as well as irregular shapes.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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