RESEARCH ARTICLE

# Study of the physicochemical and functional characterization of quinoa and kañiwa starches

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The objective of this work was to study the physico-chemical and functional properties of starch isolated from different quinoa varieties and kañiwa ecotypes regarding their possible uses in cereals-derived food. Four ecotypes of kañiwa and three varieties of quinoa were analyzed. Starch isolation from quinoa and kañiwa flour was carried out by combining two extraction procedures. Quinoa and kañiwa isolated starches had similar chemical composition but protein, lipid, and fiber content was lower for quinoa than kañiwa starches. The amylose content varied from 9.30 to 8.35% for quinoa and from 17.44 to 10.70% for kañiwa starches. Significant differences in pasting properties were observed among quinoa varieties and kañiwa ecotypes, quinoa starches had higher peak and final viscosity and lower setback than kañiwa. Amylose content correlated negatively with peak viscosity and positively with setback. Kañiwa starches yielded higher firmness starch pastes than quinoa starches. No differences in starch granule morphology between quinoa and kañiwa were observed, both species showed polygonal granules. However, granules from quinoa were larger (≈2.53 μm) than kañiwa granules (≈1.45 μm). Differences in granule size, amylose content, pasting and thermal properties among quinoa and kañiwa provide new starch types with a wide range of possibilities for food applications.

**Keywords:**
Amylose content / Kañiwa starch / Pasting properties / Quinoa starch

## 1 Introduction

Quinoa (*Chenopodium quinoa*) and kañiwa (*Chenopodium pallidicaule*) are indigenous grains from the Andean region. Peru is the largest producer of quinoa in the world, followed by Bolivia, the United States, Canada, and Ecuador. In Chile, quinoa is cultivated in the north, in the area known as *altiplano*, and in southern fields at sea level [1]. In Argentina, it is grown in small areas in the highlands of Jujuy and Salta and it is mainly produced for family consumption. Kañiwa is cultivated only in the Peruvian-Bolivian *altiplano* region.

These crops have been used for centuries for their high nutritional value by pre-Columbian cultures in South America. Due to the genetic variability of quinoa and kañiwa cultivars, these two crops are adaptable to a wide range of environmental conditions, i.e., from sea level to high mountains – particularly kañiwa which can be grown at over 4000 m a.s.l. – and from cold highland climates to subtropical conditions.

At present, both kañiwa and quinoa are used in Bolivia and Peru in a wide variety of recipes and preparations, mostly soups and refreshing drinks. Kañiwa is also consumed as *kañihuaco* or *pito* which is roasted and ground grain. This roasted flour can be consumed as breakfast when it is mixed with sugar, milk, water, or juice. Quinoa seeds can be mixed with honey and used in the preparation of energy bars.

Due to their nutritional value quinoa and kañiwa are becoming of increasing interest worldwide. Both, have been shown to have high protein content, as well as a balanced amino acid composition, minerals such as calcium and iron, and they are a source of good quality edible oil [2]. In addition, quinoa – as well as kañiwa – is rarely allergenic because of the absence of gluten [3]. Hence, it can be used in foods designed to reduce allergies in sensitive individuals, such as people

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**Abbreviations: BD,** breakdown; **FV,** final viscosity; **PT,** pasting temperature; **PV,** peak viscosity; **SB,** setback

 

with celiac disease. Moreover, the use of these Andean crops could offer economic benefits to some South American countries, where cereals cultivation – such as wheat and corn – is low due to geographical and climatic conditions.

Both species belong to the Chenopodiaces family. Kañiwa is less known outside of its place of origin. However, it is the most nutritional, the best adapted cereal in the Andean environment.

The major component of Andean grains is starch (approximately 60–70% of dry matter). Quinoa starch occurs as small polygonal granules with a diameter of 1.0–2.5 μm [4, 5]. It has been reported a considerable variability in the amylose content of quinoa starch (4–20%) [2, 4–8], although, in general quinoa presents lower amylose content than cereal starches [4, 5] and it gelatinizes in a range of temperatures between 50–65°C [8].

Starch is used in many food preparations because it contributes greatly to textural properties and has many industrial applications as a thickener, colloidal stabilizer, gelling, bulking, water retention, and adhesive agent. Currently potential uses of starches with small granule size have been described [9]. However, in order to be used regularly by the food industry, starch production has to meet with quality requirements of food industry. At the moment no process for separation and characterization of kañiwa starch has been reported, and there are few studies on the physicochemical and functional properties of quinoa starches from different varieties. The objective of this work was to study the physicochemical and functional properties of starch isolated from different quinoa varieties and kañiwa ecotypes, regarding their possible industrial uses, particularly in cereals-derived food applications.

## 2 Materials and methods

### 2.1 Materials

Four kañiwa ecotypes (K-Local, K-381, K-081, and K-300) and three sweet quinoa varieties (Q-Chucapaca, Q-Kurmi, and Q-Jacha Grano) from Bolivia PROINPA germplasm bank were analyzed. Quinoas are commercial varieties from PROINPA foundation. Kurmi was obtained from Amarilla de Maranganí variety, as maternal parent, and accession L-57(85) as paternal parent (pedigree 61(93)/1/1/1-4/1-8/8/1-4/M/M/). Jacha Grano was obtained from accession 1489 and Huaranga variety crossing (pedigree 26(85)/4/1/2/1/1/1/M/1-6/1-10/M/) (http://www.proinpa.org/index.php?option=com_phocadownload&view=category&id=1%3Arq01&lang=es). Chucapaca variety was obtained crossing 0086 and 005 quinoa accessions. Kañiwa ecoptypes came from Quipaquipani y Jalsuri communities of Viacha city in Bolivian central *altiplano*. All grain was from 2006 growing season.

The quinoa and kañiwa grains were subjected to a manual cleaning process to remove impurities and chaff. Then quinoa seed were washed with cold current water to remove saponin. Subsequently, the samples were dried at 40°C until the moisture content reached 15 ± 2 g/100 g. The flour of quinoa and kañiwa were made in a blade mill (Oster, Shelton, USA) and were then sieved to 60 mesh.

Grain compositions are shown in Table 1. The moisture, lipid, ash, crude fiber, and protein (N × 6.25) contents were determined according to approved methods 44-19, 30-10, 08-01, 32-10, and 30-25, respectively [10]. Carbohydrate content was determined by difference. All determinations were made in duplicate.

### 2.2 Methods

#### 2.2.1 Starch isolation

Starch isolation from quinoa and kañiwa flours was carried out by combining two extraction procedures [5, 11]. For quinoa starch isolation, quinoa flour was suspended (1:5) in NaOH 0.25% w/v, shaken for 5 min and centrifuged for 20 min at 2465 × *g*. The precipitate was then washed with water and finally the suspension was filtered through a 270 mesh sieve. The filtrate collected was centrifuged and the precipitate (quinoa starch) was dried at 30°C for 24 h. For kañiwa starch isolation, kañiwa flour was suspended (1:3) in water and the suspension was filtered through a 270 mesh sieve. The material retained was subjected to the suspension-

**Table 1.** Flour compositions of kañiwa ecotypes and quinoa varieties

| Flour | Moisture (%) | Protein (%) | Ash (%) | Fat (%) | Crude fiber (%) | Carbohydrate[a)] (%) |
|---|---|---|---|---|---|---|
| K-Local | 9.88e | 12.02a | 4.55e | 11.67e | 4.26c | 61.88a |
| K-081 | 8.00cd | 14.75b | 2.32c | 11.42de | 3.42b | 63.51a |
| K-300 | 6.26a | 14.63b | 2.79d | 11.18d | 5.71e | 65.14a |
| K-381 | 7.46b | 17.55c | 2.54c | 9.83c | 5.08d | 62.62a |
| Q-Chucapaca | 7.61bc | 13.76ab | 2.08b | 6.41ab | 1.95a | 70.14b |
| Q-J.Grano | 8.41d | 14.51b | 1.54a | 6.71b | 2.00a | 68.83b |
| Q-Kurmi | 7.99cd | 13.64ab | 2.07b | 6.19a | 1.98a | 70.11b |

Values followed by different letters in the same column are significantly different ($p<0.05$).
a) Carbohydrate content = 100 − moisture content − lipid content − ash content − protein content.

 

filtration procedure three times. All filtered suspensions were collected and centrifuged for 20 min at 2465 × *g*. The precipitate was resuspended (1:5) in NaOH 0.25% w/v, shaken for 5 min and centrifuged for 20 min at 2465 × *g*. Subsequently, the precipitate was washed with water and then with alcohol. The final precipitate (kañiwa starch) was dried at 30°C for 24 h.

#### 2.2.2 Starch isolated composition

Starch moisture, lipid, and ash contents were determined according to approved methods 44-19, 30-10, and 08-01, respectively [10]. The crude fiber content was determined according to approved method 32-10 [10] by acid digestion ($H_2SO_4$ 1.25%) followed by an alkaline digestion (NaOH 1.25%). Protein content of the starch samples was determined according to approved method 30-25 [10]. Protein content was calculated as N × 6.25. All determinations were done in duplicate and expressed in dry basis.

#### 2.2.3 Determination of amylose content

Amylose content of starch samples was determined using the Megazyme amylose and amylopectin assay kit (Megazyme International, Ireland), according to the procedure described by Gibson et al. [12]. Assays were done in duplicate and the results were expressed as g of amylose/100 g of starch. Total starch content was simultaneously estimated in starch isolates (Table 2).

#### 2.2.4 Scanning electron microscopy (SEM) and size particle analyze

Starch granules were coated with gold particles for 4 min. The images were taken using a Jeol 35 CF (Tokyo, Japan) scanning electron microscope with a 6 kV acceleration voltage and 50.00 KX magnifications. Subsequently, the starch granules (approximately 50 mg) were fully suspended in water, and then the particle size distribution was obtained (0–100 μm) by a laser diffraction particle size analyzer (Horiba LA-950V2, Kyoto, Japan).

#### 2.2.5 X-ray diffraction (XRD)

Powder XRD patterns of starches were obtained using an X-ray Philips PW3020 (Eindhoven, Netherlands) diffractometer. X-ray patterns were taken with Cu Kα radiation ($1\lambda = 0.154$ nm) and the X-ray tube (Philips PW3830) was operated at 40 Kv and 30 mA. Scanning regions of the diffraction angle ($2\theta$) were 4–30° with scanning speed 2°/min.

Crystalline and amorphous areas were quantified using PeakFit v4 for Win32 Software (AISN Software, Inc.). Crystalline peaks were analyzed as pseudo-Voigt form and the amorphous background as Gaussian form peaks. A total area for crystalline phase and another for amorphous phase were obtained, and relative crystallinity was determined.

#### 2.2.6 DSC

The thermal characteristics of the starches were measured using a differential scanning calorimeter DSC 823 (Mettler-Toledo, Switzerland). The samples were weighed (15 mg of starch) directly into 100 μL aluminum pans, and water (45 mg) was added with a Hamilton microsyringe. Before the heating process, pans were sealed and stored for 24 h at 25°C. The samples were heated from 25 to 120°C at a rate 10°C/min. The DSC calibration was performed with indium, and an empty pan was used as reference. After analysis, all pans were stored for 14 days at 4°C to allow starch retrogradation, and re-analyzed (25–120°C at a rate 10°C/min) in order to study retrogradation. Onset temperature ($T_O$), peak temperature ($T_P$), gelatinization ($\Delta H$), and retrogradation ($\Delta H$) enthalpies were calculated. Samples were evaluated at least in duplicate.

#### 2.2.7 RVA

Pasting properties of starches were measured with a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty. Ltd., Warriewood, Australia), using the RVA general pasting method. Three grams of sample (dry basis) were transferred to a canister and approximately 25.0 mL distilled water was added. For a thorough dispersion of ingredients, the slurry

**Table 2.** Isolated composition of quinoa and kañiwa starches

| Starch | Moisture (%) | Ash (%) | Fat (%) | Protein (%) | Crude fiber (%) | Starch[a)] (%) | Amylose (%) |
|---|---|---|---|---|---|---|---|
| K-Local | 7.99a | 1.76c | 2.17ab | 1.69c | 1.27e | 82.94ab | 16.10e |
| K-081 | 8.70b | 0.97a | 2.40bc | 1.55b | 0.96c | 86.35c | 10.70c |
| K-300 | 7.92a | 1.41b | 2.87d | 2.74e | 1.19d | 82.62a | 17.44f |
| K-381 | 8.70b | 1.03a | 2.54c | 2.36d | 1.80f | 84.98bc | 14.56d |
| Q-Chucapaca | 9.96d | 1.46b | 1.94a | 1.09a | 0.24b | 85.01bc | 9.30b |
| Q-J.Grano | 9.29c | 1.48b | 2.00a | 1.13a | 0.19a | 83.49ab | 9.15b |
| Q-Kurmi | 10.87e | 1.64c | 2.56c | 1.11a | 0.22ab | 84.39abc | 8.22a |

Values followed by different letters in the same column are significantly different ($p<0.05$).
a) Starch percentage was estimated using the Megazyme amylose and amylopectin assay kit (Megazyme International, Ireland), according to the procedure described by Gibson et al. [12].

 

was stirred at 160 rpm while being heated to 50°C. The slurry was held at 50°C for 1 min, and then heated to 95°C at a heating rate of 9.4°C/min and a stirring rate of 960 rpm. Then it was held at 95°C for 2.5 min, and finally cooled to 50°C at a cooling rate of 11.8°C/min. Pasting temperature (P. Temp), peak viscosity (PV), peak time (P. Time), final viscosity (FV), breakdown (BD), and setback (SB) were obtained from the pasting curves. Samples were evaluated in duplicate.

#### 2.2.8 Penetration test of starch gelatinized pastes

Starch suspensions in water to 6% w/w in glass bottles were prepared. Suspensions were equilibrated at room temperature by 20 min with constant shake. The gelatinization of different starch types was carried out by immersing the glass bottle in water bath at 95°C for 10 min with manual agitation. Starch pastes were decanted in polypropylene bottles of 60 mm diameter and left to cool at room temperature. Subsequently, samples were stored at 4°C for 24 h. Paste firmness was determined by penetration test. Starch pastes were compressed with a probe of 2.5 cm in diameter at 10 mm/s up to 10 mm in depth. Starch paste firmness was calculated as the strength the probe needs to penetrate 10 mm into the sample.

#### 2.2.9 Statistical analysis

INFOSTAT statistical software (Facultad de Ciencias Agropecuarias, UNC, Argentina) was used to perform the statistical analysis. Determinations were done in duplicate. A Fisher's test (LSD) was made in order to evaluate differences among samples, while the relationship between measured parameters was assessed by Pearson's test (significant level at $p<0.05$).

## 3 Results and discussion

### 3.1 Starch composition

Starch isolated composition of quinoa and kañiwa is shown in Table 2. Slight composition differences were observed between kañiwa and quinoa starches. Quinoa starches showed slightly lower values for crude fiber and protein than kañiwa starches. This result agreed with kañiwa flour composition (Table 1), since this sample presented the highest crude fiber and protein contents. Possibly, some differences observed between starch isolates composition of kañiwa and quinoa could be due to the differences between the extraction methods used for each crop. The modifications were made in order to obtain a greater purity of isolated starch [13].

Kañiwa showed higher amylose content than quinoa, but both have lower contents than cereals or tuber starches. Typical levels of amylose and amylopectin in wheat are 25–28% and 72–75% [14], respectively. In sweet potato the range in amylose contents is 10–25% [15]. Among kañiwa ecotypes, the K-Local and K-300 presented significantly higher amylose contents than K-081 and K-381 ecotypes. Q-Kurmi variety of quinoa presented the lowest content. The amylose content of different varieties and ecotypes were in agreement with the considerable variability in quinoa starch informed by other authors [6, 7, 16].

### 3.2 SEM and size particle analyses

The morphological characteristics of starches from different plant sources vary with the genotype and growing conditions. The size and shape of starch granules depend on their biological origin [17]. Quinoa and kañiwa starch granules presented a bimodal size distribution (data not shown) since they form aggregated which are typical of most starches that consist of small granules [16]. The size range of quinoa and kañiwa starch granules could be estimated from the first peak of the bimodal curve. Size of starch granules showed significant variations; quinoa granules ranged between 1 and 3.5 μm while kañiwa granules were smaller than 2.0 μm. The size mean of granules from quinoa were larger (≈2.53 μm) than kañiwa granules (≈1.45 μm). Scanning electron micrographs of the starch granules from quinoa varieties and kañiwa ecotypes are shown in Fig. 1. Starch granule shapes of Quinoa and kañiwa were similar: irregular, polygonal, and angular, typical of small granule starches. In addition, granule surfaces of quinoa and kañiwa were less smooth than potato starch granules. Similar results were observed by Lindeboom et al. [8], Tang et al. [7], and Wright et al. [11] in starches from different quinoa varieties.

### 3.3 XRD

X-ray diffractometry was used to evaluate the presence and characteristics of the crystalline structure of starch granules. Starch from quinoa and kañiwa presented the A-type crystalline arrangement pattern that is associated with quinoa and is also typical of cereal starches (Fig. 2). Estimated X-ray crystallinities of Q-Chucapaca, Q-J.Grano, and Q-Kurmi quinoa starches were 38.0, 36.3, and 39.6%, respectively. The ecotypes K-Local, K-300, and K-381 for kañiwa starches presented lower crystallinity (34.0, 34.3, and 35.6%), compared to quinoa varieties. Ecotype K-081 was the only one that had a similar crystallinity (36.8%) to quinoa starches.

The different degree of granules crystallinities between quinoa and kañiwa could be due to the different botanical origin, to differences in the starches composition (kañiwa starches have significantly higher content of protein and fiber with respect to starches quinoa) and/or to changes in the starch extraction methods [18].

 

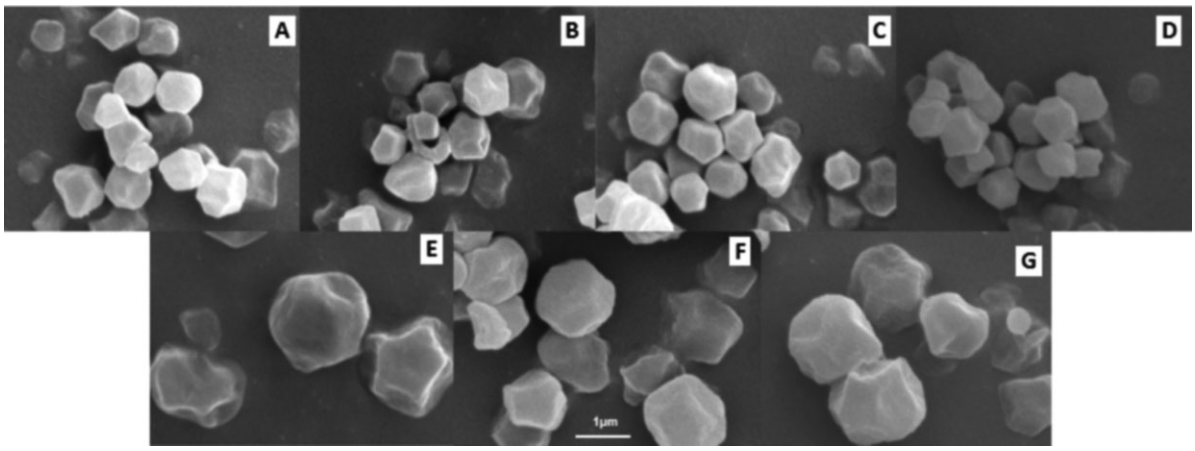


**Figure 1.** Scanning electron micrographs (50.00 kX magnifications) of starch granules from Andean Crops. (A) K-300, (B) K-381, (C) K-081, (D) K-Local, (E) Q-Chucapaca, (F) Q-J.Grano, (G) Q-Kurmi.

Crystallinity values for quinoa starches reported here are in good agreement with values reported by Tang et al. [7]. Starch granules have a semicrystalline structure. Amorphous regions are associated with amylose molecules, whereas crystalline ones are associated with amylopectin molecules [19, 20]. As expected, crystallinity percentage correlated negatively ($r = -0.90$; $p<0.05$) with amylose content indicating that kañiwa starches with higher level of amylose had lower crystallinity.

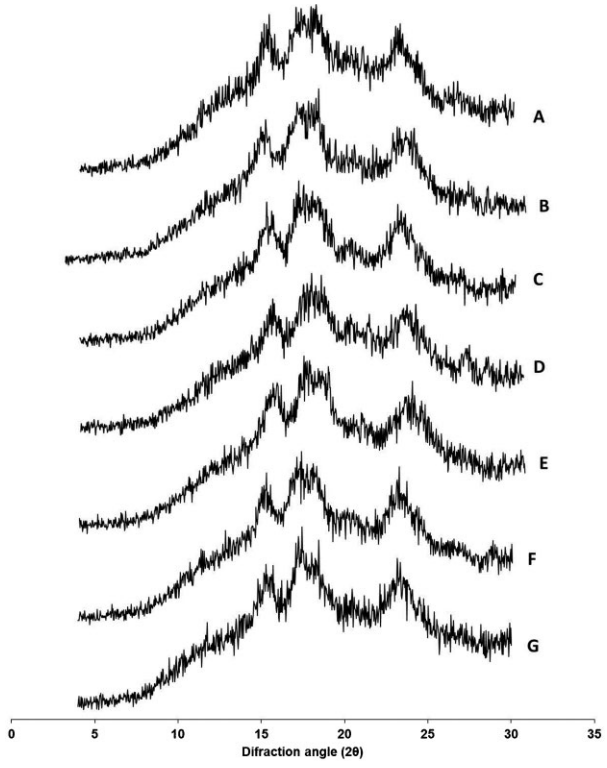


**Figure 2.** XRD of starch granules from Andean Crops. (A) K-300, (B) K-381, (C) K-081, (D) K-Local, (E) Q-Chucapaca, (F) Q-J.Grano, (G) Q-Kurmi.

### 3.4 DSC

The gelatinization and retrogradation parameters of starches are shown in Table 3. Gelatinization and swelling properties are a function of the molecular structure of amylopectin (chain length, branching ratio, MW, etc.), as well as amylose/amylopectin ratio, protein and lipid content, and the architecture of the granule (amorphous to crystalline ratio) [21]. Granule swelling usually starts at the onset temperature ($T_O$) of the DSC endothermic transition [22]. Kañiwa starches presented high onset and peak temperatures, compared to quinoa starches. Probably, high amylose, lipid, and protein contents of kañiwa starches hinder starch swelling properties and consequently onset was increased ($r = 0.76$, $r = 0.62$, and $r = 0.81$, respectively; $p<0.05$). In addition, amylopectin chain length plays an important role in gelatinization behavior, as longer chains require higher temperature than shorter chains to completely dissociate [23]. Jane et al. [24] reported that high amylose starches with longer CL presented high transition temperatures.

Gelatinization enthalpy gives an overall measure of crystallinity (quantity and molecular architecture of the crystalline region) and is an indicator of the loss of molecular order within the granule [25–27]. Among kañiwa ecotypes, K-300 starch presented the lowest gelatinization enthalpy, suggesting that granule architecture has a low molecular order and shorter amylopectin double helices. In addition, this sample has a lower crystallinity percentage and the highest amylose content. Among quinoa varieties, Q-J.Grano had, significantly, the lowest gelatinization enthalpy and this same sample presented low crystallinity, with respect to other quinoas.

 

**Table 3.** Thermal properties and retrogradation of quinoa and kañiwa starches

| | Gelatinization | | | Retrogradation | | | |
|---|---|---|---|---|---|---|---|
| Starch | $\Delta H$ (J/g)[a] | $T_0$ (°C)[b] | $T_P$ (°C)[c] | $\Delta H$ (J/g)[a] | $T_0$ (°C)[b] | $T_P$ (°C)[c] | $R$ (%)[d] |
| K-Local | 8.91c | 58.39d | 66.68d | 1.29d | 46.24b | 54.31c | 14.44e |
| K-081 | 9.32d | 59.16e | 66.16c | 1.27d | 46.90b | 53.40bc | 13.56d |
| K-300 | 7.49a | 59.18e | 66.30c | 1.17c | 44.18a | 52.02ab | 15.34f |
| K-381 | 9.06cd | 59.06e | 66.12c | 1.33d | 46.08b | 54.24c | 14.61e |
| Q-Chucapaca | 9.00cd | 54.90b | 61.97a | 0.40b | 45.97b | 52.16ab | 4.43b |
| Q-J.Grano | 8.45b | 54.25a | 61.66a | 0.48b | 44.31a | 51.75a | 5.63c |
| Q-Kurmi | 8.93c | 55.72c | 63.01b | 0.19a | 44.71a | 50.81a | 2.09a |

Values followed by different letters in the same column are significantly different ($p<0.05$).
a) Transition enthalpy.
b) Onset temperature.
c) Peak temperature.
d) Retrogradation percentage.

After gelatinization and during storage (4°C), starch retrogradation occurs: amylose forms double helical associations of 40–70 glucose units [28] and amylopectin recrystallizes by association of the outer branches [29]. Quinoa starches showed the lowest retrogradation enthalpy and percentage ($R$); these values were consistent with low amylose content ($r = 0.8$ and $r = 0.87$, respectively; $p<0.05$). Amylose content has been reported to be an influential factor for starch retrogradation [30–32]. Higher amylose content has been associated to an increase in starch retrogradation [33]. In addition, the retrogradation percentage correlated negatively with crystallinity ($r = -0.85$, $p<0.05$).

### 3.5 Pasting properties

The pasting properties of quinoa and kañiwa are shown in Table 4. All kañiwa starches presented low value of PV and FV and had high pasting temperature (PT). Amylose content negatively correlated with PV and FV ($r = -0.90$ and $r = -0.94$, $p<0.05$, respectively) and positively with PT ($r = 0.91$, $p<0.05$). High amylose content prevents granule swelling and the temperature of crystallites dissociation is usually higher [34]. The same result was observed by differential scanning calorimeter. Pearson's correlation coefficient between onset and PT was $r = 0.92$ ($p<0.05$). BD of starch granules is related to their ability to withstand heating and shear stress, and it is an important factor in many processes [35]. The K-300 and K-381 ecotypes had the lowest PV and they showed the highest granule stability, as indicated by the lowest BD. This result indicated that these starches can keep the kind of viscosity necessary during the elaboration processes of some foods, where high temperature and mechanical stirring are required. The increase in viscosity during cooling (SB) of a paste is a measure of retrogradation and is due to reassociation of starch molecules, especially amylose, resulting in the formation of a gel structure [22]. Starches from kañiwa had high SB values related to their high amylose content that retrograde at greater rate.

**Table 4.** Pasting properties of quinoa and kañiwa starches

| Starch | PV[a] (cp) | BD[b] (cp) | FV[c] (cp) | SB[d] (cp) | P. Time[e] (min) | P. Temp[f] (°C) |
|---|---|---|---|---|---|---|
| K-Local | 2173b | 673c | 2832ab | 1332d | 4.67 | 74.7c |
| K-081 | 2657c | 409ab | 3332c | 1085bc | 5.40 | 71.1b |
| K-300 | 1907a | 272ab | 2787a | 1151cd | 5.00 | 74.3c |
| K-381 | 2174b | 234a | 2981b | 1041bc | 5.43 | 71.4b |
| Q-Chucapaca | 3322d | 439b | 3725d | 843b | 5.17 | 62.7a |
| Q-J.Grano | 4168e | 743c | 4101e | 676a | 4.97 | 62.7a |
| Q-Kurmi | 4306f | 1161d | 4109e | 963bc | 4.97 | 62.7a |

Values followed by different letters in the same column are significantly different ($p<0.05$).
a) Peak viscosity.
b) Breakdown.
c) Final viscosity.
d) Setback.
e) Peak time.
f) Pasting temperature.

 

The SB correlated positively with amylose content and with retrogradation enthalpy ($r = 0.66$ and $r = 0.65$, respectively; $p<0.05$).

Quinoa starches showed high PV values, indicating a greater thickening power of starch at high temperature. Starch from Q-kurmi variety presented the highest peak and FV and, as expected, showed the highest BD value. High BD values of were associated with high peak viscosities ($r = 0.76$, $p<0.05$), which in turn, are related to the degree of swelling of the starch granules during heating. In consequence, the granules of Q-J.Grano, Q-Chucapaca, and Q-Kurmi varieties may have greater swelling capacity because these samples presented high PV values. Starches that swell in a high degree also show a low resistance to BD on cooking and hence they significantly exhibit a viscosity decrease after reaching the maximum value [36]. The industrial use of quinoa starches – which impart high viscosities during heating even when they present low stability under such conditions, resulting from high BD values – will depend on the final purpose that is pursued. The low SB values of quinoa starches, mainly of Q-J. Grano variety, indicated low rate of starch retrogradation. PT for kañiwa starches (71–74.5°C) were high compared to quinoa starches (62.7°C). PT indicates the minimum temperature required to cook a given food sample. This fact can have implications for the stability of other components in a formula and also indicates energy costs [37]. Starch with high viscosity peaks and low SB values could be used in foodstuffs that have to keep consistency, without getting hard or gelifying after cooling, such as instant creamy dessert.

### 3.6 Texture of starch pastes

Firmness of starch pastes of different samples of quinoa and kañiwa are shown in Fig. 3. Kañiwa starches presented higher values of firmness than quinoa starches. These starches could be used in various foodstuffs to get a desired consistency and firmness. No significant differences were observed in quinoa starches firmness; starch pastes were weak and showed water release indicating high syneresis. On the contrary, kañiwa pastes were harder than quinoa pastes and presented lower syneresis. The main factors that contribute to gel strength are the extent of the amylose gel network and the deformability of swollen granules [38]. The formation of weak pastes in quinoa starch samples may be the result of the low content of amylose molecules which re-associate among themselves and with amylopectin molecules to form the gel network. Whereas kañiwa starch of K-Local ecotype presented the highest firmness paste and the highest amylose content as well. Starch firmness correlated positively with amylose content ($r = 0.86$, $p<0.05$); moreover, Pearson's correlation coefficients between the SB and retrogradation percentage with firmness pastes were high ($r = 0.80$ and $r = 0.91$, respectively; $p<0.05$).

## 4 Conclusions

The starch from Andean crops presented different composition, characteristic, and properties. In general, quinoa starch granules were larger and had higher crystallinity than kañiwa granules. K-Local, K-300, and K-381 ecotypes had higher amylose contents compared to K-081 ecotype and three quinoa varieties. The different amylose content of varieties and ecotypes explained most of the differences in the pasting properties. Kañiwa starches presented high PTs and great SB values and retrogradation percentages. However, the Q-J. Grano and Q-Kurmi quinoa varieties showed the highest peak viscosities. K-300 and K-381 ecotypes had low BD values indicating a high ability to withstand heating and shear stress. Kañiwa starches yielded high firmness starch pastes that could be used in foodstuffs to get consistency and firmness, depending on the final food texture wished. In conclusion, quinoa and kañiwa starch properties indicated that these new types of starch can be used in the food industry and non-food applications, such as the pharmaceutical or textile industries, and the possibility of undertaking a systematic breeding program to develop quinoa and kañiwa lines with particular starch characteristics.

*The authors have declared no conflict of interest.*

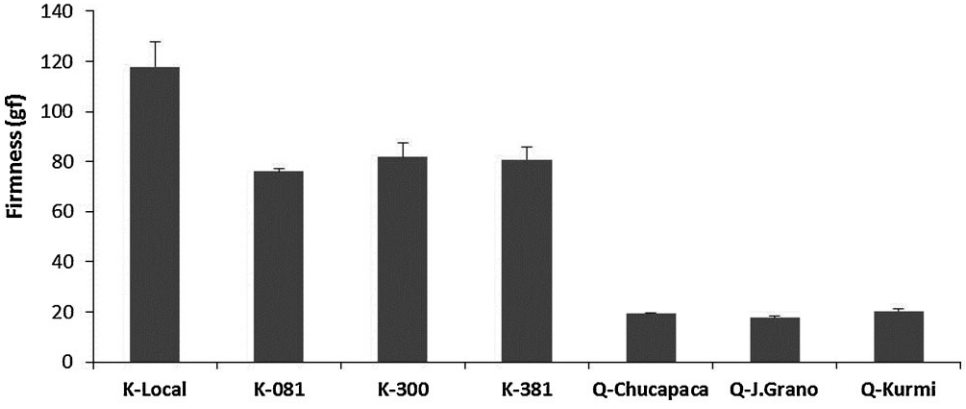


**Figure 3.** Starch firmness of different samples from quinoa and kañiwa.

 

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