Physico-chemical properties and nutrition quality of potato flour: chuño vs modern processing technology

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Zhao-Jun Wang: Design and executed the experiments, interpreted the results and wrote the draft manuscript; Xiao-Feng Liu: Executed the experiments and edit manuscript; Jian Xu: Wrote the draft manuscript and edit manuscript; Jaspreet Singh: Edit manuscript; Lovedeep Kaur: Edit manuscript; Gang Liu: Interpreted the results and edit manuscript; Fan-Kui Zeng: Wrote the draft manuscript and edit manuscript.

Competing interests
The authors declare no conflicts of interest.

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Abbreviations
AD, air drying; FD, freezing drying; WC, white chuño; BC, black chuño; PPO, polyphenol oxidase; Fe, iron; Ca, calcium; K, potassium; Mg, magnesium; Zn, zinc; TAC, total antioxidant capacity; FRAP, ferric reduction antioxidant power; ABTS, 2,2′-azino-bis (3-ethylbenzotiazoline-6-sulphonic acid); FW, fresh weight; K, potassium.

Citation

Abstract
Chuño production is a kind of ancient method of potato preservation that has been used to the present day. In this study, physicochemical property and nutrition quality of white chuño (WC), black chuño, and dehydrated potato flour prepared by hot air drying (AD) and freezing drying were analyzed and compared. The results revealed that the average particle size of the starch in WC is almost 10 times of the dehydrated potato flour by AD treatment according to the laser particle size meter. During the dehydration of WC, water-soluble minerals (K\(^{+}\), Mg\(^{2+}\)), proteins, ascorbic acid, etc. were partly lost while Ca\(^{2+}\) content increased dramatically. In addition, WC showed the lowest antioxidant capacity among the four different kinds of dehydrated potato products. The polyphenol oxidase activity of WC, black chuño and AD were between 0.62–12.2 U/g fresh weight, which indicated that the color will be stable when chuño was used as staple food ingredient in the subsequent process. Therefore, as a potato processed food, chuño displayed great potential for promotion in the cold and poor rural areas of the northern China.

Keywords: white chuño; black chuño; hot air drying; freezing drying; potato products
**Introduction**

As the world’s third largest food crop next to rice and wheat, potatoes play a major role in feeding the world’s population [1]. Potatoes are known for their high agricultural yields and significant nutritional value, providing a variety of macronutrients (carbohydrates and protein), micronutrients (vitamin C, potassium, magnesium) and potentially healthy phytochemicals [2]. As living organism, fresh potato tubers can be stored for only a few months under very good conditions. During the storage process, the quality of potato tubers usually declines, for becoming green, germinate, diseases and showing other physiological defects such as hollow heart, black heart, black spot, frostbite, browning reaction, and internal necrosis [3]. Dehydration provides a good solution to potato preservation, low-temperature vacuum drying method was reported in our previous study to prepare raw dehydrated potato flour. The obtained product possesses attractive properties similar to the dehydrated potato flour prepared by freezing drying, with low degree of protein denaturation, low degree of starch gelatinization, and less loss of other nutrients compared to the potato flakes [4].

Chuño production is an ancient method for potato preservation and potatoes are actually freeze-dried in the cold mountains. Currently, evidence of the presence of chuño’s starch grains has been found at the Middle Horizon (A.D. 600–1000) site in Quillacapampa La Antigua of Peru [5]. The process has been continually used to this day to yield the chuño products, which are highly prized by the people of the Andean countries [6–11]. Chuño production process is usually simple, mainly including material selection, trampling, freezing and drying [9]. This process refers to the black chuño, while the production process of white chuño (also called tunta) usually involves several steps: tending, treading, freezing, washing and drying [10], adding a cleaning step compared to black chuño. Criteria for the identification of different chuño in archaeological samples based on starch metrics and morphological properties has been developed by Melton, Biwer and Panjarjian [12]. The dehydrated product of chuño processing can be stored for several years and used when fresh potatoes are scarce. A recent study presented a thorough review of the existing literature on chuño about their nutritional and chemical properties, including their use in the Andean cuisine as a kind of important food ingredient [13].

There is no denying that modern drying technology has many advantages, such as high efficiency, convenience, standardized processing, and more stable quality, etc. [4]. However, many potatoes are grown in poor areas of the world, take China for example, 549 grow potatoes among 592 poverty-stricken counties. In all, more than 70 percent of the country’s potato cultivation acreage is distributed in poor areas [14]. Therefore, economic input is the primary consideration at these poor rural areas as for potato dehydration.

Due to the historical, cultural, and indeed economic importance of chuño processing, the chemical composition and nutritional value of this product deserved to be further investigated. A considerable amount of literature has been published on this issue [7–9], but most of the available research on chuño is published using Spanish language, and few studies have compared chuño with other dehydrated potato products. The present study was designed to compare and analyze the physiochemical properties and nutrition quality of potato flour prepared by chuño processing, hot air drying, and freezing drying. Through the comparison of the total antioxidative capacity and polyphenol oxidase activity among different samples, chuño was considered as an effective potato processed method and displayed great potential for promotion in the cold and poor rural areas of the northern China.

**Materials and methods**

Hot air drying (AD) potato flour and freezing drying (FD) potato flour were prepared in our own laboratory. White chuño (WC) and black chuño (BC) were gifts from International Potato Center, before testing the physical and chemical indicator, a mortar was used to grind them into powder. Black chuño production process is mainly including material selection, trampling, freezing and drying. The production process of white chuño (also called tunta) usually involves the following steps: tending, treading, freezing, washing and drying, adding a cleaning step compared to black chuño.

The ABTS assay kit and the FRAP test kit were purchased from the Beyotime Institute of Biotechnology (Nantong, China). Polyphenol oxidase (PPO) activity detection kit was purchased from Beijing Solarbio Science & Technology Co., Ltd. (Beijing, China).

**Color measurement**

According to $L^*$, $a^*$ and $b^*$ values, the color parameters of dehydrated potato flour were determined by a Color-Eye automatic differential colorimeter (X-Rite, G7 8000). The value of $L^*$ shows the lightness, the value of $a^*$ shows the degree of the red-green color. The value of $b^*$ displays the degree of the yellow-blue color. Under the same process conditions, the color analysis of the three treated samples was carried out. Accordingly, the mean values and the standard deviations were obtained. The scale of $L^*$ ranges from black (0) to white (100). The scale of $a^*$ extends from a negative value (green tone) to a positive value (red tone) and the scale of $b^*$ ranges from negative blue to positive yellow.

**Particle size analysis**

The granule size distribution of the potato starches was measured using a Mastersizer 3000 laser diffraction particle size analyzer (Malvern Pananalytical Ltd., Malvern, England). The wet sample dispersion unit was used to obtain information on 64 channels with particle size ranging from 0.05 to 900 μm. Using Mastersizer S software (Version 3.1, 1996), the results were expressed as a percentage by volume (%).

**Nutritional components analysis**

Dry matter was obtained according to the method of Chinese National Standard GB 5009.3-2016, the content of crude protein was measured on the nitrogen analyzer of Kjeldahl, which determines the nitrogen content of the sample. The content of protein was calculated by multiplying the nitrogen content with a factor of 6.25 (GB5009.5-2016).

The starch content was determined following the enzyme hydrolysis method of Chinese National Standard GB 5009.9-2016. The total ascorbic acid content was obtained based on GB/T 5009.86-2016 (2,6-dichlorophenol titration).

The contents of mineral were analyzed by flame atomic absorption spectrometry including iron (Fe), calcium (Ca), potassium (K), magnesium (Mg) and zinc (Zn), based on Chinese National Standard (GB 5009.90-2003, GB 5009.90-2003, GB 5009.14-2003, GB/T 5009.92-2003 and GB/T 5009.91-2003, respectively).

**Scanning electron microscopy**

Dehydrated potato flours were coated with gold and examined using a scanning electron microscopy (JSM-6701F, JEOL, Tokyo, Japan) under an acceleration voltage of 20 kV at a magnification of 1000 ×.

**The total antioxidant capacity (TAC)**

Two methods of ferric reduction antioxidant power (FRAP) [15] and 2,2’-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) [16] were utilized to determine the TAC of potato flour in this study.

The stock solution of FRAP was mixed in a ratio of 10:1:1 (v/v/v) with 2,4,6-tripyridyl-s-triazine solution and detective buffer, and then added to FRAP solution in a certain ratio. 5 μl samples with a concentration range of 0.05 to 1.5 mM were then added to 180 μl of FRAP working solution and stored at 37 °C for 5 min. The absorbance was measured at 593 nm. The FeSO₄ values of 0.15–5 mM were used to prepare a standard curve. The activity was expressed as the FeSO₄ values, which were calculated from the standard curves, and the results were calculated in unit of μmol/100 g.

The ABTS working stock solution consists of an ABTS solution and an oxidizing agent solution, mixed in an equal volume form, and kept...
in the dark at room temperature for 12–16 hours. The solution was then mixed and diluted with 80% ethanol to obtain an absorbance of 0.7 ± 0.05 at 734 nm. 10 μL samples with a concentration range of 0.05–1.5 mM were then mixed with 200 μL of fresh ABTS solution and the absorbance at 734 nm was measured after incubating at room temperature for 6 min. The results were expressed with μmol/100 g Trolox equivalent antioxidant capacity.

**Determination of PPO activity**

PPO activity was determined according to the instruction of Beijing Solarbio Science & Technology Co., Ltd. (Beijing, China). The sample was weighed 0.1 g, then 1 mL of the extract was added for homogenization, centrifuged at 8000 RPM for 10 min, and the supernatant was taken for testing. When the test liquid is measured, it is divided into a test sample and a control sample (water bath at 37 °C for 10 min, rapidly placed in boiling water for another 10 min), after cooling, centrifuge at 5000 g for 10 min at room temperature, zero with distilled water, and measured with a spectrophotometer at 410 nm. The PPO activity of the sample was calculated as follows: PPO (U/g) = 60 × (A1–A2), where A1 is determination, A2 is control group.

**Statistical analysis**

All experiments were conducted three times, and average values with standard deviation errors were reported. Statistical Product and Service Solutions 22.0 software was used to conduct one-way analysis of variance.

**Results and discussion**

**Color**

Previous literature described the color of black chuño as grey to light brown, while white chuño as white to light gray [13]. In this study, automatic differential colorimeter was used to measure the color parameters L*, a* and b*, the results are shown in Table 1. FD and WC had the largest L* values, followed by AD, and the smallest of BC. The difference of the L* values between the FD and WC were not significant, but they were significantly different from the AD and BC (P < 0.05). According to the definition of L*, the higher the L* value the brighter the sample, which indicates that there was not a browning reaction in freezing drying method. WC was similar to FD in process, so its color was also very white. As shown in digital pictures (Figure 1), the color differences of the four dehydrated potato flour samples could be seen intuitively. AD and BC were processed in a high-temperature environment, high temperature can cause browning reaction, and the color was therefore very dark. High-temperature drying method in potatoes flour affected the color, just as the high-temperature color changed during cooking, resulting in a Maillard reaction that produced a characteristic golden portion [17]. Similarly, the freezing state during drying process also affected the color, which can provide a whiter product with an uneven porous structure and a higher packing density [18].

In a* values, BC was the largest, followed by AD and FD, but FD was the smallest without a negative value of a* and there is no red hue. In the b* values, four samples were positive, the yellow component of FD and BC were more than FD and WC. Usually, the relationship between the color parameters and the dry temperature is that an increase in temperature, a decrease in sample brightness (L*), and redness (a*), increasing in yellowness (b*) [19]. Another thing worth mentioning is that the stability of the color of dehydrated potato flour needs to be further studied, especially whether it will change during processing. It is reasonable to believe that the color of samples processed at high temperature will be more stable, while the color of freeze-dried potato flour may change during further processing.

**Particle size**

Figure 2 shows the particle size distributions of four samples of the starch particles measured by laser scanning method. The granule size distribution of FD and AD starches was unimodal, but bimodal for WC and BC. WC had the largest average particle size (374 ± 2 μm), followed by BC (135 ± 3 μm). Compared to the starch granules of chuño, the starch granules in FD (81.2 ± 1.4 μm) and AD (40.2 ± 0.6 μm) had a normal particle size, which is consistent with the results of our previous study [20]. It also can be seen from the scanning electron microscopy pictures (Figure 2) that starch particles in WC and BC were significantly bigger than that in AD and FD, the average particle size of the starch in WC was almost 10 times that of the AD according to the results of the laser particle size meter.

<table>
<thead>
<tr>
<th>Table 1 The color characteristic of AD, FD, WC and BC</th>
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<tr>
<td><strong>L</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>a</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>b</strong>&lt;sup&gt;c&lt;/sup&gt;</td>
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</table>

The reported results are means ± standard deviation (n = 3) of the samples in three replicates, with different letters in the same line indicating significant differences (P < 0.05) among groups. Superscript of a, b, c, d represents the significance of data differences when performing the statistical analysis. AD, hot air drying; FD, freezing drying; WC, White chuño; BC, black chuño.

**Figure 1 Digital photographs of four different kinds of dehydrated potato flours.** AD, hot air drying; FD, freezing drying; WC, White chuño; BC, black chuño.

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It is also observed that the FD had the most concentrated particle size, followed by AD, and the WC and BC were relatively dispersed, which may be related to the drying method since chuño was frozen and thawed repeatedly during the processing. Another reason comes from the fact that the potatoes used for chuño processing were wild varieties of the Andes Mountains. Due to the potato variety for chuño processing is unknown, it is difficult to use the same variety for hot air drying and freezing drying in this study, but it reflects in some extent that the starch particle size in chuño is very huge and much larger than the results reported in previous literature [20]. Whether the size of the starch particle size is related to the digestibility and functional properties of the starch still need further investigation, Esther et al. [21] reported that the small particle size is easy to decompose faster, and the particle size is slower to hydrolyze.

**Nutritional components**

The nutrient composition of AD, FD, WC, and BC in this study is given in Table 2. As can be seen, the dry matter content of FD (90.45%) was the lowest meant high moisture content among the four samples. With a value of 95.83%, WC’s drying matter content was the highest, followed by BC (95.21%), it meant that the water loss was much during the drying processing, which was related to the processing procedure, especially the dry time. According to the Standards for Domestic Trade of the People’s Republic of China (SB/T 10752-2012), the moisture content of potato flakes should be ≤ 9%, which means except for the FD, the other three dehydrated potato products AD, WC and BC can meet the standard requirements of moisture content for safe storage.

The starch content of the four dehydrated potato products can also be found in Table 2. With a value of 91.16%, WC had the highest starch content, followed by FD (86.92% fresh weight (FW)) and BC (85.31% FW), AD had the lowest starch content of 73.19% FW. The previous study had reported that nearly 70% of dry matter of potato is starch, with is a major component in potatoes amounting approximately to 12.6%–18.2% of their fresh weight [22], as an effect, starch is considered to be a major factor in the function of the potato for food applications.

The protein concentration in BC and WC were 1.65% FW and 1.25% FW (Table 2). All the dehydrated potato products showed a lower protein concentration than that reported for raw potato tuber due to the dehydration water-soluble lost [13]. Burgos et al. [23] also reported a reduction of 48%–83% of protein during chuño processing.

Another nutrient that seriously decreased is vitamin C, the lowest total ascorbic acid content (0.58 ± 0.03 mg/100 g) was found in WC (Table 2) because one of the most important procedures in white chuño producing was washing and vitamins C were water-soluble substances. Ascorbic acid is known to be an unstable vitamin whose activity is affected by a variety of factors, including pH, moisture content, oxygen, temperature and metal ion catalysis [24]. The retention rate of vitamin C can be used as a quality indicator of dried products because if the ascorbic acid content is well retained, the other nutrients will usually be preserved as well [25]. In this study, FD contained 5.5 ± 0.05 mg total ascorbic acid/100g FW dehydrated potato flour, which is more than twice of that in AD. The content of total ascorbic acid in BC was slightly higher than that of AD.

![Figure 2 Particle size distribution (A) and scanning electron micrographs (B) of four different kinds of dehydrated potato flours. AD, hot air drying; FD, freezing drying; WC, white chuño; BC, black chuño.](https://www.tmrjournals.com/fh)

### Table 2 The nutritional components of AD, FD, WC and BC.

<table>
<thead>
<tr>
<th>Composition</th>
<th>AD</th>
<th>FD</th>
<th>WC</th>
<th>BC</th>
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<tbody>
<tr>
<td>Dry matter (%)</td>
<td>92.65 ± 0.89^a</td>
<td>90.45 ± 0.10^a</td>
<td>95.83 ± 0.49^b</td>
<td>95.21 ± 0.23^b</td>
</tr>
<tr>
<td>Total starch (%)</td>
<td>73.19 ± 0.85^c</td>
<td>86.92 ± 0.66^c</td>
<td>91.16 ± 0.87^c</td>
<td>85.31 ± 0.71^b</td>
</tr>
<tr>
<td>Total ascorbic acid (mg/100 g)</td>
<td>2.46 ± 0.08^d</td>
<td>5.50 ± 0.05^e</td>
<td>0.58 ± 0.03^f</td>
<td>2.94 ± 0.11^h</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>0.07 ± 0.06^d</td>
<td>1.40 ± 0.00^ab</td>
<td>1.25 ± 0.04^bc</td>
<td>1.65 ± 0.10^c</td>
</tr>
<tr>
<td>Potassium (mg/100 g)</td>
<td>7185.67 ± 6.34^f</td>
<td>15702.67 ± 15.20^f</td>
<td>297.07 ± 3.81^g</td>
<td>9784.00 ± 11.52^d</td>
</tr>
<tr>
<td>Calcium (mg/100 g)</td>
<td>36.39 ± 0.42^d</td>
<td>18.74 ± 0.20^c</td>
<td>273.63 ± 1.07^d</td>
<td>13.22 ± 0.18^c</td>
</tr>
<tr>
<td>Iron (mg/100 g)</td>
<td>28.26 ± 0.46^d</td>
<td>14.87 ± 0.11^b</td>
<td>36.67 ± 0.31^e</td>
<td>33.57 ± 0.70^b</td>
</tr>
<tr>
<td>Magnesium (mg/100 g)</td>
<td>402.15 ± 5.66^b</td>
<td>808.25 ± 2.80^a</td>
<td>169.33 ± 0.53^c</td>
<td>399.38 ± 1.96^a</td>
</tr>
<tr>
<td>Zinc (mg/100 g)</td>
<td>11.39 ± 0.12^e</td>
<td>13.09 ± 0.15^f</td>
<td>9.00 ± 0.15^i</td>
<td>11.93 ± 0.11^h</td>
</tr>
</tbody>
</table>

The reported results are means ± standard deviation (n = 3) of the samples in three replicates, with different letters in the same line indicating significant differences (P < 0.05) among groups. Superscript of a, b, c, d represents the significance of data differences when performing the statistical analysis. AD, hot air drying; FD, freezing drying; WC, white chuño; BC, black chuño.
Table 2 also shows the minerals content in four different kinds of dehydrated potato flour. With the values of 297.07 mg/100 g FW of potassium (K), 169.33 mg/100 g FW of Mg, and 9 mg/100 g FW of Zn, WC had significantly lower content of K, Mg, and Zn than that of AD, FD and BC, especially K and Mg. As for Ca content, the four samples ranged from 13.22 to 273.63 mg/100 g FW, WC had the highest value which was much higher than the other three samples. With a value of 36.67 mg/100 g FW, WC also had the highest content of iron, the difference was significant compared to the other three samples, but not as large as the difference in Ca content. Peñarrieta et al. [13] also reported that WC had high content of Ca and Fe.

In addition to potato varieties has an influence on minerals content [26, 27], the effect of processing procedures cannot be ignored. Chullo production process mainly including material selection, trampling, freezing and drying, the biggest difference between WC and BC was that WC was washed before drying [7, 8, 13]. We speculate that the mineral loss of potassium, zinc, and magnesium is basically ascribed to the relative water solubility of these minerals. Washing and trampling are likely to be the main cause of the mineral loss, and as a result the water and soluble solid content of the potato tubers are removed [28].

When the tubers are exposed to water, leaching or absorption of nutrients occurs [29]. For example, the drastic decrease of K is observed when the potato tubers are converted to white chuño, which may be mediated by water, because it reacts quickly and violently with water to produce water-soluble compounds such as potassium hydroxide. This explains why another type of dehydrated potato such as black chuño which is not exposed to water, maintains a higher level of K, Zn, and Mg than white chuño. In contrast, the higher Ca and Fe content of white chuño may be explained by the fact that these minerals are absorbed by potato during washing process, Ca and Fe are naturally exist in water, and the Fe absorbed from water is likely to be iron hydroxide, while the Ca absorbed from water is likely to be calcium hydroxide or calcium bicarbonate.

**Total antioxidant capacity**

The TAC of the four samples is shown in Figure 3. The TAC of these samples ranged from 0.1 to 1.8 μmol Trolox equivalents/g FW using FRAP and from 0.03 to 1.1 according to the ABTS method. The highest TAC value in four samples was observed in the BC, followed by AD and FD. WC had the lowest antioxidant capacity, which is almost the same as the blank, the most fundamental reason is the loss of antioxidants during processing. Phenolics and vitamin C are the main antioxidative substances in potato tuber, the total ascorbic acid content in white chuño was very low according to the results of nutrient composition analysis (Table 2). Peñarrieta et al. [9] reported that the TAC values measured by FRAP method decreased by about 70% after freeze-drying, while the TAC values measured by ABTS method remained basically unchanged.

Drying has two main effects on the antioxidant activity of potato, on one hand, heat-sensitive antioxidant active substances are destroyed in the high-temperature processing; on another hand, water loss removes antioxidant active ingredients [30]. Without washing in production, black chuño has high antioxidant activity. White chuño process is different, besides keeping the potatoes away from sunlight, the potatoes are stored for about three weeks in a hole called “tajana” in the aymara language, a lot of antioxidant active substances were lost during this washing process. According to the results of this study, black chuño, freezing drying and hot air drying potato flour can thus still be considered as an important source of antioxidants in the diet.

**PPO activity**

As can be seen from Figure 3, FD showed the highest PPO (317.48 ± 0.49 U/g FW), the values of the other three samples were between 0.62–12.2 U/g FW, which was much lower than that of the sample FD. The temperature used for freezing drying was below freezing point, and the activity of PPO was not easy to be inactivated in FD. After hot air drying, the high temperature instantly kills the enzyme, which reduced the activity of the PPO, so the enzyme activity was extremely low in hot air drying potato flour. The natural environment was used to produce chuño, whereas, temperature fluctuation caused by repeated freezing and thawing play a key role in the loss of PPO activity [28]. In addition, potato variety is also an important factor affecting the activity of PPO [31]. Cabezás-Serrano et al. [32] investigated the suitability of five different potato varieties for processing as fresh-cut products on the basis of their PPO activities.

As mentioned above, it is important to pay careful attention to the color change in the dehydrated potato during further processing, the PPO activity in freeze-dried potato flour is the highest, which meant that it is also prone to browning when compared with the other three samples. In the past few years, people have become more and more interested in the development of steamed bread, noodles, bread and other staple foods using dehydrated potato flour to partial replacement of wheat flour [33–35], it has been found that freeze-dried dehydrated potato flour browns during processing [35].

**Conclusions**

In summary, the physiochemical and nutrient properties of WC and BC were compared to the sample of hot AD potato flour and FD potato flour. Though some soluble minerals, proteins, and ascorbic acid were partly lost during the chuño dehydration, the total antioxidant capacity and polyphenol oxidase activity remained basically stable.
when chuño was used as staple food ingredient in the subsequent process. In addition, the color of chuño were stable in the subsequent staple food processing due to the low PPO activity. As a method of potato preservation, chuño is of great potential promotion in the cold and poor rural areas of northern China.

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