The effect of process and environment on the nutritional value of *chuño*

Stef de Haan[1], Gabriela Burgos[1], Jesus Arcos[2], Raul Ccanto[3], Maria Scurrah[3], Elisa Salas[1] and Merideth Bonierbale[1]

[1] International Potato Center (CIP), Av. La Molina 1895, Lima, Peru, s.dehaan@cgiar.org
[2] Instituto Nacional de Innovación Agraria (INIA), Rinconada de Salcedo s/n, Puno, Peru
[3] Grupo Yanapai, Jr. Atahualpa 297, Concepción, Perú

Abstract

The potato in its Andean center of origin is commonly freeze-dried to assure long-term storability and consequent availability of food during periods of scarcity. The final product is known as *chuño*. Depending on the process and cultivars used, different kinds of *chuño* are prepared: white *chuño* (*moraya*, *tunta*) and black *chuño*. This paper explores the nutritional value of *chuño* using data from research in the Peruvian Andes. The paper specifically investigates the effect of regionally different processes on the mineral content of *chuño*: Zn, Fe, Ca, K, P, Mg and Na. First, the effect of 4 processes (P), resulting in 2 types of white and black *chuño* respectively, for 4 cultivars (C) belonging to distinct botanical species (P*C interaction). Second, the influence of locality, cultivar and process on nutrient concentrations (L*C*P interaction). Specifically, the effect of 3 contrasting growing environments on the mineral content of 4 cultivars processed into 2 types of white *chuño*. Results of the first experiment show that the mineral content of *chuño*, independent of the mineral analyzed, is significantly influenced by P*C interaction. Results of the second experiment show that particularly the dry matter, Ca, Mg and Na content of white *chuño* is significantly affected by L*C*P interaction. The zinc, potassium, phosphorus and magnesium content of all 'types' of *chuño* decreases in comparison with boiled (unprocessed) tubers. White *chuño* generally contains stable to high iron and high calcium concentrations.

Keywords: potato, micro and macronutrient content, traditional freeze-drying.

Introduction

The cultivated potato in its Andean center of origin is commonly freeze-dried to assure long-term storability and consequent availability of food during periods of scarcity. The final product is known as *chuño* (López Linage, 1991; Towle, 1961). Depending on the process followed and cultivars used, different kinds of *chuño* are recognized (Condori Cruz, 1992). So-called black and white *chuño* are the result of different steps involved in the processing pipeline. The elaboration of either 'type' takes advantage of severe frosts at night alternated with high daytime levels of solar radiation and low levels of relative humidity during the months of June and July (Woolfe, 1987). White *chuño*, also commonly known as *moraya* or *tunta* in the Quechua and Aymara languages respectively (Gianella, 2004; Yamamoto, 1988), is frequently commercialized at markets while the use of black *chuño* is generally restricted to home consumption.

A main difference between the process of preparing black or white *chuño* relates to the prolonged exposure of tubers to (running) water. White *chuño* is always washed or soaked, in part to remove glycolalkaloids. Black *chuño*, on the other hand, is not exposed to water and its elaboration is generally simpler, basically consisting of tending, treading, freezing and drying (Mamani, 1981). The elaboration of white *chuño* has several regional variants. It generally involves all of the following steps: tending, treading, freezing, washing and drying (Werge, 1979). Aside from the process of preparing chuño, the particular potato cultivar involved influences the final quality. Cultivars belonging to the bitter species *Solanum curtilobum*, *S. juzepczukii* and *S. ajanhuiri* are almost exclusively used for traditional freeze-drying (Christiansen, 1977). Their high glycoalkaloid content restricts their use for fresh consumption. Native-floury cultivars of non-bitter cultivated species and even improved cultivars with *S. tuberosum* subsp. *tuberosum* within their pedigree are also commonly used to prepare *chuño* (De Haan *et al.*, 2009).

Woolfe (1987), quoting Collazos (1974), reports high energy contents for raw (non-boiled) white and black *chuño* of 323 and 333 kcal / 100 g on a fresh weight basis (FWB) compared to 80 kcal / 100 g for raw (non-boiled) potatoes. De Haan *et al.* (2009) report slightly higher values in the case of boiled white *chuño* ranging from 390 to 394 kcal / 100 g on a dry weight basis (DWB). According to Christiansen (1978), between 67 to 83% and 18 to 30% of protein is lost during the elaboration of white and black *chuño* respectively. Other authors also report the protein content of raw (non-boiled) black *chuño* to be higher compared to white *chuño* (Paredes and Gomez, 1987; Woolfe, 1987). Zavaleta *et al.* (1996) list the average energy, protein, iron and calcium content of 100 g of raw (non-boiled) white *chuño* to be 323 kcal, 1.9 g, 3 mg and 92 mg and that of black *chuño* 333 kcal, 4.0 g, 0.9 mg and 44 mg (FWB). These values are the same as those reported by Collazos (1974). Burgos *et al.* (2008) show the protein, iron, zinc and calcium concentration of boiled white *chuño* of 9 native cultivars to range from 0.49 to 1.15 g, 0.29 to 0.65 mg, 0.04 to 0.14 mg and 18.9 to 31.0 mg respectively per 100 g (FWB). With the exception of carbohydrate, calcium and iron, the nutrient content of white *chuño* is greatly reduced in comparison with fresh potato (Woolfe, 1987). This is confirmed by recent research from Burgos *et al.* (2008) and De Haan *et al.* (2009) which shows that the transformation of potato into white *chuño* does not significantly affect iron concentrations, yet results in a decrease of the protein and zinc content, and an increase of calcium. Woolfe (1987) points out that the nutrient content of black *chuño* is also reduced, but not to such a great extent as in white *chuño*.

Highland farmers in central and southern Peru typically consume black and white *chuño* of diverse freeze-dried potato cultivars rather than *chuño* from a single cultivar. However, little is known about the nutritional content of diverse native cultivars (cultivars; C), the effect of regionally distinct 'traditional' processes (P), and the influence of the environment (locality; L) on the macro- and micronutrient content of the black and white *chuño* variants. The research presented in this article explores the effect of 2 variants of both black and white *chuño* processing following standard 'traditional' procedures common to the departments of Huancavelica (central Peru) and Puno (southern Peru) on the mineral content of 4 frequently used native potato cultivars grown in a uniform growing environment. Additionally, it investigates the influence of 3 different growing environments (localities; departments of Junín, Huancavelica and Puno) on the mineral content of 4 cultivars processed into 2 'types' of white *chuño*.

Materials and methods

*Process by cultivar experiment (P*C)*

Seed tubers of 4 cultivars were collected in Huancavelica and Puno. A native-floury and a native-bitter cultivar were obtained from each department (table 1). Seed from the cultivars collected in Huancavelica were shipped to Puno where a uniform trial site was located in the community of Salcedo at an altitude of 3,820 m. All cultivars were planted on November the 12th 2007 in a field trial following a completely randomized block design (CRBD) with 3 repetitions. Crop management was uniform and tubers were harvested on June the 5th 2008.

After harvest, fresh medium-sized and undamaged tubers from each locality, cultivar and repetition were dispatched to the CIP's nutrition laboratory for preparation and subsequent mineral analysis of unprocessed tubers. Simultaneously, tubers of the same quality were sent to Huancavelica and Puno to process black and white *chuño* following standard 'traditional' procedures. Processing of the 4 'types' of *chuño* was done by Andean farmers: black and white *chuño* of the 'Huancavelica-type', black and white *chuño* of the 'Puno-type'. Each of the different 'types' of *chuño* was processed at a different location and, depending on the specific steps involved, took between 12 to 38 days to complete. Samples of all cultivars, repetitions and 'types' of *chuño* were used for mineral analysis.

Table 1. Native potato cultivars cultivated in a field trial at a uniform location (Salcedo, Puno)

Cultivar	Cultivar category	Species	Ploidy	Seed source
Azul Qanchillu	Bitter	*S. juzepczukii*	$2n=3x=36$	Huancavelica
Puqya	Floury	*S. stenotomum*	$2n=2x=24$	Huancavelica
Piñaza	Bitter	*S. juzepczukii*	$2n=3x=36$	Puno
Ccompis	Floury	*S. tuberosum* subsp. *andigena*	$2n=4x=48$	Puno

*Locality by cultivar by process experiment (L*C*P)*

Seed tubers of 4 native-bitter cultivars were collected in Huancavelica and Puno (table 2). Seed of each cultivar was shipped to locations in Junín, Huancavelica and Puno where field trials were installed following a completely randomized block design (CRBD) with 3 to 4 repetitions (table 3). Crop management was uniform for each locality with no agrochemicals applied and a single application of organic manure at 8 tons / ha.

After harvest, fresh medium-sized and undamaged tubers from each locality, cultivar and repetition were dispatched to CIP's nutrition laboratory for preparation and subsequent mineral analysis of unprocessed tubers. Simultaneously, tubers of the same quality were sent to Huancavelica and Puno to process white *chuño* following standard 'traditional' procedures. Two 'types' of *chuño* were prepared by Andean farmers from both departments: white *chuño* of the 'Huancavelica-type' and the 'Puno-type'. Samples from all localities, cultivars, repetitions and 'types' of *chuño* were used for mineral analysis.

Table 2. Native potato cultivars cultivated in a field trial at a single location (Salcedo, Puno)

Cultivar	Cultivar category	Species	Ploidy	Seed source
Azul Qanchillu	Bitter	*S. juzepczukii*	$2n=3x=36$	Huancavelica
Suytu Siri	Bitter	*S. curtilobum*	$2n=5x=60$	Huancavelica
Locka	Bitter	*S. juzepczukii*	$2n=3x=36$	Puno
Piñaza	Bitter	*S. juzepczukii*	$2n=3x=36$	Puno

Table 3. Basis data for each of 3 different trial sites (localities; L)

Location	Community	District	Province	Altitude	Planting	Harvesting
Junín	Quilcas	Quilcas	Huancayo	3,987 m	12-11-2007	10-06-2008
Huancavelica	Dos de Mayo	Yauli	Huancavelica	4,357 m	29-10-2007	04-06-2008
Puno	Salcedo	Puno	Puno	3,820 m	12-11-2007	05-06-2008

Preparation of analytical samples

Unprocessed tubers: a sample of 10 fresh tubers was prepared for each locality, cultivar and repetition. Tubers were washed with tap water, rinsed with deionized, distilled water and subsequently boiled. The boiled tubers were peeled and cut longitudinally into 4 sections (stem to bud end). Two opposite sections of each of the 10 tubers were combined to prepare each sample for mineral analysis. Two to 3 slices were taken from each section to obtain a 50 g sample; these were placed in a glass petri dish and oven-dried for 24 hours at 80ºC. The dried samples of approximately 12 to 16 g each were subsequently weighed and ground in an IKA A11 stainless steel mill and stored at -20ºC in hermetically sealed plastic bags.

Processed tubers: a sample of 10 freeze-dried tubers was prepared for each locality, cultivar, repetition and 'type' of *chuño*. *Chuño* tubers were washed, boiled, peeled and prepared to obtain samples for mineral analysis applying the same procedures as detailed above for unprocessed tubers.

Mineral determination

Analytical sub-samples of 0.6 g each were taken after boiling from each of the repetitions of each cultivar and for all treatments and digested at 140ºC in 70% (v/v) HNO3/HClO4. Samples were analyzed for iron (Fe), zinc (Zn), calcium (Ca), potassium (K), phosphorus (P), magnesium (Mg), sodium (Na) and aluminum (Al) by inductively coupled plasma-optical emission spectrophotometry (ICP-OES) using and ARL 3580 ICP. Aluminum (Al) was included to provide an indication of possible iron contamination from soil particles (Darrell and Glanh, 1999). Mineral determination was done on boiled samples because this is how potato tubers and traditionally freeze-dried *chuño* are consumed and therefore the results are more appropriate for estimation of the contribution of native potato cultivars and *chuño* to the human diet.

Statistical analysis

All the statistical tests were performed using SAS/STAT (version 8.2) software (SAS Institute 1999). Prior to the analysis of variance (ANOVA), the data sets were tested for normality using the Kolmogorov-Smirnov test and as not all the data were normally distributed, they were $\log^{10}$ transformed. When the combined ANOVA showed significant differences for the interactions, simple effect analysis on the GLM procedure was conducted considering the localities, cultivars and processes as fixed effects.

Results

The effect of process by cultivar

The mineral content of boiled *chuño*, independent of the mineral analyzed (Fe, Zn, Ca, K, P, Mg and Na), is significantly influenced by the process (P), cultivar (C), and P*C interaction. Tables 4 and 5 show the general results of the overall ANOVA for each of the 7 minerals analyzed. As an exception, only the dry matter content of boiled *chuño* is not significantly influenced by the interaction between process and cultivar (P*C). Content values for all cultivars and 'types' of *chuño* are shown in annex I. Findings described below are based on these values.

Dry matter (DM). Independently of the cultivar employed, black *chuño* of the 'Huancavelica-type' retains significantly higher levels of dry matter after boiling compared to the other 'types' of *chuño*. On average, the cultivar *Azul Qanchillu* maintained a higher dry matter content compared to the other cultivars in boiled tubers, both 'types' of boiled black *chuño* and boiled white *chuño* of the 'Huancavelica-type'. To the contrary, the cultivar *Piñaza* consistently had much lower dry matter contents compared to the other cultivars.

Iron (Fe). Only in the case of white *chuño* from Puno the influence of contamination was minimal (soil, dust). Results for this particular 'type' of *chuño* show that its iron content is significantly influenced by the cultivar employed. Interestingly, the iron content of boiled white *chuño* of the 'Puno-type' originating from native-bitter cultivars was higher while that of native-floury cultivars was lower compared to content values of boiled tubers of the same cultivars.

Zinc (Zn). Without exception, processing of *chuño* significantly reduces the tuber zinc concentration of all cultivars analyzed with an average loss of 71.3% for white *chuño* of the 'Huancavelica-type', 65.7% for white *chuño* of the 'Puno-type', 49.6% for black *chuño* of the 'Huancavelica-type' and 51.0% for black *chuño* of the 'Puno-type'. Results show that black *chuño*, independent of the specific 'type', retains higher levels of zinc compared to white *chuño*. The cultivar *Puqya* contained the highest concentration of zinc in boiled tubers while the cultivar *Piñaza* contained the highest concentration in boiled *chuño* for 3 out of 4 'types' analyzed.

Calcium (Ca). Both 'types' of white *chuño* contained significantly higher concentrations of calcium compared to boiled tubers while the content of both 'types' of black *chuño* generally tended to be lower. The only exception to the latter is boiled black *chuño* of the 'Huancavelica-type' from the cultivar *Piñaza*. The average calcium content of boiled white *chuño* of the 'Huancavelica-type' and the 'Puno-type' was 75.6% and 103.2% higher compared to the concentration of boiled tubers. On the other hand, the average calcium content of boiled black *chuño* of the 'Huancavelica-type' and the 'Puno-type' was 16.5% and 35.0% lower compared to boiled tubers. The cultivar *Piñaza* contained considerably higher levels of calcium in boiled tubers, both 'types' of white *chuño* and black *chuño* of the 'Huancavelica-type' compared to the other cultivars.

Potassium (K). The content of this mineral in boiled white and black *chuño* is affected negatively by freeze-drying. Both 'types' of boiled black *chuño* show an average 2.6-fold decrease in their potassium concentration compared to boiled tubers. White *chuño* is particularly subject to sizable losses with the 'Huancavelica-type' and 'Puno-type' respectively suffering an average 136-fold and 93-fold reduction of their potassium content compared to potato tubers. The potassium content of both 'types' of boiled white *chuño* is not significantly influenced by the cultivar used while its concentration in boiled tubers and both 'types' of black *chuño* is significantly dependent on the cultivar.

Phosphorus (P). The phosphorus content of all 'types' of *chuño* is reduced significantly by traditional freeze-drying. The average phosphorus concentration of boiled black *chuño* as compared to boiled potato tubers reduced 45.2% and 45.8% for the 'Huancavelica-type' and 'Puno-type' respectively. Losses for both 'types' of white *chuño*, the 'Huancavelica-type' and 'Puno-type' respectively, average 67.8% and 62.7%. Differences in the phosphorus content of the different cultivars were significant for boiled tubers and both 'types' of black *chuño* while differences in the content of the distinct cultivars was insignificant for both 'types' of white *chuño*.

Magnesium (Mg). Without exceptions, the magnesium concentration of all 'types' of boiled *chuño* was significantly lower compared to the content of boiled potato tubers. On average losses were higher for both 'types' of white *chuño*, 67.6% for white *chuño* of the 'Huancavelica-type' and 72.3% for white *chuño* of the 'Puno-type', compared to both 'types' of black *chuño*: 53.2% for black *chuño* of the 'Huancavelica-type' and 56.5% for black *chuño* of the 'Puno-type'. The cultivar *Piñaza* retained the highest concentration in (unprocessed) tubers, both 'types' of black *chuño* and white *chuño* of the 'Puno-type' when compared to the other cultivars while the cultivar *Azul Qanchillu* maintained the highest content in black *chuño* of the 'Huancavelica-type'. Both native-floury cultivars show higher average losses of magnesium compared to both native-bitter cultivars.

Sodium (Na). Both 'types' of black *chuño* show a decrease of sodium concentrations for all of the cultivars analyzed. Depending on the specific cultivar, levels of decrease range from 4.9 to 45.8% for black *chuño* of the 'Huancavelica-type' and 5.3 to 31.8% for black *chuño* of the 'Puno-type'. With the exception of the cultivar *Ccompis*, the sodium content of boiled white *chuño* of the 'Huancavelica-type' was 18.7 to 88.0% lower compared to the content of boiled tubers. Interestingly, the sodium content of boiled white *chuño* of the 'Puno-type' was significantly higher compared to the content of boiled tubers. Depending on the cultivar, the average sodium content of white *chuño* of the 'Puno-type' increases by 53.7 to 811.4%. No significant differences between cultivars were encountered concerning the sodium concentration of white *chuño* of the 'Huancavelica-type' and black *chuño* of the 'Puno-type'. However, the sodium content of boiled tubers, black *chuño* of the 'Huancavelica-type' and white *chuño* of the 'Puno-type' depended significantly on the specific cultivar employed.

Table 4. Analysis of variance for the dry matter, iron, zinc and calcium content of boiled *chuño*

Source	DF	Dry Matter (%)			Fe (mg / kg)[a] §, DWB			Zn (mg / kg)[a], DWB			Ca (mg / kg), DWB		
		Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F
Repetition (proc)	10	6,932	1,830		0,006	1,400		0,002	0,940		1709,013	0,380	
Cultivar (C)	3	133,961	35,350	**	0,120	26,700	**	0,071	31,590	**	516688,064	114,020	**
Process (P)	4	126,482	33,370	**	0,171	37,990	**	0,538	238,320	**	658781,303	145,380	**
Process*Cultivar	12	5,527	1,460		0,017	3,830	**	0,018	7,930	**	50374,516	11,120	**
Error	30	3,790			0,004						4531,569		
Corrected total	59	1157,156											
Mean		30,402			27,260			5,924			473,014		
CV		6,403			4,767			6,608			14,231		
R^2		0,902			0,907			0,975			0,972		

[a] = data transformed to $\log^{10}$; ** p>0,01; § = values likely influenced by contamination

Table 5. Analysis of variance for the potassium, phosphorus, magnesium and sodium content of boiled *chuño*

Source	DF	K (mg / kg), DWB			P (mg / kg), DWB			Mg (mg / kg)[a], DWB			Na (mg / kg), DWB		
		Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F
Repetition (proc)	10	338333,000	0,660		10310,000	0,430		0,001	0,540		177,948	0,420	
Cultivar (C)	3	4104863,000	7,990	**	822215,560	34,550	**	0,177	97,060	**	6185,000	14,530	**
Process (P)	4	431689321,000	840,150	**	5568310,830	234,000	**	0,575	316,070	**	33408,032	78,460	**
Process*Cultivar	12	3071236,000	5,980	**	167541,940	7,040	**	0,015	7,990	**	1909,905	4,490	**
Error	30	513826,000			23796,670			0,002			425,778		
Corrected total	59												
Mean		5441,186			1386,333			417,594			51,702		
CV		13,174			11,127			1,667			39,910		
R^2		0,991			0,974			0,982			0,933		

[a] = data transformed to $\log^{10}$; ** p>0,01

The effect of locality by cultivar by process

The overall ANOVA indicates that the dry matter, Fe, Ca, Mg and Na content of boiled white *chuño* is significantly dependent on the locality (L), cultivar (C), process (P), and L*C*P interaction effect (tables 6 and 7). However, iron content levels, particularly of white *chuño* of the 'Huancavelica-type', were influenced by contamination. The Zn content of boiled white *chuño* is significantly influenced by the locality (L), cultivar (C), process (P) and L*P interaction while the K content is significantly influenced by the locality (L), process (P) and L*P interaction. Both Zn and K are not significantly dependent on L*C or L*C*P interaction effects. The P content of boiled white *chuño* is significantly influenced by the locality (L), cultivar (C), process (P), L*C and L*P interaction, but not by the L*C*P interaction effect. Annex II shows the dry matter, Fe, Ca, Mg and Na content values for all localities, cultivars and 'types' of *chuño*. In the case of Zn, K and P the same annex shows average content values by locality (L) and process (P), but not by cultivar (C), as no significant L*C*P interaction effects were found. Findings described below are based on results shown in annex II.

Dry matter (DM). Without exception the dry matter content of boiled (unprocessed) tubers and both 'types' of white *chuño* of all cultivars is significantly influenced by the locality where the potato has been grown. Interestingly, for all localities and cultivars, the dry matter content of white *chuño* of the 'Huancavelica-type' was always higher while that of white *chuño* of the 'Puno-type' was always lower compared to content values of boiled (unprocessed) tubers. The average dry matter content of boiled (unprocessed) tubers and both 'types' of white *chuño* from tubers grown in Huancavelica was always lower compared to materials from the other localities. The only exception to the former concerns white *chuño* of the 'Puno-type' from the cultivar *Azul Qanchillu*. The dry matter content of *chuño* from all localities and cultivars, with the exception the cultivar *Locka* produced in Puno and Junín, was significantly influenced by the process.

Iron (Fe). High aluminum concentrations indicate likely soil contamination of white *chuño* of the 'Huancavelica-type'. Therefore only the results concerning iron content values for boiled (unprocessed) tubers and white *chuño* of the 'Puno-type' are considered for detailed interpretation. Results for unprocessed tubers and white *chuño* of the 'Puno-type' indicate that the influence of the locality on iron content values is non-significant for both processes and all cultivars with the single exception of boiled (unprocessed) tubers from the cultivar *Suytu Siri*. Depending on the locality and cultivar, average iron concentrations of white *chuño* of the 'Puno-type' were between 11.2 to 45.6% higher compared to boiled (unprocessed) tubers.

Zinc (Zn). The average zinc content of boiled (unprocessed) tubers and white *chuño* of both the 'Huancavelica-type' and 'Puno-type' is significantly influenced by the locality where the potato has been produced (L*P interaction effect). The zinc content of white *chuño* is not significantly influenced by L*C or L*C*P interaction effects. The zinc content of both 'types' of white *chuño* is always significantly lower compared to boiled tubers. Depending on the locality, average losses fluctuated between 70.0 to 80.5% for white *chuño* of the 'Huancavelica-type' and 48.3 to 81.5% for white *chuño* of the 'Puno-type'.

Calcium (Ca). Without exception the calcium content of boiled (unprocessed) tubers and both 'types' of white *chuño* of all cultivars is significantly influenced by the locality where the potato has been grown. The calcium concentration of both types of white *chuño*, independent of the locality and cultivar, was always higher compared to boiled (unprocessed) tubers. In the case of white *chuño* of the 'Huancavelica-type' 1.7 to 5.6-fold and in the case of white *chuño* of the 'Puno-type' 2.1 to 8.1-fold higher. Independently of the cultivar employed, the calcium concentration of both types of *chuño* processed from tubers produced in Huancavelica always tended to be considerably higher compared to the same *chuño* elaborated from tubers produced in Puno or Junín. The calcium content of *chuño* from all localities and cultivars was also significantly influenced by the process.

Potassium (K). The potassium content of boiled (unprocessed) tubers is significantly influenced by the locality where potatoes have been produced (L*P interaction effect). Yet, no significant effect of locality on the potassium concentration of both 'types' of white *chuño* was found. The potassium content of white *chuño* is not significantly influenced by L*C, C*P or L*C*P interaction effects. The potassium content of both 'types' of white *chuño* was always significantly lower compared to boiled tubers. Average losses above 99% of the original content are normal.

Phosphorus (P). The phosphorus content of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' is significantly influenced by the locality where potatoes have been produced (L*P interaction effect). No significant effect of locality on the phosphorus concentration of white *chuño* of the 'Puno-type' was found. The phosphorus content of white *chuño* is also significantly influenced by L*C and C*P interaction effects. The phosphorus content of both 'types' of white *chuño* was always significantly lower compared to boiled tubers.

Depending on the locality, average losses fluctuated between 62.3 to 73.0% for white *chuño* of the 'Huancavelica-type' and 61.2 to 71.4% for white *chuño* of the 'Puno-type'.

Magnesium (Mg). Without exception the magnesium concentration of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' of all cultivars is significantly influenced by the locality where the potato has been grown. With the exception of the cultivar *Piñaza*, the magnesium concentration of white *chuño* of the 'Puno-type' was generally not significantly influenced by locality. The magnesium concentration of both 'types' of *chuño* was always significantly lower compared to boiled tubers. Depending on the locality and cultivar, average losses fluctuated between 69.7 to 81.9% for white *chuño* of the 'Huancavelica-type' and 62.0 to 89.7% for white *chuño* of the 'Puno-type'.

Sodium (Na). The sodium content of boiled (unprocessed) tubers of all cultivars is significantly influenced by the locality where the potato has been grown. The content of both 'types' of white *chuño*, on the other hand, is not significantly influenced by the locality. Indepent of the cultivar, both 'types' of *chuño* elaborated with tubers from the locality Huancavelica increased its sodium content compared to boiled tubers. White *chuño* of the 'Huancavelica-type' elaborated from tubers produced in Puno and Junín generally had lower sodium concentrations compared to content values of boiled tubers. To the contrary, white *chuño* of the 'Puno-type' elaborated from tubers produced in Puno and Junín generally had higher sodium concentrations compared to content values of boiled tubers.

Table 6. Analysis of variance for the dry matter, iron, zinc and calcium content of boiled white *chuño*

Source	DF	Dry Matter (%)			Fe (mg / kg)[a] §, DWB			Zn (mg / kg), DWB			Ca (mg / kg), DWB		
		Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F
Locality (L)	2	305,24	72,51	**	0,24	29,89	**	126,14	402,31	**	2229788,71	72,78	**
Repetition (Loc.)	8	4,24	2,39	*	0,01	0,76		0,30	0,20		30882,78	3,76	**
Cultivar (C)	3	29,91	16,86	**	0,07	6,72	**	12,66	8,25	**	52286,49	6,37	**
Locality*Cultivar	6	10,74	6,05	**	0,02	1,99		2,28	1,49		20988,01	2,56	*
Process (P)	2	372,54	209,96	**	1,50	140,77	**	2064,51	1345,99	**	7172493,15	874,13	**
Locality*Process	4	17,48	9,85	**	0,00	0,16		137,98	89,96	**	156551,50	19,08	**
Cultivar*Process	6	41,89	23,61	**	0,01	0,63		2,38	1,55		33953,48	4,14	**
L*C*P	12	13,45	7,58	**	0,03	2,58	**	2,32	1,51		20545,42	2,50	**
Error	80	1,77			0,01			1,53			8205,25		
Corrected total	123												
Mean		26,90			31,35			8,86			811,88		
CV		4,95			7,18			13,97			11,16		
R^2		0,94			0,84			0,98			0,97		

[a] = data transformed to $\log^{10}$; ** p>0.01; * p>0.05; § = values likely influenced by contamination

Table 7. Analysis of variance for the potassium, phosphorus, magnesium and sodium content of boiled white *chuño*

Source	DF	K (mg / kg), DWB			P (mg / kg), DWB			Mg (mg / kg), DWB			Na (mg / kg), DWB		
		Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F	Mean Square	F-value	Pr > F
Locality (L)	2	75184365,00	195,77	**	4263259,30	35,18	**	549813,04	417,82	**	3,62	94,86	**
Repetition (Loc.)	8	382292,00	0,70		122161,40	3,93	**	1302,08	0,50		0,04	0,65	
Cultivar (C)	3	807321,00	1,48		212787,00	6,85	**	36373,09	14,04	**	0,18	3,02	*
Locality*Cultivar	6	507969,00	0,93		86016,90	2,77	*	2557,91	0,99		0,15	2,51	*
Process (P)	2	4772247574,00	8732,49	**	59663754,60	1921,50	**	9966966,67	3847,63	**	12,20	207,57	**
Locality*Process	4	83968718,00	153,65	**	2542023,30	81,87	**	323775,76	124,99	**	2,49	42,31	**
Cultivar*Process	6	681194,00	1,25		30123,50	0,97		11968,91	4,62	**	0,13	2,18	
L*C*P	12	549756,00	1,01		41521,30	1,34		4867,04	1,88	*	0,11	1,92	*
Error	80	546494,00			31050,60			2590,42					
Corrected total	123												
Mean		6835,89			1680,24			650,89			60,59		
CV		10,81			10,49			7,82			10,04		
R^2		1,00			0,98			0,99			0,91		

[a] = data transformed to $\log^{10}$; ** p>0.01; * p>0.05

Conclusions

Process by cultivar

The zinc, potassium, phosphorus and magnesium contents of all 'types' of boiled *chuño* are low in comparison with those of boiled (unprocessed) tubers. The process of traditional freeze-drying, without exception, negatively affects the nutritional value of *chuño* for these 4 minerals. In addition, the content of these minerals is reduced more drastically in both 'types' of white *chuño* as compared to both 'types' of black *chuño*. It seems likely that the higher loss of these minerals in white compared to black *chuño* originates from the exposure of tubers to (running) water during the process of freeze-drying.

The influence of the 4 different regional variants of freeze-drying on the dry matter, iron, calcium and sodium content of *chuño* was not as linear as for the minerals discussed above. Differences in the dry matter content of boiled tubers versus *chuño* were fairly modest for all 'types' of *chuño*, except black *chuño* of the 'Huancavelica-type' which had a considerably higher dry matter content compared to boiled tubers. Iron content values for white *chuño* of the 'Puno-type' clearly indicate a strong influence of the cultivar. The calcium concentration of boiled *chuño* is strongly influenced by the actual process of freeze-drying. Both 'types' of white *chuño* contained significantly higher concentrations of calcium compared to boiled (unprocessed) tubers. Both 'types' of black *chuño*, on the other hand, on average contained lower concentrations of calcium compared to boiled tubers. The fact that the calcium content of white *chuño* is nearly double compared to (unprocessed) potato tubers and black *chuño* suggests that that this particular mineral might be absorbed from the water. A similar phenomenon may be occurring in the case of sodium as average concentrations of this mineral in white *chuño* of the 'Puno-type' were generally much higher compared to those of boiled tubers. Sodium concentrations in all other 'types' of *chuño* tended to be significantly lower compared to content values of boiled tubers.

Locality by cultivar by process

Independent of the locality where potatoes are produced, the zinc, potassium, phosphorus and magnesium concentrations of *chuño* always decrease in comparison with mineral content values of boiled tubers of the same treatment. The dry matter, calcium, magnesium and sodium content of boiled white *chuño* is significantly dependent on the L*C*P interaction effect. Without exception the dry matter and calcium content of boiled (unprocessed) tubers and both 'types' of white *chuño* of all cultivars is significantly influenced by the locality where the potato has been grown. Results confirm that the calcium content of white *chuño* from all localities and cultivars increases considerably in comparison with concentrations in boiled tubers.

The magnesium concentration of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' of all cultivars is significantly influenced by the locality where the potato has been produced while it's content in white *chuño* of the 'Puno-type' is generally not significantly affected by locality. The sodium content of boiled (unprocessed) tubers of all cultivars is, whereas content vales of both 'types' of *chuño* are not, significantly influenced by the locality. Results confirm that the sodium content of white *chuño* of the 'Puno-type' is always higher in comparison with concentrations in boiled tubers. Content levels of sodium in white *chuño* of the 'Huancavelica-type' may either increase or decrease in comparison with boiled (unprocessed) tubers, depending on the locality where the potato was produced.

The concentrations of some minerals is significantly influenced by the locality, but not by L*C*P interaction effects. Such is the case for zinc and phosphorus. The zinc content of boiled (unprocessed) tubers and white *chuño* of both the 'Huancavelica-type' and 'Puno-type' is significantly influenced by the locality where the potato has been produced. Further, the phosphorus content of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' is significantly influenced by locality whereas concentrations in white *chuño* of the 'Puno-type' are not significant affected.

The locality of potato production has little influence on the iron and potassium content of white *chuño*. Results for white *chuño* of the 'Puno-type' indicate that the influence of the locality on iron content values is non-significant. Average iron concentrations of white *chuño* of the 'Puno-type' were always higher compared to boiled (unprocessed) tubers. While the potassium content of boiled (unprocessed) tubers is significantly influenced by the locality where potatoes have been produced, the same is not true for potassium concentrations of both 'types' of white *chuño*. The main cause is the enormous reduction of potassium caused by traditional freeze-drying, amounting to losses above 99% of the original content.

Chuño and human nutrition

In general terms, both white and black *chuño* are relatively poor sources of macro- and micronutrients. Interventions aimed at combating child malnutrition in the Andean highlands will probably have the highest possible impact when levels of consumption of meat, milk products, fruit and (leafy) vegetables can be increased. Nevertheless, these products are generally scarce in Andean communities located above 3.500 m of altitude. Potato, consumed as boiled tubers or *chuño* and often combined with grains such as barley, makes up the bulk of daily food intake. In an environment where harvests and food storage occur once a year, and where risks of crop failure and consequent temporal food shortages caused by frost, hail or drought are frequent, the preparation of *chuño* does contribute significantly to local food security. *Chuño*, just as other traditionally freeze-dried products (e.g. *kaya*), allow Andean households to overcome periods of relative food shortage. Additionally, the consumption of *chuño* is imbedded in the Andean culture and cuisine. From a human nutrition perspective the benefits of *chuño* consumption, beyond its long-term storability and year-round availability as an energy-rich food source, include the stable to high iron and high calcium content of white *chuño* as compared to unprocessed potato tubers and the comparatively high levels of retention of zinc, potassium, phosphorus and magnesium in black compared to white *chuño*. Additionally, the commercial value of high-quality white *chuño* may allow rural families to enrich their diets with foods obtained through monetary purchase.

Literature cited

Burgos, G., De Haan, S., Salas, E. and Bonierbale, M. 2008. Protein, iron, zinc and calcium concentrations of potato following traditional processing as "chuño". Journal of Food Composition and Analysis: doi:10.1016/j.jfca.2008.09.001.

Christiansen, J. 1977. The utilization of bitter potatoes to improve food production in the high altitude of the tropics. PhD thesis. Cornell University, Ithaca.

Christiansen, J. 1978. Las papas amargas: fuente de proteínas y calorías en los Andes. pp. 201-203. In: UNSCH (ed.), Anales del Primer Congreso Internacional de Cultivos Andinos. Universidad Nacional de San Cristóbal de Huamanga (UNSCH), Inter-American Institute for Cooperation on Agriculture (IICA), Ayacucho.

Collazos, C. 1974. La Composición de los Alimentos Peruanos. Ministerio de Salud, Lima.

Condori Cruz, D. 1992. Tecnología del chuño. Boletín del IDEA 42(2):70-97.

Darrell, R. and Glanh, R. 1999. Micronutrient bioavailability techniques: accuracy, problems and limitations. Field Crop Research 60:93-113.

De Haan, S., Burgos, G., Liria, R., Bonierbale, M. and Thiele, G. 2009. The role of biodiverse potatoes in the human diet in central Peru: nutritional composition, dietary intake and cultural connotations. pp. 161-182. In: S. de Haan, Potato Diversity at Height: multiple dimensions of farmer-driven *in-situ* conservation in the Andes. PhD thesis. Wageningen University, Wageningen.

Gianella, T. 2004. Chuño blanco, 'tunta' o 'moraya': un proceso natural de conservación. LEISA Revista de Agroecología 20(3):29-31.

López Linage, J. (ed.) 1991. De Papa a Batata: la difusión española del tubérculo andino. Ministerio de Agricultura, Pesca y Alimentación, Madrid.

Mamani, M. 1981. El Chuño: preparación, uso, almacenamiento. pp. 235-246. In: H. Lechtmand and A.M. Soldi (eds.), La Tecnología en El Mundo Andino: runakunap kawsayninkupaq rurasqankunaqa (Tomo 1). Universidad Nacional Autónoma de México (UNAM), México.

Paredes, S. and Gomez, O. 1987. Elaboración del chuño negro y blanco a partir de papa amarga, var. 'Ruckii' y var. 'Q'etta'. pp. 358-362. In: UNAP (ed.), Procedimientos del V Congreso Internacional de Sistemas Agropecuarios Andinos. Universidad Nacional del Altiplano (UNAP), Corporación Departamental de Desarrollo de Puno (CORDEPUNO) Instituto Nacional de Investigación y Promoción Agropecuaria (INIPA), Puno.

Towle, M.A. 1961. The Ethnobotany of Pre-Columbian Peru. Viking Fund Publications in Anthropology, Chicago.

Werge, R.W. 1979. Potato processing in the central highlands of Peru. Ecology of Food and Nutrition 7:229-234

Woolfe, J.A. 1987. The Potato in the Human Diet. Cambridge University Press, Cambridge.

Yamamoto, N. 1988. Potato Processing: learning from a traditional Andean system. pp. 160-172. In: CIP (ed.), The Social Sciences at CIP: social science planning conference, Lima, Peru (7-10 September 1987). International Potato Center (CIP), Lima.

Zavaleta, A., Cabezas, C., Chang, O. and Baiochi, N. 1996. Tablas Peruanas de Composición de Alimentos. Ministerio de Salud (MINSA), Instituto Nacional de Salud (INS), Lima.

Annex 1. Dry matter and mineral content values (process by cultivar experiment; P*C)

Dry matter content (%) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'	
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)
Qanchillu	33.4	1.3	32.7	3.4	39.8	6.9	28.8	0.7	32.7	1.1
Ccompis	29.0	1.0	32.0	1.1	37.6	1.1	29.8	1.5	29.0	1.8
Piñaza	24.3	1.8	27.7	1.9	31.0	1.9	22.3	1.8	26.7	2.0
Puqya	30.6	0.1	30.4	0.6	34.2	0.7	26.4	0.6	29.8	0.9

Iron content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'[a]		Black *chuño* 'Hvca-type'[a]		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'[a]		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	21.9	2.8	62.1	15.8	38.1	6.4	25.0	0.7	31.0	1.7	**
Ccompis	17.3	0.6	21.9	3.0	27.0	2.9	13.7	2.2	23.2	1.9	**
Piñaza	18.6	2.8	32.4	12.0	28.2	2.3	24.0	3.7	27.6	4.6	**
Puqya	21.5	2.9	41.1	10.6	27.3	4.5	15.7	1.6	27.3	3.9	**
P x G effect sliced by P	ns		**		*		**		ns		

[1] = Dry Weight Basis; [a] = values likely influenced by contamination; P = process; C = cultivar; ** p>0.01; * p>0.05

Zinc content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	10.2	0.6	3.7	0.5	5.8	0.5	3.4	0.4	5.4	0.5	**
Ccompis	10.6	0.5	3.0	0.4	4.8	0.3	2.9	0.2	4.2	0.1	**
Piñaza	11.3	0.7	3.4	0.8	6.5	0.4	5.7	0.8	8.4	0.4	**
Puqya	13.4	2.4	2.7	0.3	5.6	0.4	3.5	0.3	3.9	0.4	**
P x G effect sliced by P	*		**		*		**		**		

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Calcium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	383.3	46.2	703.3	20.8	356.7	63.5	870.0	78.1	293.3	11.5	**
Ccompis	270.0	10.0	490.0	60.8	199.0	28.1	463.3	25.2	191.4	25.2	**
Piñaza	523.3	119.3	1030.0	26.5	533.3	37.9	1236.7	98.1	253.3	41.6	**
Puqya	303.3	5.8	426.7	75.7	198.7	2.3	540.0	155.9	194.5	4.5	**
P x G effect sliced by P	**		**		**		**		ns		

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Potassium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	14000.0	1417.7	146.6	22.8	7233.3	472.6	98.1	13.3	6266.7	57.7	**
Ccompis	14133.3	1159.0	165.4	100.4	5366.7	251.7	530.0	10.0	5033.3	152.8	**
Piñaza	15766.7	1361.4	70.5	21.3	5966.7	208.2	119.7	30.4	8766.7	808.3	**
Puqya	15366.7	1222.0	109.9	53.4	5066.7	873.7	216.9	24.8	4400.0	953.9	**
P x G effect sliced by P	**		ns		**		ns		**		

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Phosphorus content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	2866.7	321.5	810.0	45.8	1600.0	60.0	850.0	17.3	1463.3	72.3	**
Ccompis	1986.7	196.3	893.3	104.1	1263.3	97.1	956.7	41.6	1153.3	125.8	**
Piñaza	3033.3	208.2	750.0	17.3	1543.3	100.2	1023.3	15.3	1860.0	87.2	**
Puqya	2150.0	229.1	666.7	96.1	1050.0	130.0	810.0	190.8	996.7	202.6	**
P x G eff. sliced by P	**		ns		**		ns		**		

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Magnesium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	863.3	60.3	316.7	5.8	443.3	11.5	213.3	23.1	380.0	17.3	**
Ccompis	706.7	60.3	256.7	20.8	290.0	10.0	183.5	10.2	253.3	15.3	**
Piñaza	916.7	104.1	306.7	30.6	526.7	15.3	340.0	26.5	600.0	20.0	**
Puqya	826.7	83.3	191.9	25.1	310.0	10.0	189.8	43.9	236.7	32.1	**
P x G eff. sliced by P	*		**		**		**		**		

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Sodium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

	Potato tubers		White *chuño* 'Hvca-type'		Black *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		Black *chuño* 'Puno-type'		P x G effect sliced by G
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Qanchillu	43.2	26.5	20.2	1.7	41.0	26.1	118.8	20.2	31.8	11.5	**
Ccompis	16.2	13.5	18.8	2.1	13.6	12.5	147.9	12.9	12.6	7.7	**
Piñaza	123.8	55.2	14.9	2.0	67.1	27.6	190.3	19.5	5.3	2.5	**
Puqya	17.2	14.6	14.0	1.6	13.7	9.9	113.5	15.4	10.3	6.1	**
P x G eff. sliced by P	**		ns		**		**		ns		

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Annex 2. Dry matter and mineral content values (locality by cultivar by process experiment; L*C*P)

Dry matter content (%) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

Locality	Cultivar	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*C*P effect sl. by L*C
		Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	*Azul Qanchillu*	25.92	1.44	26.19	1.07	22.72	0.57	**
Puno	*Azul Qanchillu*	33.36	1.33	34.36	2.29	19.21	0.91	**
Junin	*Azul Qanchillu*	29.39	0.81	34.60	2.38	26.22	0.74	**
L*C*P effect sliced by C*P		**		**		**		
Huancavelica	*Locka*	24.43	1.23	25.42	1.61	21.80	0.83	**
Puno	*Locka*	26.87	1.53	27.35	1.42	25.50	0.54	ns
Junin	*Locka*	27.60	0.52	28.03	0.48	25.54	0.82	ns
L*C*P effect sliced by C*P		**		*		**		
Huancavelica	*Piñaza*	22.03	0.67	27.19	1.40	21.12	0.80	**
Puno	*Piñaza*	24.27	1.79	32.04	1.24	23.62	0.96	**
Junin	*Piñaza*	25.59	1.64	35.24	2.32	24.11	0.44	**
L*C*P effect sliced by C*P		**		**		*		
Huancavelica	*Suytu Siri*	23.09	1.21	24.26	1.49	20.26	0.68	**
Puno	*Suytu Siri*	28.27	1.28	31.45	2.07	27.49	0.83	**
Junin	*Suytu Siri*	28.82	1.00	34.31	3.16	26.68	0.84	**
L*C*P effect sliced by C*P		**		**		**		

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Iron content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

Locality	Cultivar	Potato tubers		White *chuño* 'Hvca-type'[a]		White *chuño* 'Puno-type'		L*C*P effect sl. by L*C
		Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	*Azul Qanchillu*	28.19	3.02	80.94	34.38	35.22	1.11	**
Puno	*Azul Qanchillu*	21.94	2.85	45.56	15.96	31.94	4.27	**
Junin	*Azul Qanchillu*	18.92	2.69	35.62	8.20	24.97	2.42	**
L*C*P effect sliced by C*P		ns		**		ns		
Huancavelica	*Locka*	20.03	2.84	34.91	3.40	25.82	1.34	**
Puno	*Locka*	18.09	1.98	38.29	12.98	25.90	1.63	**
Junin	*Locka*	14.85	0.97	48.76	20.35	17.93	0.74	**
L*C*P effect sliced by C*P		ns		ns		ns		
Huancavelica	*Piñaza*	22.00	1.06	79.95	38.64	24.46	0.91	**
Puno	*Piñaza*	18.64	2.75	44.50	12.29	25.01	0.42	**
Junin	*Piñaza*	16.08	0.92	32.97	13.04	19.39	0.26	**
L*C*P effect sliced by C*P		ns		**		ns		
Huancavelica	*Suytu Siri*	22.44	1.77	37.94	7.64	26.81	2.19	**
Puno	*Suytu Siri*	19.14	0.47	64.18	18.24	21.95	1.26	**
Junin	*Suytu Siri*	14.19	1.95	38.62	15.49	17.41	0.57	**
L*C*P effect sliced by C*P		*		**		ns		

[1] = Dry Weight Basis; [a] = values likely influenced by soil contamination; L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Zinc content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x process)

Locality	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*P effect sl. by L
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	21.05	2.24	4.11	1.24	3.89	0.76	**
Puno	10.40	0.95	3.12	0.66	5.38	1.60	**
Junin	18.11	1.94	4.82	0.89	4.68	0.82	**
L*P effect sl. by P	**		**		*		

Calcium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

Locality	Cultivar	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*C*P effect sl. by L*C
		Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	*Azul Qanchillu*	427.50	56.79	1255.00	165.83	1446.67	64.29	**
Puno	*Azul Qanchillu*	383.33	46.19	773.33	55.08	1226.67	49.33	**
Junín	*Azul Qanchillu*	155.34	22.93	700.00	91.29	790.00	26.46	**
L*C*P effect sliced by C*P		**		**		**		
Huancavelica	*Locka*	485.00	57.45	1392.50	84.61	1480.00	62.45	**
Puno	*Locka*	543.33	70.24	1143.33	90.74	1123.33	58.59	**
Junín	*Locka*	220.34	62.56	700.00	42.43	920.00	69.28	**
L*C*P effect sliced by C*P		**		**		**		
Huancavelica	*Piñaza*	432.50	130.74	1095.00	203.06	1436.67	15.28	**
Puno	*Piñaza*	523.33	119.30	913.33	75.72	1146.67	61.10	**
Junín	*Piñaza*	129.53	48.45	652.50	136.72	1010.00	85.44	**
L*C*P effect sliced by C*P		**		**		**		
Huancavelica	*Suytu Siri*	457.50	179.14	1277.50	219.15	1656.67	159.48	**
Puno	*Suytu Siri*	460.00	98.49	813.33	111.50	1173.33	64.29	**
Junín	*Suytu Siri*	123.13	50.23	690.00	34.64	1003.33	51.32	**
L*C*P effect sliced by C*P		**		**		**		

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Potassium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x process)

Locality	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*P effect sl. by L
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	23062.50	1388.94	90.97	58.38	69.70	22.46	**
Puno	14500.00	1231.41	96.50	45.91	113.04	43.90	**
Junin	18500.00	1067.08	152.24	69.49	117.33	33.14	**
L*P effect sl. by P	**		ns		ns		

Phosphorus content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x process)

Locality	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*P effect sl. by L
	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	3862.50	452.95	1066.25	56.08	1105.00	65.30	**
Puno	2858.33	264.43	772.50	38.41	957.50	114.58	**
Junin	2291.88	276.63	865.00	75.10	888.33	88.51	**
L*P effect sl. by P	**		**		ns		

Magnesium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

Locality	Cultivar	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*C*P effect sl. by L*C
		Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	*Azul Qanchillu*	1360.00	65.83	407.50	34.03	263.33	15.28	**
Puno	*Azul Qanchillu*	863.33	60.28	300.00	10.00	256.67	25.17	**
Junín	*Azul Qanchillu*	1247.50	86.17	420.00	25.82	293.33	30.55	**
L*C*P effect sliced by C*P		**		**		ns		
Huancavelica	*Locka*	1450.00	102.31	370.00	34.64	270.00	43.59	**
Puno	*Locka*	856.67	56.86	263.33	15.28	293.33	15.28	**
Junín	*Locka*	1292.50	20.62	420.00	21.60	310.00	26.46	**
L*C*P effect sliced by C*P		**		**		ns		
Huancavelica	*Piñaza*	1587.50	53.15	430.00	58.31	293.33	66.58	**
Puno	*Piñaza*	916.67	104.08	286.67	20.82	400.00	17.32	**
Junín	*Piñaza*	1305.00	79.37	450.00	35.59	320.00	17.32	**
L*C*P effect sliced by C*P		**		**		*		
Huancavelica	*Suytu Siri*	1357.50	60.76	417.50	65.00	270.00	26.46	**
Puno	*Suytu Siri*	800.00	26.46	293.33	28.87	216.67	5.77	**
Junín	*Suytu Siri*	1180.00	14.14	425.00	36.97	310.00	65.57	**
L*C*P effect sliced by C*P		**		**		ns		

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Sodium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

Locality	Cultivar	Potato tubers		White *chuño* 'Hvca-type'		White *chuño* 'Puno-type'		L*C*P effect sl. by L*C
		Av.	SD (±)	Av.	SD (±)	Av.	SD (±)	
Huancavelica	*Azul Qanchillu*	0.93	0.77	15.56	2.44	86.38	3.95	**
Puno	*Azul Qanchillu*	43.15	26.48	16.23	1.16	163.77	20.24	**
Junín	*Azul Qanchillu*	17.38	6.57	17.85	2.57	146.96	4.13	**
L*C*P effect sliced by C*P		**		ns		ns		
Huancavelica	*Locka*	2.19	2.48	10.73	0.48	112.32	3.38	**
Puno	*Locka*	196.54	78.38	13.87	1.32	159.51	8.11	**
Junín	*Locka*	31.53	31.60	15.81	1.89	141.38	12.87	**
L*C*P effect sliced by C*P		**		ns		ns		
Huancavelica	*Piñaza*	6.24	3.78	15.52	3.74	129.78	9.12	**
Puno	*Piñaza*	123.80	55.19	13.48	0.40	199.23	17.99	**
Junín	*Piñaza*	21.13	18.15	19.73	1.90	176.20	16.52	**
L*C*P effect sliced by C*P		**		ns		ns		
Huancavelica	*Suytu Siri*	4.25	2.86	13.70	2.54	120.07	11.80	**
Puno	*Suytu Siri*	35.37	13.58	13.54	1.72	131.08	7.55	**
Junín	*Suytu Siri*	22.85	21.74	17.64	2.82	171.11	50.65	**
L*C*P effect sliced by C*P		**		ns		ns		

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05