Traditional Processing of Black and White *Chuño* in the Peruvian Andes: Regional Variants and Effect on the Mineral Content of Native Potato Cultivars[1]

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Traditional Processing of Black and White *Chuño* in the Peruvian Andes: Regional Variants and Effect on the Mineral Content of Native Potato Cultivars. Farmers in the high Andes of central to southern Peru and Bolivia typically freeze-dry potatoes to obtain *chuño*. Processing of so-called black *chuño* follows tending, treading, freezing, and drying. The making of white *chuño* is generally more complex and involves exposure of tubers to water. Regional variants exist for each of these processes, yet their influence on the nutritional composition of native potato cultivars is little known. Tubers belonging to four distinct cultivars and produced in a replicated trial under uniform conditions were processed into four types of *chuño* following standard traditional procedures (farmer-managed). These regional variants were documented, and the dry matter, iron, zinc, calcium, potassium, phosphorus, magnesium, and sodium content of the four resulting different types of boiled *chuño* determined at the International Potato Center's Quality and Nutrition Laboratory (Lima, Peru). Content values were compared with those of boiled (unprocessed) tubers from the same experiment. Regional variants of processing are to a large extent determined by tradition, environmental condition, and market demand. The zinc, potassium, phosphorus, and magnesium content of all types of *chuño* decreases in comparison with unprocessed tubers. Concentrations of these same minerals decrease more drastically for white as compared to black *chuño*. The effect of the four regional variants of freeze-drying on the dry matter, iron, calcium, and sodium content of *chuño* differs by process and/or cultivar.

Procesamiento tradicional de *chuño* negro y blanco en los Andes Peruanos: Variantes regionales y efecto sobre el contenido de minerales en cultivares nativos de papa. Los agricultores de la zona Alto Andina del centro al sur del Perú y Bolivia someten a la papa a un proceso de congelado-secado para obtener *chuño*. El procesamiento del *chuño* negro involucra tender, pisar, congelar y secar. Por lo general la elaboración del *chuño* blanco es más compleja y requiere que los tubérculos se remojen en agua. Existen variantes regionales para cada uno de los procesos. Sin embargo, la influencia de estas sobre la composición nutricional de cultivares nativos es poco conocida. Tubérculos de cuatro cultivares distintos y producidos en un ensayo replicado bajo condiciones uniformes fueron procesados en cuatro 'tipos' de *chuño* siguiendo procedimientos tradicionales estándar (manejo de agricultor). Se documentaron las variantes regionales y se determinó el contenido de materia seca, hierro, zinc, calcio, potasio, fósforo, magnesio y sodio de los cuatro diferentes 'tipos' de *chuño* en el Laboratorio de Calidad y Nutrición del Centro Internacional de la Papa (Lima, Perú). Se compararon los valores de contenido del *chuño* con los de tubérculos hervidos (sin procesar) provenientes del mismo experimento. Los variantes regionales de procesamiento se determinan principalmente por tradición, condición ambiental y demanda de mercado. El contenido de zinc, potasio, fósforo y magnesio de todos los tipos de *chuño* disminuyó en comparación con

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tubérculos sin procesar. Las concentraciones de estos minerales disminuyó más drásticamente para *chuño* blanco comparado con *chuño* negro. El efecto de los cuatro variantes de congelado-secado sobre el contenido de materia seca, hierro, calcio y sodio del *chuño* varió dependiendo del proceso y/o cultivar.

Key Words: Potato, micro- and macronutrient content, traditional freeze-drying, Andes.

Introduction

The cultivated potato in the high Andes of central to southern Peru and Bolivia is traditionally freeze-dried to assure long-term storability and consequent availability of food during periods of scarcity. The final product is known as *chuño* (Cardenas 1989; López Linage 1991). *Chuño* can be stored for up to 10 years and is generally prepared as a food by just boiling the freeze-dried tubers. Archaeological and linguistic evidence suggests that freeze-drying was common among pre-Columbian Andean farmers (Ballón Aguirre and Cerrón-Palomino 2002; Coe 1994; De la Vega 1609; Towle 1961; Ugent and Peterson 1988). Nowadays, *chuño* processing and consumption is still widespread throughout the Peruvian and Bolivian highlands. Often *chuño* is only one of few food items available to highland farmers living close to the transition zone of agriculture to livestock herding, around 4,000 to 4,300 m of altitude.

Depending on the process followed and cultivars used, different kinds of *chuño* are recognized (Condori Cruz 1992). So-called black and white *chuño* is generally processed at altitudes from 3,600 up to 4,300 m and is the result of different steps involved in the processing pipeline. 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. 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 (Sattaur 1988). The combination of sunny days and freezing cold nights causes breakdown of the cell walls, making it feasible for farmers to squeeze out the moisture from the tubers through treading with their feet.

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 (Johns 1990). Black *chuño*, on the other hand, is not exposed to water and its preparation is generally simpler, basically consisting of tending, treading, freezing, and drying (Mamani 1981). The processing of white *chuño* has several regional variants. It generally involves all of the following steps: tending, treading, freezing, washing, and drying (Werge 1979). However, the sequence, frequency, and duration of each step and attention to quality management differ by highland region (see Guevara Velasco 1945; Huallpa 1983; Paredes 1990; Tillmann 1983). Paredes (1992), when describing different traditional methods for white *chuño* processing in Puno (southern Peru), shows that procedures can differ considerably between ethnic groups: Quechua versus Aymara communities. Furthermore, in some regions where white *chuño* has a high commercial value, extra care is given during particular steps so that a snow-white *chuño* of the highest possible quality is obtained (Fonseca et al. 2008).

Aside from the actual process of preparing *chuño*, the particular potato cultivar involved may influence the final quality. Cultivars belonging to the bitter species *Solanum curtilobum* Juz. et Buk., *S. juzepczukii* Buk., and *S. ajanhuiri* Juz. et Buk. are almost exclusively used for traditional freeze-drying (Christiansen 1977; Rea and Vacher 1992). Their high glycoalkaloid content generally restricts their use for fresh consumption. However, some Aymara communities do consume unprocessed bitter potatoes together with a clay substance called *Ch'ago* (see Johns 1990). Medicinal uses are also reported for bitter species (see CIP 2006; Valdizán and Maldonado 1922). Native floury cultivars of the non-bitter species *S. tuberosum* L. ssp. *andigena* Hawkes and *S. stenotomum* Juz. et Buk., and even improved cultivars, with *S. tuberosum* ssp. *tuberosum* within their pedigree, are also commonly used to prepare *chuño*. *Chuño* made from small tubers of mixed native-floury cultivars is particularly valued as a quality foodstuff for special family occasions (De Haan et al. 2009).

Even though *chuño* is a mainstay within the Andean highland diet, relatively few studies have

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* ssp. *andigena*	$2n=4x=48$	Puno

investigated its nutritional value. Early reports were speculative; e.g., Hawkes (1941, p. 16) writes that "tubers when converted into *chuño* are said to contain all the starch and a greater part of the protein." 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), from 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; Valdez and Romero 1997; 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, 3.3 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. (2009) 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. (2009) and De Haan et al. (2009), showing 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* elaborated with diverse freeze-dried potato cultivars rather than *chuño* from a single cultivar. However, little is known about the nutritional content of diverse native cultivars (C) when processed into *chuño*, particularly the effect of regionally distinct traditional processes (P) on the mineral content of the black and white *chuño* variants. This article reports on the effect of two variants of both black and white *chuño* processing, following traditional procedures common to the departments of Huancavelica (central Peru) and Puno (southern Peru), on the mineral content of four

TABLE 2. AVERAGE MONTHLY TEMPERATURE AND RELATIVE HUMIDITY DURING THE CROPPING SEASON.

	2007		2008					
	Nov.	Dec.	Jan.	Feb.	March	April	May	June
DAP[a]	1–19	20–50	51–81	82–110	111–141	142–171	172–202	203–207
Av. T (°C)	12.0	11.5	9.5	9.6	9.2	9.5	7.3	6.6
Min. T (°C)	6.3	5.5	5.1	3.8	3.5	1.6	−1.1	−1.5
Max. T (°C)	19.6	19.5	17.5	18.8	18.4	20.4	19.2	19.0
Av. RH (%)	40.3	53.4	77.1	72.6	71.3	46.9	30.1	28.8

[a]days after planting.

TABLE 3. BASIC DATA OF LOCATIONS AND PERIODS OF TRADITIONAL FREEZE-DRYING FOR EACH TYPE OF *CHUÑO*.

	White *Chuño* Puno-type	Black *Chuño* Puno-type	White *Chuño* Hvca-type	Black *Chuño* Hvca-type
Farmer	Eleuterio Ccalle	Juan Cahuana	Valeriano Ataypoma	Rufino Palomino
Community	Chijichaya	Mallcomayo	Ccasapata	Ccolpaccasa
Department	Puno	Puno	Huancavelica	Huancavelica
Province	El Collao	Puno	Huancavelica	Huancavelica
District	Ilave	Puno	Yauli	Yauli
Altitude	3,896 m	3,907 m	4,034 m	3,932 m
Duration of process	38 days	14 days	27 days	12 days
Starting date	05-06-08	28-06-08	01-07-08	18-06-08
Ending date	13-07-08	12-07-08	27-07-08	29-06-08

frequently used native potato cultivars grown under uniform conditions.

Materials and Methods

PREPARATION OF SOURCE MATERIAL

Seed tubers of four 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 (longitude 70°43′30″; latitude 15°14′35″) at an altitude of 3,820 m. All cultivars were planted on November 12, 2007, in a field trial following a completely

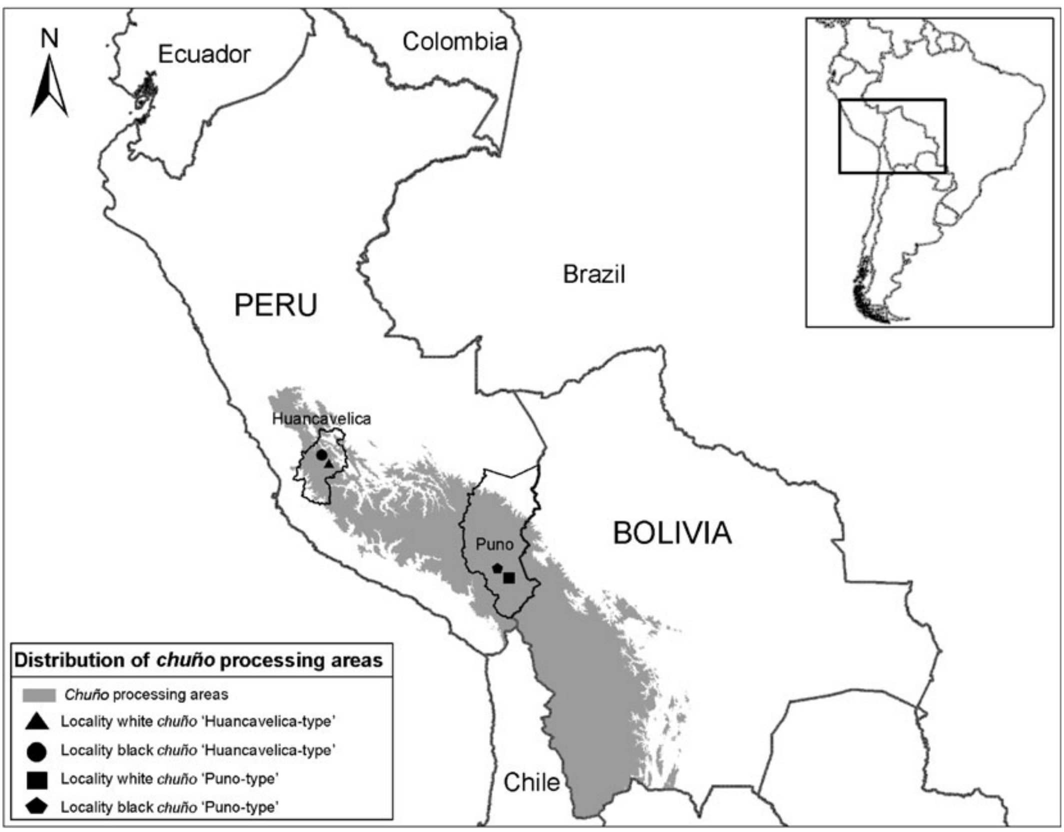

Fig. 1. Map showing the distribution of *chuño* processing areas.

TABLE 4. BASIC DESCRIPTION OF THE STEPS INVOLVED IN PROCESSING BLACK *CHUÑO* IN TWO LOCATIONS.

Black *Chuño* Puno-type			Black *Chuño* Hvca-type		
Steps	Time	Details	Steps	Time	Details
Tending	Day 1	On grassland	Tending	Day 1	On grassland; late afternoon
Freezing	Day 1–4	On grassland	Freezing	Day 1–4	On grassland
Treading	Day 5	Tubers gathered on small piles and treaded bare foot on grassland	Treading	Day 5	Tubers gathered on small piles and treaded barefoot on grassland
Drying	Day 5–14	On grassland	Drying	Day 5–12	On iron sheet
Cleaning	Day 14	Abrading; partial skin removal			
Selecting	Day 14	Separation of whole & broken tubers (sale & home consumption)			

randomized block design (CRBD) with three repetitions. Crop management was uniform and tubers were harvested on June 5, 2008 (see Table 2 for climate variables).

TRADITIONAL *CHUÑO* PROCESSING

After harvest, fresh medium-sized and undamaged tubers from each cultivar and repetition were dispatched to specific farmer communities in Huancavelica and Puno to process black and white *chuño* following local traditional procedures (Table 3). Processing of the four types of *chuño* was done by individual Andean farmers: black and white *chuño* of the "Huancavelica-type," black and white *chuño* of the "Puno-type." In each of the localities the process was documented so that the regional variants could be described (see Fig. 1). Depending on the specific steps involved, processing took between 12 and 38 days to complete. Samples of all cultivars, repetitions, and types of *chuño* were used for mineral analysis.

In Puno the average minimum temperature during the black and white *chuño* processing period was −2.4 and −1.5°C and in Huancavelica −1.6 and −1.4°C, respectively. During some days average minimum temperatures of −5.0°C and −4.3°C were recorded in Puno and Huancavelica, respectively. The average relative humidity in Puno during the black and white *chuño* processing period was very low: 25.7% and 28.7%, respectively. In Huancavelica the average relative humidity during the black and white *chuño* processing period was considerably higher: 66.0% and 55.9%, respectively.

Preparation of Analytical Samples

Unprocessed Tubers. A sample of 10 fresh tubers was prepared for each 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 four 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 three 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 80°C. 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 –20°C in hermetically sealed plastic bags.

Chuño. A sample of 10 freeze-dried tubers was prepared for each 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 subsamples of 0.6 g were taken from each repetition, cultivar, and treatment and digested at 140°C 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 an 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 for 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 unprocessed potato 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,

a: treading of tubers after four nights of exposure to frost (Huancavelica)

b: drying of frozen and treaded tubers on grassland (Puno)

c: black chuño of the 'Puno-type' elaborated with the native-bitter cultivar 'Azul Qanchillu'

d: black chuño of the 'Puno-type' elaborated with the native-floury cultivar 'Ccompis'

Fig. 2. Black *chuño* processing in Huancavelica and Puno.

TABLE 5. BASIC DESCRIPTION OF THE STEPS INVOLVED IN PROCESSING WHITE *CHUÑO* IN TWO LOCATIONS.

White *Chuño* Puno-type			White *Chuño* Hvca-type		
Steps	Time	Details	Steps	Time	Details
Tending	Day 1	On grassland	Tending	Day 1	On grassland
Freezing	Day 1–3	On grassland; night: tubers are spread out for max. exposure; day: tubers are piled and covered with straw or nets to prevent exposure to sunlight.	Freezing	Day 1–4	On grassland, tubers are turned around (twice in total).
Washing	Day 4–24	Transfer of tubers to a river before daybreak; tubers in nets; after 7 days in the water the tubers are turned around.	Treading	Day 5	Tubers are gathered on small piles and treaded barefoot on grassland.
Freezing	Day 25	Washed tubers spread on grassland, covered with straw or nets.	Washing	Day 5–13	In a pond with very little running water; *Stipa ichu* straw on the bottom.
Treading	Day 26	Tubers are piled together and covered to prevent exposure to sunlight. During the day tubers are treaded in the water (quantities of 30–40 kg in net bags). Tuber skin is removed.	Drying	Day 13–27	On grassland
Drying	Day 27–37	On a straw cover			
Cleaning	Day 38	Abrading: removal of remaining tuber skin so that *chuño* is completely white.			
Selecting	Day 38	Grading by size (home consumption and sales)			

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

Regional Variants of *Chuño* Preparation

Differences between the steps involved in the preparation of black *chuño* of the Puno-type and Huancavelica-type were minimal (Table 4 and Fig. 2). In Puno the process took two more days compared to Huancavelica and additionally involved cleaning and selection to separate out black *chuño* for home consumption and sales.

Differences between the process of elaborating white *chuño* of the Puno-type and Huancavelica-type were considerable (Table 5 and Fig. 3). Processing white *chuño* in Puno took 11 more days than Huancavelica. It also involved more steps and meticulous attention to quality management in order to obtain a marketable product. Some of the main differences involved the use of a river with running water versus a pond with near stagnant water, the use of a straw cover versus no protection to prevent exposure to sunlight, and treading of tuber in the water versus on a solid surface in Puno and Huancavelica, respectively. In Puno the process involved cleaning and selection to separate out *chuño* for home consumption and sales.

a: washing of tubers in a pond with near stagnant water in Huancavelica

b: washing of tubers in a river with running water in Puno

c: white chuño of the 'Puno-type' elaborated with the native-bitter cultivar 'Piñaza'

d: white chuño of the 'Puno-type' elaborated with the native-floury cultivar 'Puqya'

Fig. 3. White *chuño* processing in Huancavelica and Puno.

TABLE 6. 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	
Genotype (G)	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*Genotype	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 7. 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	
Genotype (G)	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*Genotype	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 $\log^{10}$.
** $p<0.01$.

TABLE 8. DRY MATTER CONTENT (%) OF BOILED 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

INFLUENCE OF PROCESS AND CULTIVAR ON THE NUTRIENT COMPOSITION OF *CHUÑO*

The mineral content of boiled *chuño* is significantly influenced by the process (P), cultivar (C), and P*C interaction. Tables 6 and 7 show the general results of the overall ANOVA for each of the seven minerals analyzed. The dry matter content of boiled *chuño* is not significantly influenced by the interaction between process and cultivar (P*C).

Dry Matter (DM). The DM content of boiled (unprocessed) potato tubers and boiled *chuño* depends significantly on the type of traditional freeze-drying and the cultivar employed (Table 8). Independently of the cultivar employed, black *chuño* of the Huancavelica-type retains significantly higher levels of DM after boiling compared to the other types of *chuño*. On average, the cultivar 'Azul Qanchillu' maintained a higher DM 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 DM contents compared to the other cultivars.

Iron (Fe). High standard deviation concerning Fe content values of the different types of *chuño*, particularly those from the department Huancavelica, in combination with high aluminum contents, particularly for black *chuño* types, indicates probable contamination from soil or dust (see Table 9 and Fig. 4). Only in the case of white *chuño* from Puno was the influence of contamination minimal. Results for this particular type of *chuño* show that its Fe content is significantly influenced by the genotype employed. Interestingly, the Fe 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 Zn 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 (see Table 10). Results show that black *chuño*, independent of the specific type, retains higher levels of Zn compared to white *chuño*. The cultivar 'Puqya' contained the highest concentration of Zn in boiled tubers, while the cultivar 'Piñaza' contained the highest concentration in boiled *chuño* for three out of four types analyzed.

Calcium (Ca). Both types of boiled white *chuño* contained significantly higher concentrations of Ca compared to boiled tubers, while the content of both types of boiled black *chuño* generally tended to be lower (see Table 11). The only exception to the latter is boiled black *chuño* of the Huancavelica-type from the cultivar 'Piñaza.' The average Ca 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 Ca 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 Ca compared to the other cultivars in boiled tubers, white and black *chuño* of the Huancavelica-type, and white chuño of the Puno-type.

Potassium (K). The content of this mineral in boiled white and black *chuño* is negatively affected by freeze-drying (see Table 12). Both types of boiled black *chuño* show an average 2.6-fold decrease in their potassium concentration

TABLE 9. IRON CONTENT (MG/KG; DWB[1]) OF BOILED 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 C effect sliced by C
	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 C 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.

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 (see Table 13). The average phosphorus concentration of boiled black *chuño* as compared to boiled potato tubers declined 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, averaged 67.8% and 62.7%. Differences between the different cultivars were significant for boiled tubers and both types of black *chuño,* while differences between cultivars were 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 (see Table 14). 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

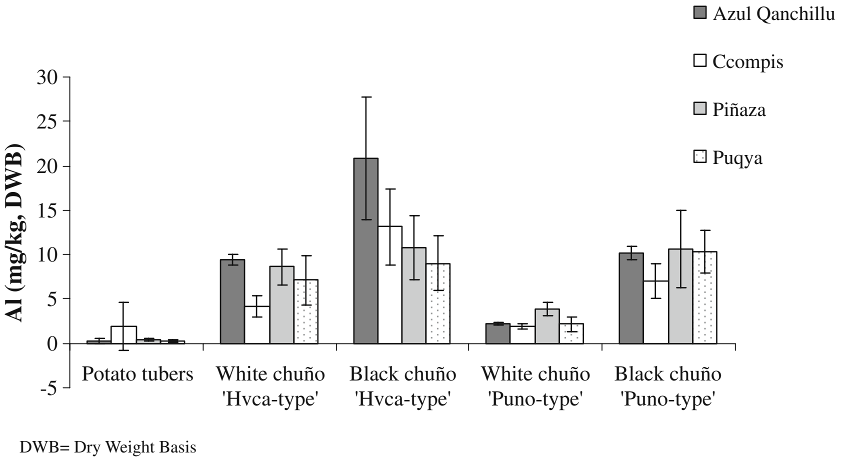

Fig. 4. Aluminum content (mg/kg; DWB[1]) of boiled tubers and four types of boiled *chuño.*

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 (see Table 15). 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.

Conclusions

Regional Variants of *Chuño* Preparation

Regional differences concerning the preparation of both black and white *chuño* are to a large extent determined by tradition, environmental conditions, and market demand. Differences are particularly notable in the case of regional variants of white *chuño* and involve the sequence and duration of each step in the processing pipeline. The lack of sources of (running) water in the highlands of Huancavelica strongly influences the final quality of white *chuño*. *Chuño* in Huancavelica is predominantly produced for home consumption and little attention is paid to commercial quality control, e.g., selection or grading. Commercial demand in Puno, particularly for white *chuño*, has stimulated innovations such as the use of floating deposits, net bags, and rubber boots for treading in order to obtain the highest possible quality. Increased export of white *chuño* (*tunta* / *moraya*) to Bolivia has made both processing and value chain management more quality-oriented.

Effect of Process and Cultivar on the Nutritional Value

The zinc, potassium, phosphorus, and magnesium content of all types of boiled *chuño* is significantly lower compared to content values of boiled (unprocessed) tubers. The process of traditional freeze-drying, without exception, negatively affects the nutritional value of *chuño* for these four 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*. Rates of additional loss for zinc, phosphorus, and magnesium of white compared to black chuño were modest and averaged 36.5%, 38.2%, and 34.3%, respectively. However, the loss of potassium in white compared to black *chuño* was sizable, and, on average, black *chuño* retained 33 times higher levels of potassium than white *chuño*. It seems likely that the higher loss of these minerals in white as compared to black *chuño* originates from the exposure of tubers to (running) water during the process of freeze-drying.

The influence of the four 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

TABLE 10. ZINC CONTENT (MG/KG; DWB[1]) OF BOILED 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 (±)	P x C effect sliced by C
'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 C effect sliced by P	*		**		*		**		**		

[1] = Dry Weight Basis.
P = process.
C = cultivar.
** $p<0.01$.
* $p<0.05$.

TABLE 11. CALCIUM CONTENT (MG/KG; DWB[1]) OF BOILED 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 (±)	P x C effect sliced by C
'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 C effect sliced by P	**		**		**		**		ns		

[1] = Dry Weight Basis.
P = process.
C = cultivar.
** $p<0.01$.
* $p<0.05$.

TABLE 12. POTASSIUM CONTENT (MG/KG; DWB[1]) OF BOILED 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 (±)	P x C effect sliced by C
'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 C effect sliced by P	**		ns		**		ns		**		

[1] = Dry Weight Basis.
P = process.
C = cultivar.
** p<0.01.
* p<0.05.

TABLE 13. PHOSPHORUS CONTENT (MG/KG; DWB[1]) OF BOILED 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 (±)	P x C effect sliced by C
'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 C eff. sliced by P	**		ns		**		ns		**		

[1] = Dry Weight Basis.
P = process.
C = cultivar.
** p<0.01.
* p<0.05.

TABLE 14. MAGNESIUM CONTENT (MG/KG; DWB[1]) OF BOILED 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 (±)	P x C effect sliced by C
'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 C eff. sliced by P	*		**		**		**		**		

[1] = Dry Weight Basis.
P = process.
C = cultivar.
** $p<0.01$.
* $p<0.05$.

TABLE 15. SODIUM CONTENT (MG/KG; DWB[1]) OF BOILED 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 (±)	P x C effect sliced by C
'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 C eff. sliced by P	**		ns		**		**		ns		

[1] = Dry Weight Basis.
P = process.
C = cultivar.
** $p<0.01$.
* $p<0.05$.

content compared to boiled tubers. Unfortunately, contamination of samples of both types of black *chuño* and white *chuño* of the Huancavelica-type do not allow us to draw conclusions concerning the influence of processing on the iron content. Iron content values for white *chuño* of the Puno-type clearly indicate a strong influence of the genotype (cultivar/cultivar category). The iron content of *chuño* originating from native-bitter cultivars was higher, while the content of *chuño* originating from native-floury cultivars was lower compared to content values of boiled tubers of the same cultivars.

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, since average concentrations of this mineral in white *chuño* of the Puno-type were generally much higher compared to those of boiled tubers, while sodium concentrations in all other types of *chuño* tended to be significantly lower compared to content values of boiled tubers.

The boiled *chuño* of some cultivars is considerably more nutritious and contains comparatively high mineral levels after freeze-drying compared to other cultivars. Such is the case for the native-bitter cultivar 'Piñaza', which turned out to be a particularly nutritious genotype. With some notable exceptions, the cultivar 'Piñaza' contained the highest average content of zinc, calcium, and magnesium for most types of *chuño*.

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 an altitude of 3,500 m. Potato, consumed as boiled tubers or *chuño* and often combined with grains such as barley, makes up the bulk of daily food intake (Graham et al. 2007). 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. Historically, *chuño* has made human life in the Andes above 3,800 m possible. *Chuño*, just as other traditionally freeze-dried products, allow Andean households to overcome periods of relative food shortage. Additionally, the consumption of *chuño* is embedded 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, 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 *chuño* as 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.

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