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Original Article

Ascorbic acid concentration of native Andean potato varieties as affected by environment, cooking and storage

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ABSTRACT

The ascorbic acid (AA) concentration of tubers was determined in 25 Andean potato varieties (*Solanum tuberosum* L.) grown in three environments, and the effect of cooking and storage time in subsets of samples was evaluated. Significant variation due to genotype, environment and genotype $\times$ environment (G $\times$ E) interaction was found. AA concentration in freshly harvested raw, peeled tubers ranged from 22.2 to 121.4 mg/100 g on a dry weight basis (DW) and from 6.5 to 36.9 mg/100 g on a fresh weight basis (FW) with the accession 704393 showing the highest levels of AA in all three locations. Differences in AA concentration were found among cooking methods and storage times; and significant non-crossover interactions with genotype were observed for both of these parameters. It was found that AA concentration of boiled tubers of the six varieties evaluated was higher than in oven and microwaved tubers and that AA concentration of tubers of the 23 varieties evaluated decreased with storage time. The variety 704393 retained 54 and 34% of its original AA concentration after boiling and storage during 26 weeks under farmer conditions. One hundred grams of fresh harvested boiled potatoes of this variety (704393) could provide adults with 17–20% of the recommended daily allowance (RDA) of AA.

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the world's most important crops, ranking fifth in terms of human consumption and fourth in worldwide production (Horton, 1987). Beyond supplying energy and good quality protein, potato is also an important source of vitamins and minerals. However, its value within the human diet—particularly as a source of vitamin C—is often underestimated or ignored, (Dale et al., 2003; Woolfe, 1987). There are two major forms of vitamin C: L-ascorbic acid (AA) and L-dehydroascorbic acid (DHAA); however, the terms vitamin C and ascorbic acid are frequently used as synonyms (Bates, 1997).

AA is an essential component of most living tissues. As an antioxidant, it plays an important role in protection against oxidative stress. AA is an important scavenger of free radical species, such as reactive oxygen species that can cause tissue damage resulting from lipid peroxidation, DNA breakage or base alterations, and may contribute to degenerative diseases such as heart disease or cancer (Bates, 1997). In addition, due to its participation in the oxidation of transition metal ions, AA also plays an important role in enhancing the bioavailability of non-haem iron (Teucher et al., 2004). The Food and Agriculture Organization (FAO/WHO, 2001) indicated that the recommended nutrient intake of vitamin C ranges from 25 to 45 mg/day, depending on age. However, based on available biochemical, clinical, and epidemiological studies, the current RDA for AA is suggested to be 100–120 mg/day for adults to achieve cellular saturation and reduce risk of heart disease, stroke and cancer in healthy individuals (Naidu, 2003).

Newly harvested potato tubers have been reported to contain up to 46 mg AA/100 g FW (Han et al., 2004; Mishra, 1985; Mullin et al., 1991; Nordbotten et al., 2000) depending primarily upon the variety, the maturity of the tubers at harvest, the sampling method, and—to almost as great an extent—the environmental conditions under which they were grown (Murphy, 1946).Several authors have described considerable reduction in the quantities of AA during cooking and storage in potatoes as well as in vegetables, with losses that vary widely according to cooking method (Augustin et al.,

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1978a; Lešková et al., 2006; Suárez et al., 2004) and storage time (Casañas et al., 2003; Mishra, 1985; Zee et al., 1991).

However, almost all information about the AA concentration of potato in freshly harvested and stored potatoes in raw and cooked tubers relates to improved commercial varieties and there is scant information about the nutrient concentration of potato genetic resources, including the many native cultivars still grown and consumed in the Andean center of origin and diversity of potato.

The present study sought to determine the AA concentrations of a taxonomically diverse set of native Andean potato cultivars grown in three different environments, and the effects of cooking and storage on those concentrations. This information will be very useful to recommend those varieties and preparation methods with the highest retention of AA, as well as to assess genetic diversity for use in breeding programs seeking to improve the nutritional value of potato.

2. Materials and methods

2.1. Plant material

Twenty-five native varieties representing five taxonomic groups of cultivated potato conserved in the germplasm collection at CIP were used for this study. Samples of tubers were taken from seed plots grown in randomized complete block designs with three replications of 10 hills per plot in each of three sites of the central Peruvian Andes: Inyaya Alto (3700 m above sea level [masl]), District of Chiara, Huamanga, Ayacucho) in 2004, and La Victoria (3280 masl; District El Tambo, Huancayo; Junín) and Aymara (3800 masl; District of Pazos, Tayacaja; Huancavelica) in 2005. Well-matured tubers were harvested at 150 days after planting in La Victoria and 180 days in Inyaya and Aymara. A maximum of 75 unblemished tubers of representative size for each variety were collected from across the replicate plots at each site. 2 weeks after harvest, 15 raw, peeled tubers from each variety in each location were used to determine the AA concentrations of fresh tubers. One month after harvest, 15 tubers of each of six varieties from plots in Inyaya were boiled, baked and microwaved to evaluate the effect of the type of cooking on the AA concentration. 2 weeks after harvest, 15 tubers of all the 25 varieties from the plots in La Victoria were used to determine the AA concentration on boiled tubers. Forty-five tubers of the 23 varieties grown in La Victoria were used to assess the effect of three storage times (Fig. 1).

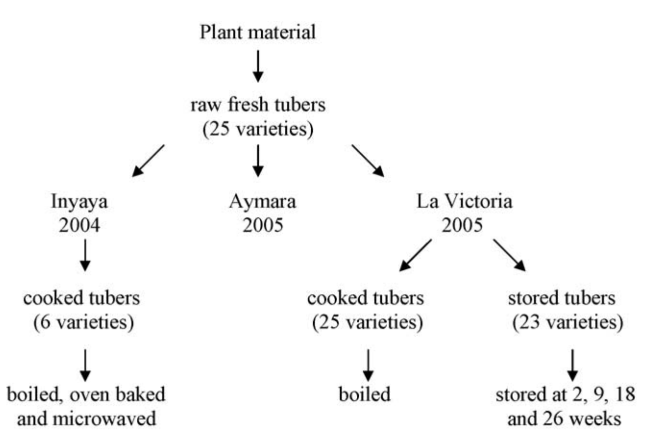

Fig. 1. Plant material distribution for analysis of raw, cooked and stored potatoes.

2.2. Sample preparation

2.2.1. Freshly harvested raw tubers

Tubers were stored at 5 °C until sample preparation. Three samples of 4–5 raw peeled tubers each were prepared for each variety 2 weeks after harvest. Tubers were washed with abundant tap water, rinsed with deionized water, dried with paper towels, peeled and cut longitudinally into four sections. One or two slices of two opposite sections of each tuber were used to prepare each of three laboratory samples. The slices were cut and mixed, and a 15 g laboratory sample was taken and placed in a stainless steel beaker and immediately analyzed as described below.

2.2.2. Cooked tubers

The effects of three cooking methods (boiling, oven baking and microwaving) on the AA concentration were tested using three laboratory samples of 4–5 tubers each per method for six of the varieties grown in Inyaya; and the AA concentrations of boiled tubers of all of the varieties grown in La Victoria were determined using three samples of 4–5 tubers each per variety. Tubers were stored at 5 °C until sample preparation.

Boiling: Each sample of each variety was placed in a stainless steel pot, covered with cool water and cooked over uniform high temperature during 25–35 min.

Microwaving: The three samples of each variety were wrapped separately with moistened paper towel and microwaved during 4–5 min.

Baking: Tubers of three samples of each variety were wrapped with aluminum foil and baked together in an oven at 160–180 °C during 39–57 min.

Tubers were considered cooked when a stainless steel probe penetrated them easily. Each variety showed a different time of cooking in each cooking treatment. Cooked tubers were peeled and sampled for AA determination in the same way as raw tubers, above.

2.2.3. Stored raw tubers

Tubers of 23 varieties grown in La Victoria were stored under highland farmers' conditions: in a dark, well-ventilated room, with a mean relative humidity (RH) of 69% (58–79%) and a mean temperature of 13 °C (12–15 °C), and the AA concentrations of tubers were determined at 2, 9, 18 and 26 weeks after harvest. Three samples of 4–5 peeled tubers per variety were prepared for each storage time and the laboratory sample was obtained as explained above for freshly harvested raw tubers.

2.3. Analytical method

AA concentrations were evaluated by the spectrophotometric method of Egoville et al. (1988). The method is based on the ability of AA to reduce the dye 2,6-dichloroindophenol. Since DHAA is present in very low amount in potatoes we do not evaluate its concentration. Briefly, the 15 g laboratory sample was extracted with an oxalic acid and acetone solution (0.4 and 20%, respectively) by homogenizing in a Sorvall Omni Mixer during 5 min at 4000 rpm. The extract was filtered under vacuum through filter paper Whatman 2 and brought to 100 ml with the same extracting solution. One millilitre of the extract was reacted with 9 ml of 2,6-dichloroindophenol (1.6%) during 1 min and read at 520 nm on a spectrophotometer (SHIMADZU 160UV). The AA concentration was quantified through comparison with a standard curve of L-AA (MERCK).

2.4. Quality control

The implemented analytical method showed a good repeatability with a coefficient of variation of triplicate analyses in 10 different samples ranging between 3 and 5%. As no reference material was available at the time, 10 potato samples with different AA concentration (from 9.7 to 22.9 mg/100 g) were sent to a certified laboratory and analyzed by the dichlorophenol indophenol titration procedure (AOAC, 1990). The concentrations reported by the certified laboratory ranged from 10.3 to 21.4 mg/100 g and showed a correlation of 0.97 ($p < 0.01$) with the results obtained at CIP.

Concentrations were expressed in mg/100 g, FW. The dry matter content of the individual samples was also determined at the time of each AA analysis on the basis of differences in weight before and after oven drying at 100 °C and used to estimate the concentration in mg/100 g, DW. The percentages of retention after the different methods of cooking and after 26 weeks storage were calculated using values on a DW basis in order to account for loss or gain of water after cooking and storage.

2.5. Statistical analysis

Simple analysis of variance (ANOVA) was performed for each site considering a randomized complete design with three replications (laboratory samples), and genotypic means were compared by Tukey's test. The effect of environment (Inyaya, La Victoria and Aymara) and the G $\times$ E interaction were analyzed by ANOVA considering the factors genotypes as fixed and sites as random effects.

The effects of the cooking method, and of boiling and storage were analyzed by ANOVA, considering the genotypes and the method of cooking (raw, boiled, microwaved and oven baked), boiling (boiled vs. raw) and storage (2, 9, 18 and 26 weeks after harvest) treatments as fixed effects, and means were compared by Tukey's test.

All statistical tests were performed using SAS/STAT (version 8.2) software.

3. Results and discussion

3.1. AA concentrations in freshly harvested raw potato tubers

The AA concentration of the 25 native potato varieties grown in Inyaya, La Victoria and Aymara are shown in Table 1. ANOVA indicated significant ($p < 0.001$) variation in the AA concentration of the different genotypes in each site. The AA concentration observed in the varieties grown in Inyaya, La Victoria and Aymara ranged from 22.2 to 105.2 mg/100 g, from 35.9 to 121.4 mg/100 g and from 25.5 to 105.1 mg/100 g DW and from 6.5 to 34.0 mg/100 g, from 9.0 to 36.9 mg/100 g and from 7.6 to 33.6 mg/100 g FW, respectively. Previously reported values of the AA concentration of raw tubers on a FW basis ranged from 7.9 to 36.3 for American varieties (Augustin et al., 1978b; Murphy, 1946), 10.4–17.0 mg/100 g for Indian varieties (Mishra, 1985); from 8.4 to 20.1 mg/100 g for Norwegian varieties (Nordbotten et al., 2000); from 8.8 to 24.1 mg/100 g for Canadian varieties (Mullin et al., 1991) and from 16 to 46 mg/100 g for Korean varieties (Han et al., 2004).

The variety 704393 showed the highest AA concentration on both a DW (105.1–121.4 mg/100 g) and a FW (33.6–34.0 mg/100 g) basis. This value is considerably higher than the highest previously reported values for Indian, Canadian and Norwegian potato varieties but lower than the highest reported value for Korean varieties. However, it should be emphasized that the values reported in this study are representative of the whole tuber while those reported for the Korean varieties represent the concentration in the center part of tubers.

The substantial genotypic variation that exists in the AA concentrations means that breeders can select genotypes and develop varieties with high levels of AA. Further evaluation of the varieties during the growing and storage cycles is required to monitor the dynamics of AA concentration and determine the degree to which tuber size, maturity or physiological aspects and

Table 1
Ascorbic acid concentration of native potato varieties in three environments.

CIP number	Cultivar name	Taxonomic group[A]	mg/100 g DW			p[B]	mg/100 g FW		
			Inyaya[C]	La Victoria[C]	Aymara[C]		Inyaya[C]	La Victoria[C]	Aymara[C]
700234	SA-2563	Adg	35.4 ± 4.8^{fghi}	51.7 ± 8.8^{defg}	62.6 ± 0.6^{bcd}	**	8.8 ± 1.4^{ijk}	13.0 ± 1.6^{defg}	15.1 ± 0.3^{cde}
700787	EE-2057	Adg	22.2 ± 3.7^{l}	37.0 ± 3.5^{gh}	40.4 ± 1.6^{ghi}	**	6.5 ± 1.1^{l}	9.0 ± 1.2^{h}	11.0 ± 0.2^{fgh}
701273	Muro Shocco	Adg	70.8 ± 0.9^{b}	65.6 ± 7.2^{bcd}	50.8 ± 6.5^{defgh}	**	18.3 ± 0.8^{b}	17.3 ± 1.3^{bcd}	13.9 ± 1.3^{def}
701515	Rucuma o Lucuma	Adg	69.1 ± 0.9^{b}	66.1 ± 8.5^{bcd}	47.4 ± 5.7^{efghi}	**	17.7 ± 0.6^{bc}	15.7 ± 1.1^{bcde}	12.1 ± 1.3^{efg}
701997	Sullu	Adg	30.8 ± 3.9^{ghij}	52.0 ± 6.6^{def}	58.1 ± 8.7^{bcdef}	**	8.2 ± 1.0^{jk}	13.5 ± 1.5^{def}	14.1 ± 1.9^{def}
702363	Socco Huaccoto	Adg	50.0 ± 3.3^{c}	64.1 ± 2.1^{bcd}	59.7 ± 6.2^{bcde}	**	11.4 ± 0.7^{efgh}	13.7 ± 0.5^{def}	13.8 ± 1.5^{def}
702395	Puma Maqui	Adg	24.0 ± 1.9^{kl}	49.2 ± 3.7^{defgh}	43.8 ± 1.9^{fghi}	**	7.7 ± 0.6^{kl}	13.6 ± 0.6^{def}	11.8 ± 0.2^{efgh}
702453	Waca-uno	Adg	35.7 ± 4.7^{fghi}	52.5 ± 7.0^{def}	63.9 ± 7.0^{bcd}	**	9.4 ± 0.7^{hijk}	12.9 ± 1.6^{defg}	16.4 ± 1.3^{bcd}
702464	Natin Suito	S $\times$ G	49.9 ± 1.7^{c}	78.3 ± 3.7^{b}	69.1 ± 9.1^{bc}	**	13.5 ± 0.6^{defg}	20.8 ± 0.1^{b}	20.5 ± 2.3^{b}
702736	Puca Micnush	Stn	36.7 ± 2.5^{efgh}	64.1 ± 2.5^{bcde}	44.0 ± 1.4^{fghi}	**	12.0 ± 0.3^{defgh}	16.6 ± 0.9^{bcde}	14.5 ± 0.6^{cde}
702815	Morar Nayra	Stn	40.3 ± 0.5^{cdef}	65.3 ± 1.0^{bcd}	46.4 ± 1.0^{efghi}	**	11.2 ± 0.4^{efgh}	16.7 ± 0.7^{bcde}	13.1 ± 0.1^{defg}
703265	Yurac Sole	Adg	35.3 ± 2.7^{fghi}	64.6 ± 6.2^{bcd}	$40.7 \pm 2{,}7^{ghi}$	**	11.0 ± 0.6^{fghi}	14.9 ± 2.0^{cde}	11.8 ± 0.6^{efg}
703268	Bolona	Adg	45.0 ± 3.9^{cde}	55.7 ± 1.1^{cde}	52.8 ± 4.2^{cdefg}	*	14.2 ± 1.3^{cdef}	14.4 ± 0.5^{de}	13.4 ± 1.7^{defg}
703312	Morada Taruna	Stn	38.2 ± 0.7^{defg}	36.7 ± 6.1^{h}	37.7 ± 1.5^{ij}		11.0 ± 0.5^{fghi}	9.1 ± 1.5^{h}	10.6 ± 0.3^{gh}
703421	Poluya	Stn	34.3 ± 1.2^{fghi}	66.0 ± 4.4^{bcd}	51.2 ± 3.0^{defgh}	**	10.3 ± 0.5^{hij}	16.9 ± 1.4^{bcd}	13.6 ± 0.3^{defg}
703741	Ambar	GxS	47.3 ± 1.7^{cd}	73.9 ± 4.1^{bc}	64.9 ± 4.7^{bcd}	**	15.0 ± 0.7^{bcd}	19.8 ± 1.2^{bc}	16.1 ± 1.3^{bcd}
703825	China Runtush	Gon	46.6 ± 2.7^{cd}	79.0 ± 5.5^{b}	60.7 ± 2.0^{bcde}	**	14.39 ± 1.0^{cde}	21.3 ± 1.8^{b}	18.3 ± 0.8^{bc}
703899	Chaucha Roja	Adg	26.8 ± 0.8^{jkl}	38.3 ± 6.0^{fgh}	39.4 ± 7.0^{hi}	**	7.9 ± 0.2^{kl}	10.6 ± 1.4^{fgh}	11.2 ± 2.3^{fgh}
703985	Runtu	Gon	28.2 ± 1.5^{ijk}	53.7 ± 1.8^{cde}	41.9 ± 1.8^{ghi}	**	9.8 ± 0.4^{hijk}	15.3 ± 1.2^{cde}	13.4 ± 0.4^{defg}
704143	Negra Ojosa	Adg	29.5 ± 1.9^{hijk}	52.7 ± 9.9^{def}	59.3 ± 2.7^{bcde}	**	8.7 ± 0.7^{ijk}	14.1 ± 1.9^{def}	15.7 ± 1.0^{cd}
704393	Maria Cruz	Gon	105.2 ± 1.7^{a}	121.4 ± 3.4^{a}	105.1 ± 1.7^{a}		34.0 ± 2.4^{a}	36.9 ± 0.9^{a}	33.6 ± 0.9^{a}
705009	Purranca	Tbr	46.0 ± 0.6^{cde}	74.4 ± 8.4^{bc}	73.2 ± 4.8^{b}	**	10.7 ± 0.9^{ghi}	15.7 ± 1.3^{bcde}	14.4 ± 0.9^{cde}
705543	Yana Warmi	Cha	32.2 ± 1.1^{fghij}	45.8 ± 4.3^{efgh}	28.8 ± 4.1^{jk}	**	10.5 ± 0.4^{ghij}	12.4 ± 1.8^{efg}	9.2 ± 1.1^{hl}
706191	Cuchi Chucchan	Adg	30.4 ± 0.7^{hij}	35.9 ± 2.1^{h}	25.5 ± 2.3^{k}	**	9.4 ± 0.3^{hijk}	9.9 ± 0.7^{gh}	7.6 ± 0.6^{l}
707135	Duraznillo	Cha	31.7 ± 2.2^{ghik}	52.0 ± 4.4^{def}	37.8 ± 1.1^{ij}	**	10.2 ± 0.7^{hij}	13.6 ± 1.4^{def}	11.0 ± 0.7^{fgh}
	Mean		41.7 ± 18.0	59.8 ± 18.1	52.2 ± 16.5		12.1 ± 5.4	15.5 ± 5.5	14.2 ± 4.9

[A] Phu, Phureja; Adg, Andigena; Tbr, Tuberosum; Gon or G, Goniocalyx; Stn or S, Stenotomum; Cha, Chaucha.
[B] Differences between sites for each accession: *significant at 5% level and **significant at 1% level.
[C] Mean values $\pm$ standard deviation (n = 3). Different letters indicate significant differences between accessions for each site. HSD = 5.7 (α = 0.05).

Table 2
Combined ANOVA for ascorbic acid concentration (mg/100 g DW) of potato varieties in Inyaya, La Victoria and Aymara.

Source of variation	Degrees of freedom	Sums of squares[a]	Mean squares[a]	Percent TSS	*F*-Value
Environment (E)	2	1.1	0.5	20.2	366.0**
Genotype (G)	12	3.3	0.3	60.3	15.8**
G × E	48	0.8	1.8E-02	15.3	11.6**
Error	150	0.2	1.3E-03		
Total	224	5.4	2.4E-02		
Mean		51.2			
CVa%		1.7			
CV%		8.4			
r^2		0.96			

r^2 Coefficient of determination.
[a] Transformation to $\log_{10}$.
** Significant at 1% level.

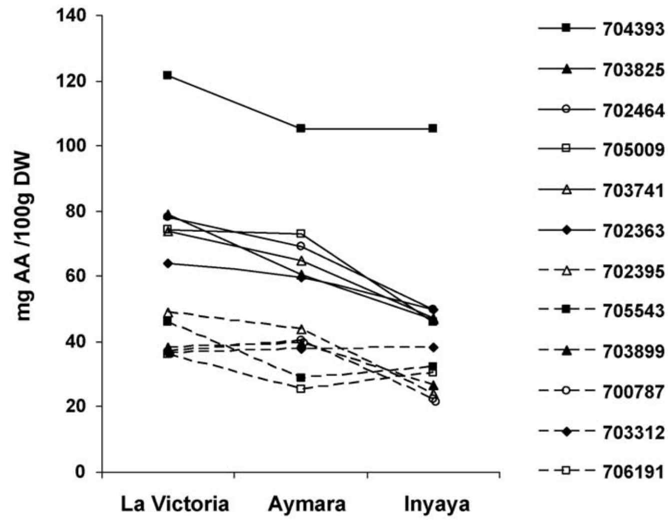

Fig. 2. Genotype × environment interaction on the ascorbic acid concentration of the upper and lower six germplasm accessions evaluated in three locations.

post harvest handling might confound genotypic effects on the parameters measured here (Kalt, 2005).

The Peruvian Food Composition Table (PFCT) (MINSA-INS-CENAN, 1996) indicates that the mean concentration of white potatoes—referring to improved varieties—is 14 mg/100 g, FW and that of yellow potatoes as Andean varieties are known is 9 mg/100 g, FW. The total mean AA concentration of all Andean varieties analyzed in each locality was higher (12.1, 15.5 and 14.2 mg/100 g, FW for Inyaya, La Victoria and Aymara, respectively) than the mean reported in the PFCT with the variety 404393 reaching more than twofold higher AA concentration.

One hundred grams of vegetables like broccoli, red pepper, watercress, cabbage and cauliflower (114.0, 108.3, 105.6, 96.3 and 75.3 mg AA/100 g, respectively) (MINSA-INS-CENAN, 1996) and fruits like orange, grapefruit, tangerine, papaya, and strawberry (92.3, 50.6, 48.7, 47.7 and 44.2 mg AA/100 g, respectively) (MINSA-INS-CENAN, 1996) have higher AA concentration than the mean in potato tubers. However, the contribution of AA from potatoes to the diet can be higher considering that in some places potato is a staple because of its higher amount consumed more frequently, while vegetables and fruits are usually only complementary components of the diet.

3.2. Effect of environment and genotype × environment interaction on AA concentration

Analysis of variance of the AA concentration of the 25 native varieties grown in three locations (Inyaya, La Victoria and Aymara) revealed significant effects due to environment and G × E interactions as well as genotype ($p < 0.01$) (Table 2). However, the contribution of the genotype (60.3%) to the variance was threefold higher than that of the environment (20.2%) and fourfold higher than that of the G × E interaction (15.3) which indicates that is possible to select progenitors with the highest AA concentrations and expect a fast progress in breeding for this character. Similar results have been found for North American potato germplasm (Love et al., 2003). Dale et al. (2003) reported significant differences for environment but not for the genotype × environment interaction for breeding material from Europe.

With the exception of the varieties 703312 and 704393, which showed no differences in the concentration of AA across environments (Table 1), crossover type G × E interactions were observed for most of the genotypes. However, it was found that six genotypes showed the highest AA concentration in the three environments while six genotypes showed the lowest AA concentration (Fig. 2). The variety 704393 showed the highest AA concentration across environments: 105.2 mg/100 g DW in Inyaya, 121.4 mg/100 g DW in La Victoria and 105.1 mg/100 g, DW in Aymara.

Despite the different performance of some cultivars across locations, there was a tendency toward higher concentration of AA in La Victoria. Potatoes in this location were grown under conditions of CIP's experiment station while those at the remaining locations were grown in farmers' fields. Another point is that the soil pH at La Victoria was considerably higher (pH 7.6) than that of the other localities: Aymara (pH 3.6) and Inyaya (pH 5.2). Higher AA concentration has been shown to be associated with higher soil pH in tomato (Pascale et al., 2001).

Table 3
Ascorbic acid concentration and retention of boiled, baked and microwaved tubers of 6 potato varieties grown in Inyaya.

CIP number	mg/100 g DW					% r[A]		
	Raw[B]	Boiled[B]	Baked[B]	Microwaved[B]	p[C]	Boiled	Baked	Microwaved
700787	17.5 ± 0.1[a]	9.9 ± 1.3[b]	8.3 ± 1.2[c]	6.6 ± 0.5[d]	**	56	47	38
702395	28.5 ± 0.3[a]	20.9 ± 1.5[b]	5.4 ± 1.2[c]	2.7 ± 0.3[d]	**	73	19	10
702815	32.5 ± 0.5[a]	31.4 ± 1.1[b]	21.4 ± 1.0[c]	12.9 ± 1.6[d]	**	97	66	40
703317	32.8 ± 0.9[a]	22.5 ± 0.9[b]	2.1 ± 0.6[c]	1.9 ± 0.8[c]	**	69	6	6
701515	37.9 ± 0.4[a]	32.8 ± 1.1[b]	18.9 ± 1.0[c]	8.7 ± 1.1[d]	**	87	50	23
704393	75.5 ± 0.8[a]	56.5 ± 1.3[b]	24.3 ± 1.4[c]	18.4 ± 1.1[d]	**	75	32	24

[A] Percentage of retention after cooking.
[B] Mean values ± standard deviation (n = 3).
[C] Differences between cooking treatments: **significant at 1% level. Different letters indicate significant differences between treatments for each accession. HSD = 5.7 (α = 0.05).

3.3. Effect of the cooking method on the AA concentrations

Because humans consume only cooked potatoes and because AA is known to be susceptible to degradation during culinary processes (Lešková et al., 2006), the effect of three cooking methods (boiling, baking and microwaving) was studied.

The AA concentration of tubers cooked by the three methods for six of the varieties grown in Inyaya is shown in Table 3. ANOVA indicated a significant non-crossover interaction between cooking method and variety ($p < 0.0001$). For all six varieties, boiling reduced the AA concentration to a lesser degree than either baking or microwaving. These results are contrary to what has been found for other vegetables like broccoli, cauliflower, spinach, etc. (How et al., 1995; Howard et al., 1999) for which the AA concentration of microwaved vegetables is higher than in the boiled form. This difference may be due to the use of unpeeled tubers during cooking in this study, as per the custom of highland potato consumers, while the other vegetables were directly exposed to hot water when boiled.

The percentage of AA retention ranged from 53 to 97%, from 6 to 66% and from 6 to 39% in boiled, baked and microwaved potatoes, respectively. A similar percentage of AA retention in boiled potatoes (53–97%) was found by Augustin et al. (1978a) who also used potatoes cooked with their peels. However, the percentages of AA retention in baked and microwaved potatoes found in this study are lower than those found by Augustin et al. (1978a) (from 69 to 77% and from 77 to 58% in baked and microwaved potatoes respectively. A recent study reported higher percentage of retention of the AA concentration when potatoes are microwaved (67–79%) than boiled (12–23%) (Han et al., 2004). However, this difference is likely due to the different methods used to prepare the boiled samples. Han et al. (2004) boiled plugs obtained from the central parts of tubers by penetrating the tuber with a cork borer from the stem end to the rose end, while in the present study tubers were boiled with their skins intact, peeled after cooking, quartered longitudinally and sliced for taking the laboratory sample.

3.4. Evaluation of the AA in tubers after boiling

As native potato varieties are commonly eaten boiled, we analyzed the AA concentrations of all the varieties after boiling, using tubers grown in La Victoria. Results are shown in Table 4. ANOVA indicated a significant non-crossover interaction between variety and boiling effect. All the varieties showed lower AA concentration after boiling, but these differences were significant for only 18 of the varieties. Retention values ranged from 54 to 97% for the set of 25 cultivars tested.

The AA concentration of boiled tubers from the 25 varieties ranged from 29.4 to 65.3 mg/100 g, DW and from 8.1 to 20.6 mg/100 g, FW; with the native variety 704393 showing the highest AA concentration after boiling. One hundred grams of boiled potatoes of this variety could provide between 17 and 20% of the RDA of AA, which is suggested to be 100–120 mg/day to achieve cellular saturation and optimum risk reduction of heart diseases, stroke and cancer in healthy individuals (Naidu, 2003). However, the contribution of potato to the RDA of AA can be higher than this, considering higher potato consumption in some places, such as the highlands of Peru (200 and 800 g, for children and women, respectively) (Burgos, 2006).

3.5. Effect of storage on the AA concentration

As a staple in Andean diets, native potatoes are grown in a single, relatively long season (5–7 months) and stored or processed under rustic conditions for consumption for several months. However, it is

Table 4
Ascorbic acid concentration and retention of boiled tubers of 25 varieties grown in La Victoria.

CIP number	mg/100 g DW			%r[A]	mg/100 g FW	
	Raw[B]	Boiled[B]	p[C]		Raw[B]	Boiled[B]
703899	38.3 ± 6.0	29.4 ± 2.9	**	77	10.6 ± 1.4	9.1 ± 0.8
706191	35.9 ± 2.1	29.6 ± 2.7	*	83	9.9 ± 0.7	8.1 ± 0.8
702453	52.5 ± 7.0	31.3 ± 2.7	**	60	12.9 ± 1.6	8.3 ± 0.7
703312	36.7 ± 6.1	32.5 ± 3.8		89	9.1 ± 1.5	8.5 ± 1.1
700787	37.0 ± 3.5	32.9 ± 4.2		89	9.0 ± 1.2	7.8 ± 0.8
700234	51.7 ± 8.8	35.0 ± 1.5	**	68	13.0 ± 1.2	9.4 ± 0.7
705543	45.8 ± 4.3	35.9 ± 2.7	**	78	12.4 ± 1.8	9.5 ± 0.3
702736	64.1 ± 2,5	37.8 ± 2.4	**	59	16.6 ± 0.9	10.5 ± 0.6
703421	66.0 ± 4,4	40.4 ± 3.5	**	61	16.9 ± 1.4	10.4 ± 0.7
704143	52.7 ± 9.9	41.5 ± 3.7	**	79	14.1 ± 1.9	10.8 ± 0.6
707135	52.0 ± 4.4	43.4 ± 1.6	*	83	13.6 ± 1.4	11.7 ± 0.7
703265	64.6 ± 6.2	43.5 ± 1.9	**	67	14.9 ± 2.0	10.8 ± 0.9
702395	49.2 ± 3.7	45.5 ± 5.3		92	13.6 ± 0.6	12.6 ± 0.9
701997	52.0 ± 6.6	47.7 ± 2.0		92	13.5 ± 1.5	12.4 ± 0.7
703825	79.0 ± 5.5	48.3 ± 1.8	**	61	21.3 ± 1.8	13.3 ± 0.8
703985	53.7 ± 1.8	48.4 ± 1.4		90	15.3 ± 1.2	14.0 ± 0,7
702815	65.3 ± 1.0	48.9 ± 3.2	**	75	16.7 ± 0.7	14.0 ± 1.0
705009	74.4 ± 8.4	52.2 ± 4.6	**	70	15.7 ± 1.3	12.2 ± 1.1
703741	73.9 ± 4.1	53.9 ± 2.5	**	73	19.8 ± 1.2	14.4 ± 0.8
703268	55.7 ± 1.1	54.1 ± 4.4		97	14.4 ± 0.5	13.5 ± 0.6
701515	66.1 ± 8.5	54.6 ± 3.2	*	83	15.7 ± 1.1	13.0 ± 0.3
701273	65.6 ± 7.2	55.1 ± 2.7	*	84	17.3 ± 1.3	14.3 ± 1.2
702464	78.3 ± 3.7	56.0 ± 4.8	**	72	20.8 ± 0.1	12.5 ± 0.8
702363	64.1 ± 2.1	56.8 ± 3.4		89	13.7 ± 0.5	13.3 ± 0.4
704393	121.4 ± 3.4	65.3 ± 1.9	**	54	36.9 ± 0.9	20.6 ± 1.1

[A] Percentage of retention after boiling.
[B] Mean values ± standard deviation ($n = 3$).
[C] Differences between raw and boiled for each variety: *significant at 5% level and **significant at 1% level.

Table 5
Ascorbic acid concentrations (mg/100 g, DW) and retention in tubers of 23 native potato varieties at four time points during storage under farmer conditions.

CIP number	T0	T1	T2	T3	p[A]	%r[B]
	2 weeks[C]	9 weeks[C]	18 weeks[C]	26 weeks[C]		
704143	52.7 ± 9.9[a]	33.8 ± 4.0[b]	30.5 ± 1.2[b]	14.6 ± 1.7[c]	**	28
703268	55.7 ± 1.1[a]	45.3 ± 5.7[b]	37.8 ± 1.5[c]	15.8 ± 1.3[d]	**	28
703741	73.9 ± 4.1[a]	56.0 ± 3.7[b]	30.2 ± 3.7[c]	16.3 ± 2.1[d]	**	22
705009	74.4 ± 8.4[a]	56.1 ± 7.9[b]	28.1 ± 3.3[c]	18.2 ± 1.6[d]	**	24
706191	35.9 ± 2.1[a]	24.6 ± 2.0[b]	24.2 ± 1.9b[c]	19.6 ± 2.2[c]	**	55
702395	49.2 ± 3.7[a]	49.4 ± 3.3[a]	36.7 ± 1.7[b]	19.6 ± 2.1[c]	**	40
701997	49.5 ± 9.2[a]	34.1 ± 1.7[b]	34.8 ± 3.1[b]	20.4 ± 1.1[c]	**	41
702453	52.5 ± 7.0[a]	35.5 ± 3.6[b]	34.8 ± 2.4[b]	20.8 ± 2.8[c]	**	40
703825	79.0 ± 5.5[a]	73.7 ± 2.5[a]	32.4 ± 1.8[b]	22.8 ± 0.9[c]	**	29
700234	53.2 ± 6.3[a]	39 ± 1.5[b]	16.1 ± 1.5[d]	23.1 ± 1.9[c]	**	43
702363	64.1 ± 2.1[a]	30.6 ± 5.1[b]	25.6 ± 2.7[b]	23.2 ± 0.9[b]	**	36
702464	72.9 ± 10.1[a]	44.7 ± 5.3[b]	31.1 ± 1.3[c]	23.3 ± 2.5[d]	**	32
705543	45.8 ± 4.3[a]	37.7 ± 3.5[b]	35.4 ± 2.3[b]	26.6 ± 1.2[c]	**	58
707135	52.0 ± 4.4[a]	39.2 ± 2.0[b]	37.4 ± 1.5[b]	27.2 ± 2.4[c]	**	52
702815	65.3 ± 1.0[a]	62.8 ± 4.8[a]	44.9 ± 2.2[b]	29.1 ± 1.0[c]	**	45
703421	66.0 ± 4.4[a]	56.4 ± 3.1[b]	32.7 ± 0.6[c]	29.5 ± 1.0[c]	**	45
701273	65.6 ± 7.2[a]	54.3 ± 3.1[b]	46.0 ± 3.7[c]	30.5 ± 3.6[d]	**	46
703312	40.5 ± 2.3[a]	34.5 ± 2.7[ab]	29.5 ± 3.4[b]	31.1 ± 4.2[b]	**	77
701515	66.1 ± 8.5[a]	56.7 ± 0.6[b]	43.7 ± 1.6[c]	32.6 ± 3.0[d]	**	49
703985	53.7 ± 1.8[a]	46.9 ± 2.5[a]	33.4 ± 1.8[c]	33.1 ± 0.4[c]	**	64
703265	64.6 ± 6.2[a]	42.7 ± 1.9[b]	44.9 ± 3.3[b]	37.5 ± 0.9[c]	**	58
704393	116.6 ± 9.0[a]	89.8 ± 3.9[b]	48.8 ± 3.9[c]	39.3 ± 1.6[d]	**	34
702736	64.1 ± 2.5[a]	55.5 ± 0.5[b]	42.4 ± 2.3[c]	42.0 ± 1.4[c]	**	66

[A] Differences between storage time for each accession: *significant at 5% level and **significant at 1% level.
[B] Percentage of retention after 26 weeks storage under farmer conditions.
[C] Mean values ± standard deviation ($n = 3$). Different letters indicate significant differences between accessions for each time point. HSD = 5.7 ($\alpha = 0.05$).

well known that AA is sensitive to air, heat and water, and can easily be destroyed by prolonged storage (Zee et al., 1991).

The AA concentration of 23 native varieties grown at La Victoria at 2 weeks after harvest and three time points after storage under farmers' conditions is shown in Table 5. ANOVA indicated that the differences in the AA concentration across the storage times and the interaction between variety and storage time were both significant ($p < 0.0001$). For all of the varieties, AA concentration was found to decrease as the storage time increased. The same tendency has been reported for European and Indian potatoes (Casañas et al., 2003; Dale et al., 2003; Mishra, 1985), as well as for vegetables and fruits (Zee et al., 1991).

The percentage of retention after 26 weeks under farmers' conditions (RH between 58–79% and T between 12 and 15 °C) ranged from 22.0 to 61.6% with the varieties 703265, 704393 and 702736 showing the highest AA concentrations after this period (42.0, 39.3 and 37.5 mg/100 g, DW). Similar percentages of retention have been reported for potatoes from Tenerife (34.2–46.7%) stored for 20 weeks at 12 °C and 80–90% RH (Casañas et al., 2003), for European varieties (37.1–78.9%) stored for 17 weeks at 4 °C by Dale et al. (2003) and for Indian varieties stored for 28 weeks at 2–7 °C by Mishra (1985) (28.5%).

4. Conclusions

Considerable variation was identified within cultivated potato germplasm with regard to inherent levels of AA, with the variety 704393 showing the highest value at harvest, after cooking and after storage during 26 weeks under farmers' conditions.

The substantial genotypic variation that exists in the AA concentrations together with the fact that the contribution of the genotype to the variance was significantly higher than that of the G × E interaction and of the environment means that breeders can select genotypes and develop varieties with high levels of AA.

Boiled tubers had higher AA concentration than baked or microwaved tubers, and the AA concentration decreased as the storage time increased. The degree of retention after cooking and storage under farmer conditions was highly variable among varieties.

One hundred grams of boiled potatoes of the variety with the highest AA concentration 704393 could provide adults with 17–20% of the RDA of AA, but the real contribution can be higher depending on the amount of potato consumed.

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References

AOAC, 1990. Official methods of analysis of AOAC: Vitamins and other nutrients, Vol. II. Helrich, K, Arlington.

Augustin, J., Johnson, S.R., Teitzel, C., True, R.H., Hogan, J.M., Toma, R.B., et al., 1978a. Changes in the nutrient composition of potatoes during home preparation. II. Vitamins. Am. Potato J. 55, 653–662.

Augustin, J., Johnson, S.R., Teitzel, C., Toma, R.B., Shaw, R.L., True, R.H., et al., 1978b. Vitamin composition of freshly harvested and stored potatoes. J. Food Sci. 43, 1566–1574.

Bates, C., 1997. Bioavailability of vitamin C. Eur. J. Clin. Nutr. Suppl. 1, S28–S33.

Burgos, G. 2006. Contribución de la papa en la alimentación de niños entre 6 y 36 meses de edad y de sus madres en comunidades rurales de Huancavelica. Thesis M.Sc. Nutrition, Universidad Nacional Agraria La Molina, Lima, Perú.

Casañas, R.R., Rodríguez, R.E., Díaz, R.C., 2003. Effects of current storage conditions on nutrient retention in several varieties of potatoes from Tenerife. J. Food Chem. 80, 445–450.

Dale, M.F., Griffiths, W., Todd, D., 2003. Effects of genotype, environment, and postharvest storage on the total ascorbate content of potato (*Solanum tuberosum*) tubers. J. Agri. Food Chem. 51, 244–248.

Egoville, M.J., Sullivan, J.F., Kozempel, M.F., Jones, W.J., 1988. Ascorbic acid determination in processed potatoes. Am. Potato J. 65, 91–97.

FAO/WHO, 2001. Human vitamin and mineral requirements. Report of a joint FAO/WHO expert consultation. Bangkok, Thailand.

Han, J., Kosukue, N., Young, K., Lee, K., Friedman, M., 2004. Distribution of ascorbic acid in potato tubers and in home-processed and commercial potato foods. J. Agri. Food Chem. 52 (21), 6516–6521.

Horton, D., 1987. Potatoes: Production, marketing and programs for developing countries. West View Press, Boulder, USA.

How, R., Regulska-How, B., Szymeak, J., 1995. Assessment of vitamin C losses in conventionally cooked and microwaved processed vegetables. Bromatologia I Chemia Toksykologiczna 28 (4), 317–321.

Howard, L.A., Wong, A.D., Perry, A.K., Klein, B.P., 1999. β-Carotene and ascorbic acid retention in fresh and processed vegetables. J. Food Sci. 64 (5), 929–936.

Kalt, W., 2005. Effect of production and processing factors on major fruit and vegetable antioxidants. J. Food Sci. 70 (1), R11–R19.

Lešková, E., Kubíková, J., Kováčiková, E., Košická, M., Porubská, P., Holčíková, K., 2006. Vitamin losses: Retention during heat treatment and continual changes expressed by mathematical models. J. Food Comp. Anal. 19 (4), 252–276.

Love, S.L., Salaiz, T., Shafii, B., Price, W.J., Mosley, A.R., Thornton, R.E., 2003. Ascorbic acid concentration and stability in North American potato germplasm. Acta Horticulturae 619, 87–93.

MINSA-INS-CENAN, 1996. Tablas peruanas de composición de alimentos. Lima (Peru). Ministerio de Salud (MINSA). Instituto Nacional de Salud (INS). Centro Nacional de Alimentación y Nuutrición (CENAM). 7 ed. 86 p.

Mishra, J.B., 1985. Effect of conditions of storage on ascorbic acid content and sprouting of tubers of some Indian potato varieties. J. Indian Potato Assoc. 12 (3&4), 158–164.

Mullin, W.J., Jui, P.Y., Nadeau, L., Smyril, T.G., 1991. The vitamin C content of seven cultivars of potatoes grown across Canada. Can. Inst. Food Sci. Technol. J. 24, 166–171.

Murphy, E., 1946. Storage conditions which affect the vitamin C content of Maine-grown potatoes. Am. Potato J. 23, 197–218.

Naidu, K.A., 2003. Vitamin C in human health and disease is still a mystery? An overview. Nutr. J. 2, 7–16.

Nordbotten, A., Loken, B., Rimestad, H., 2000. Sampling of potatoes to determine representative values for nutrient content in a national food composition table. J. Food Comp. Anal. 13, 369–377.

Pascale, S., de Maggio, A., Fogliano, V., Ambrosino, P., Ritienia, 2001. Irrigation with saline water improves carotenoids content and antioxidant activity of tomato. J. Hortic. Sci. Biotechnol. 76 (4), 447–453.

SAS Institute Inc., SAS OnlineDoc®, version 8.2, Cary, NC: SAS Institute Inc. 1999.

Suárez, H.P., Rodríguez, R.E.M., Díaz, R.C., 2004. Cambios en el valor nutritivo de patatas durante distintos tratamientos culinarios. Ciencia y Tecnología Alimentaria 4 (4), 257–261.

Teucher, B., Olivares, M., Cori, H., 2004. Enhancers of iron absorption: ascorbic acid and other organic acids. Int. J. Vitam. Nutr. Res. 76, 403–419.

Woolfe, J.A., 1987. The potato in the human diet. Cambridge University Press.

Zee, A., Carmichael, D., Codere, Poirier, D., Fournier, M., 1991. Effect of storage conditions on the stability of vitamin C in various fruits and vegetables produced and consumed in Quebec. J. Food Comp. Anal. 4, 77–86.