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Andean Potato Cultivars (*Solanum tuberosum* L.) as a Source of Antioxidant and Mineral Micronutrients

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Potato tubers were evaluated as a source of antioxidants and minerals for the human diet. A genetically diverse sample of *Solanum tuberosum L.* cultivars native to the Andes of South America was obtained from a collection of nearly 1000 genotypes using microsatellite markers. This size-manageable collection of 74 landraces, representing at best the genetic diversity among potato germplasm, was analyzed for iron, zinc, calcium, total phenolic, total carotenoid, and total vitamin C contents. The hydrophilic antioxidant capacity of each genotype was also measured using the oxygen radical absorbance capacity (ORAC) assay. The iron content ranged from 29.87 to 157.96 μg g^{-1} of dry weight (DW), the zinc content from 12.6 to 28.83 μg g^{-1} of DW, and the calcium content from 271.09 to 1092.93 μg g^{-1} of DW. Total phenolic content varied between 1.12 and 12.37 mg of gallic acid equiv g^{-1} of DW, total carotenoid content between 2.83 and 36.21 μg g^{-1} of DW, and total vitamin C content between 217.70 and 689.47 μg g^{-1} of DW. The range of hydrophilic ORAC values was 28.25−250.67 μmol of Trolox equiv g^{-1} of DW. The hydrophilic antioxidant capacity and the total phenolic content were highly and positively correlated ($r = 0.91$). A strong relationship between iron and calcium contents was also found ($r = 0.67$). Principal component analysis on the studied nutritional contents of the core collection revealed that most potato genotypes were balanced in terms of antioxidant and mineral contents, but some of them could be distinguished by their high level in distinct micronutrients. Correlations between the micronutrient contents observed in the sample and the genetic distances assessed by microsatellites were weakly significant. However, this study demonstrated the wide variability of health-promoting micronutrient levels within the native potato germplasm as well as the significant contribution that distinct potato tubers may impart to the intake in dietary antioxidants, zinc, and iron.

KEYWORDS: Potato; Andean tuber; *Solanum tuberosum*; antioxidants; ORAC; carotenoids; phenolics; vitamin C; minerals; iron; calcium; zinc; genetic diversity; microsatellite

INTRODUCTION

Population-based epidemiological studies have stressed the important role of diet and lifestyle in the emergence of many degenerative chronic diseases such as cancers and cardiovascular diseases, in both developed and developing countries. In industrialized countries, chronic diseases constitute the main cause of premature mortality (*1*). Over the past decade, the prevalence of those pathologic disorders has surprisingly increased in low-income countries as well and become a significant public health concern (*1*, *2*). In addition, infections and inadequate micronutrient intake remain major causes of death and disability in the developing world. Iron, zinc, and vitamin A deficiencies are the most widespread forms of micronutrient malnutrition (*3*).

Potato is currently the fourth most important crop worldwide after maize, wheat, and rice, with a production in 2005 of >323 million tonnes (*4*). In many developed countries, potato represents a secondary staple crop, with an average per capita consumption of 75 kg year^{-1} in 1999−2001. In developing countries, its consumption (20 kg year^{-1} per capita) is less

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widespread and mainly concentrated in Turkey, Tunisia, South America, and Malawi (*5*). In the Andes of South America, the potato consumption can reach 250 kg year^{-1} per capita (*6*). In these regions, potato constitutes the main staple crop, and most households cultivate 10−12 varieties in order to reduce their vulnerability to environmental conditions (*7*).

The nutritional value of potato is worth considering with regard to the high consumption of potato and the body of evidence showing the relationship between diet and human diseases. Potato is notably recognized as a source of high-quality proteins, carbohydrates, vitamin C, vitamin B_6, vitamin B_3, and certain minerals such as potassium, phosphorus, and magnesium (*8*). Beyond these basic nutrients, potatoes have been found to contain significant amounts of antioxidant phytochemicals (*9*−*11*). Nowadays, there is an increasing interest for their potential effect on human health. Several epidemiological studies have shown that a dietary intake of foods rich in natural antioxidants, such as fruits and vegetables, correlates with a reduced risk of cardiovascular diseases and certain cancers (*12*, *13*). Among the different groups of naturally occurring antioxidants in plants, vitamin C, vitamin E, carotenoids, and polyphenols are the best known for their health-promoting effects in human. They may indeed protect proteins, lipids, and DNA against reactive oxygen species (ROS), which are known to be involved in the pathogenesis of aging and many chronic diseases (*14*). Lachman et al. in 2000 (*15*), as well as Brown in 2005 (*16*), reviewed the contents of the main antioxidants present in potato tubers. Hydrophilic antioxidants, that is, polyphenols [1226−4405 mg kg^{-1} of dry weight (DW)] and vitamin C (170−990 mg kg^{-1} DW), predominate in potato tubers, whereas lipophilic carotenoids occur to a lesser extent (1−60 mg kg^{-1} of DW in the literature). Moreover, the health-promoting effects of potato are very promising for humans as a recent study showed that the consumption of unpeeled cooked potatoes improves the lipid metabolism and antioxidant status in cholesterol-fed rat (*17*).

Native to the Andes, potato landraces (*Solanum tuberosum* L.) are extremely diverse, ranging from diploids to pentaploids. They show a wide variability in tuber shape, flesh and skin color, and flavor and in storage and cooking quality. This wide genetic diversity among native cultivated potatoes may show a considerable variability in nutritional contents. Published data on the extent of variation with regard to antioxidant contents and mineral contents within the native potato germplasm is scarce. To our knowledge, only one study exists regarding the antioxidant compounds in Andean tubers, but it dealt with a limited number of potato genotypes (*13*, *18*). Most of the research was developed on modern potato varieties, which have been shown to have lower genetic diversity as compare to the native Andean potato landraces (*19*). The objectives of the work reported here were to determine the extent of variation of health-promoting micronutrients in the cultivated potato and to evaluate their potential to contribute to dietary antioxidant and mineral intake. Using microsatellite markers, a size-manageable collection of 74 potato genotypes was first built up as a representative sample of the genetic diversity among potato germplasm and was then analyzed for both potato antioxidants (total phenolics, total carotenoids, and vitamin C) and selected minerals (calcium, iron, and zinc). The efficacy of the major antioxidants present in the potato tubers has also been evaluated using an in vitro antioxidant capacity test, the oxygen radical absorbance capacity (ORAC) assay.

MATERIALS AND METHODS

Chemicals. Solvents (of analytical or HPLC grade as required) and Folin−Ciocalteu's phenol reagent were obtained from VWR International (Leuven, Belgium). Gallic acid, ascorbic acid, isoascorbic acid, metaphosphoric acid, butylated hydroxytoluene (BHT), dithiothreitol (DTT), fluorescein sodium salt, Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), 2,2-azinobis(2-amidinopropane) dihydrochloride (AAPH), and hexadecyltrimethylammonium bromide (cetrimide) were purchased from Sigma-Aldrich (St. Louis, MO).

Plant Materials. Molecular fingerprinting data have been produced for approximately 1000 Andean cultivars held in CIP (Centro Internacional de la Papa, Lima, Peru) gene banks (*20*). On the basis of this dataset for 10 simple sequence repeat (SSR) (or microsatellite) loci, a genetically diverse sample was selected on the basis of maximum SSR allele retention. A total of 79 accessions that bear >60% of the genetic diversity assessed by microsatellite markers have been identified and retained. However, 5 of them were not available due to inappropriate health status. From the 74 remaining healthy genotypes, the SSR-based genetic distances were calculated (using the proportion shared allele coefficient). A dendrogram was then generated on the basis of unweighted pair-group method with arithmetic averaging (UPGMA) cluster analysis using the Phylip software (Felsenstein, University of Washington, Seattle, WA) to illustrate the SSR-based genetic relationships between the genotypes. The core collection comprises samples of the eight taxonomic groups of the *S. tuberosum* species (*21*). The Andigenum group accounts for >78% of this group. The high level of polymorphism and the wide morphological and physiological variability of this group have been stressed in several studies (*22*). The 74 genotypes have been cultivated in 2004 in Huancayo (Peru) at the CIP experimental station, located in the highlands (altitude of 3280 m). They were field-grown using normal agronomic practices with minimal or no use of pesticide. Mature tubers were harvested between April and May 2004 after 6−7 months of growth, depending on the genotypes. The genotype, the cultivar group, and the skin and flesh color characteristics are listed in **Table 1** for the 74 potato cultivars of the core collection. All tubers were shipped to the Public Research Centre−Gabriel Lippmann, where they were washed and placed for storage in incubators at 10 °C for 4 months prior to sampling and analysis. All genotypes were treated in the same way. The moisture content of the tubers is given in **Table 2**.

Sample Preparation. Whole tubers were ground, freeze-dried, and stored at −20 °C under nitrogen prior to extraction and analysis. Tubers were processed with their skin due to the difficulty of uniformly peeling certain potato tubers with irregular shape. For each cultivar, three samples (each made of three tubers from one plant) were used for the antioxidant analyses. Each sample was extracted in duplicate. Four samples (each made of three tubers from one plant) were used for the mineral analyses of each cultivar.

Total Carotenoid Analysis. The concentration of total carotenoids was estimated according to the method reported by Morris et al. (*11*) with a few modifications. Briefly, 150 mg of powdered freeze-dried material was submitted to a double extraction with an acetone solution containing 1% (w/v) BHT. Both supernatants were combined, and the extract was centrifuged at 4 °C for 10 min at 5000*g*. An aliquot of the carotenoid extract was taken for spectrophotometric determination at 450 nm using a Beckman DU 800 spectrophotometer (Fullerton, CA). The total carotenoid content was calculated as described by Britton et al. (*23*) and expressed as micrograms of carotenoids per gram of DW.

Total Vitamin C Analysis. Approximately 150 mg of powdered freeze-dried material was mixed with 1.5 mL of 5% (w/v) aqueous solution of metaphosphoric acid containing 1% (w/v) DTT to allow reduction of dehydroascorbic to ascorbic acid (*24*). Isoascorbic acid was used as an internal standard. This mixture was homogenized and shaken for 1 h at 4 °C. After centrifugation at 9000*g* for 10 min at 4 °C, the supernatant was collected. A second extraction was done on the residue using the same extraction solvent. Both supernatants were pooled, and sample aliquots were filtered through a 0.45 μm syringe filter prior to injection. HPLC analysis was performed using a Dionex *Summit* system (Sunnyvale, CA) equipped with a P580 gradient pump, a GINA 50 autosampler, a UVD 340S diode array detector (DAD), and an external Bio-Rad column heater. A 15 μL aliquot was injected onto a Zorbax Bonus-RP (250 × 4.6 mm internal diameter; 5 μm particle size) (Agilent Technologies, Palo Alto, CA). The mobile phase was methanol/water (5:95, v/v) containing 50 mM potassium dihydro-

Table 1. Total Phenolics, Total Carotenoids, Total Ascorbate, and Hydrophilic Antioxidant Capacity by ORAC Assay of the 74 Native Cultivated Potato Genotypes of the CIP Core Collection[a]

genotype	skin and flesh color[b]	total phenolics[c] (mg of GAE g^{-1})	total carotenoids (μg g^{-1})	total ascorbate (μg g^{-1})	H-ORAC[d] (μmol of TE g^{-1})
Ajanhuiri group					
702683-Laram Ajawiri	P/W	1.76 ± 0.24	7.13 ± 0.86	459.10 ± 57.61	52.96 ± 3.25
702802-Jancko Ajawiri	W/C	1.53 ± 0.47	10.73 ± 1.09	374.64 ± 11.14	29.92 ± 10.92
704229-Jancko Anckanchi	W/W	2.00 ± 0.11	4.61 ± 1.23	459.30 ± 77.54	56.34 ± 20.57
Andigenum group					
700141-Wiishilla Paqui	Yr/Y	1.70 ± 0.43	17.07 ± 2.75	358.09 ± 18.50	49.69 ± 11.95
700347-SS-2613	Y/C	2.62 ± 0.11	8.94 ± 1.01	447.71 ± 40.84	81.55 ± 15.29
700815-Sale Papa	Ro/W	1.46 ± 0.34	8.24 ± 1.20	540.69 ± 44.17	40.63 ± 11.35
701127-Ojo De Buey	Py/Cp	2.24 ± 0.06	10.89 ± 0.48	438.41 ± 14.66	58.64 ± 18.96
701589-Muro Chaleco	P/Cp	2.23 ± 0.62	7.46 ± 0.70	689.47 ± 7.46	76.02 ± 13.35
702316-Pulu	P/Cp	4.43 ± 0.95	11.69 ± 1.62	531.06 ± 84.29	110.45 ± 27.56
702408-Huatay Runi	R/Y	2.23 ± 0.82	20.16 ± 1.05	338.16 ± 48.15	54.88 ± 11.79
702477-Yana Puma Maqui	DP/Cp	5.99 ± 1.22	9.52 ± 1.72	299.42 ± 69.69	142.61 ± 16.16
702535-Sipancachi	Wp/Y	1.44 ± 0.08	14.93 ± 2.43	494.53 ± 93.18	28.25 ± 3.21
702568-Pichea Papa	Py/C	1.16 ± 0.27	4.66 ± 0.85	362.04 ± 11.96	32.09 ± 5.13
702599-unknown	Rp/C	1.33 ± 0.61	12.02 ± 2.28	304.20 ± 21.61	35.08 ± 13.97
702829-Alcca Tarma	Py/Wp	1.78 ± 0.22	8.42 ± 0.68	349.40 ± 44.14	49.21 ± 14.29
702867-unknown	Y/W	2.05 ± 0.14	6.40 ± 0.67	391.42 ± 54.05	41.73 ± 5.02
703248-Wila Huaka Lajra	Ry/C	1.32 ± 0.39	7.79 ± 1.24	368.27 ± 1.10	32.43 ± 4.46
703346-Huaycha Pacena	Ry/C	2.54 ± 0.26	14.74 ± 1.92	367.72 ± 40.00	63.05 ± 15.50
703365-Holandesa	Yr/C	1.92 ± 0.37	8.94 ± 2.80	343.12 ± 56.19	50.96 ± 4.80
703370-unknown	Y/W	1.71 ± 0.17	8.10 ± 2.69	374.80 ± 46.05	42.60 ± 1.76
703426-Wacapa Naguin	Po/Wp	3.77 ± 1.39	8.47 ± 0.68	449.36 ± 38.72	73.04 ± 16.55
703428-Samba	Pr/Yp	2.68 ± 0.51	16.40 ± 0.33	513.12 ± 49.30	60.93 ± 19.15
703462-unknown	Py/C	1.94 ± 0.25	12.13 ± 2.18	288.26 ± 41.39	40.34 ± 19.03
703499-Higos	P/Cp	2.90 ± 0.95	8.92 ± 0.71	380.60 ± 42.22	79.98 ± 10.65
703505-Puca Papa	Ry/C	1.12 ± 0.21	4.89 ± 1.01	217.70 ± 13.91	32.15 ± 8.92
703558-Tuquerrena	Ry/C	2.20 ± 0.50	13.74 ± 1.48	299.01 ± 69.86	53.93 ± 7.10
703578-Quincha	Rp/Y	1.87 ± 0.16	15.39 ± 4.27	313.27 ± 50.21	38.90 ± 8.53
703721-Jallga Huarmi	R/C	1.53 ± 0.05	6.75 ± 0.34	284.71 ± 33.79	49.84 ± 11.39
703739-Lisan	Y/C	2.10 ± 0.57	12.85 ± 3.42	542.89 ± 100.91	57.31 ± 6.71
703750-Carganaca	Pr/Wp	3.41 ± 0.81	10.06 ± 2.00	340.30 ± 21.27	94.26 ± 19.59
703759-Chiar Imilla	P/C	2.72 ± 0.94	8.74 ± 2.44	526.14 ± 75.49	62.83 ± 9.50
703905-Huata Colorada	Py/Y	3.07 ± 0.67	31.23 ± 4.02	464.68 ± 95.93	71.93 ± 26.19
703988-Canchillo	P/C	1.31 ± 0.51	6.81 ± 0.91	515.78 ± 1.29	33.21 ± 6.20
704078-Malcachu	Yp/W	1.69 ± 0.31	9.79 ± 1.13	364.81 ± 42.55	53.26 ± 6.38
704152-Runa Bola	Py/Y	2.82 ± 0.09	10.31 ± 2.77	266.70 ± 47.97	63.62 ± 23.10
704201-Curipamba	Pr/Y	1.61 ± 0.34	22.15 ± 1.88	513.28 ± 106.14	54.51 ± 15.87
704338-Violeta	P/C	1.38 ± 0.42	9.60 ± 2.74	451.06 ± 20.47	35.70 ± 14.24
704353-Puma	Py/Y	2.23 ± 0.47	28.06 ± 3.00	391.90 ± 39.16	51.53 ± 1.24
704354-unknown	Yp/C	1.95 ± 0.26	14.16 ± 1.04	291.15 ± 19.48	42.34 ± 4.50
704429-Guincho Negra	DP/P	12.37 ± 0.65	9.90 ± 0.60	483.62 ± 40.82	204.41 ± 19.74
704437-Chata Colorada	Yr/W	1.56 ± 0.14	6.17 ± 2.35	417.68 ± 21.50	50.68 ± 8.46
704469-Wuiclush	Bp/C	2.00 ± 0.33	11.12 ± 1.12	396.23 ± 16.07	47.56 ± 8.28
704497-Huaccoto	P/Cp	3.17 ± 1.29	9.88 ± 2.31	431.15 ± 14.89	75.54 ± 22.49
704504-Puca Huato	Y/C	1.67 ± 0.28	17.06 ± 2.06	409.19 ± 59.34	50.19 ± 7.68
704592-Yurac Putis	Wp/C	1.63 ± 0.32	6.73 ± 1.71	308.28 ± 46.14	45.74 ± 3.43
704647-unknown	P/W	2.77 ± 0.16	6.99 ± 0.71	285.88 ± 19.58	73.52 ± 15.57
704828-Wila Immilla	Ry/Y	2.52 ± 0.38	13.53 ± 2.48	350.55 ± 20.71	56.76 ± 8.63
704864-Koli	P/Cp	2.36 ± 0.49	7.58 ± 1.76	505.19 ± 19.10	46.03 ± 9.33
704865-Holendesa	Y/C	1.53 ± 0.26	9.60 ± 0.58	286.04 ± 34.74	32.34 ± 10.06
704903-Keny Luky	Wp/Y	1.57 ± 0.34	13.31 ± 1.38	337.93 ± 37.90	42.65 ± 2.91
704916-Coyu	Y/Cp	2.54 ± 0.26	7.92 ± 1.47	266.22 ± 42.75	57.18 ± 13.28
704964-Sutumari	Ry/C	2.03 ± 0.09	9.06 ± 1.87	370.56 ± 14.42	46.28 ± 16.64
705082-Tocana Rosada	Wp/Y	2.30 ± 0.48	19.30 ± 1.21	384.35 ± 44.31	53.05 ± 13.42
705191-unknown	Y/W	2.05 ± 0.36	13.82 ± 2.96	543.58 ± 57.89	43.26 ± 6.77
705214-Morada	Py/C	1.84 ± 0.31	7.49 ± 1.09	328.26 ± 37.33	45.44 ± 8.50
705264-Roscalena	P/W	1.56 ± 0.84	7.96 ± 1.68	355.27 ± 19.22	34.33 ± 4.60
705424-Chatilla	Ry/w	2.49 ± 0.65	7.65 ± 0.99	268.76 ± 41.93	45.41 ± 2.12
705428-San Jose	R/C	2.64 ± 0.09	11.62 ± 1.14	340.24 ± 29.68	64.13 ± 14.29
705445-Uqi Nawi	Py/C	2.17 ± 0.84	13.02 ± 1.18	382.84 ± 59.03	58.29 ± 17.41
705556-Wayru	P/Cp	3.51 ± 0.24	13.02 ± 2.82	429.67 ± 93.94	70.95 ± 21.07
705601-Yana Palta	P/C	1.94 ± 0.23	10.07 ± 1.75	232.79 ± 15.65	45.87 ± 11.87
Chaucha group					
700145-Chimbina Colorada	Ro/Y	1.49 ± 0.09	21.46 ± 5.21	493.04 ± 16.77	44.25 ± 9.68
702196-Mauna Huaman Uma	Y/C	1.61 ± 0.23	11.25 ± 1.38	420.67 ± 18.55	50.12 ± 7.03
703305-Chiar Surimana o phinu	Py/W	1.48 ± 0.74	8.53 ± 1.18	273.82 ± 35.11	30.08 ± 10.31
Chilotanum group					
703610-Papacacho	P/Wr	2.05 ± 0.11	10.87 ± 3.19	255.56 ± 37.47	51.18 ± 9.04
703671-Negrita	Pr/Cp	2.12 ± 0.34	8.87 ± 0.84	319.62 ± 32.67	45.35 ± 3.04
Curtilobum group					
702455-Yuraq Ocucuri o Wana	W/W	1.64 ± 0.54	5.21 ± 1.02	306.69 ± 43.00	40.63 ± 10.10

Table 1. (Continued)

genotype	skin and flesh color[b]	total phenolics[c] (mg of GAE g^{-1})	total carotenoids ($\mu g\ g^{-1}$)	total ascorbate ($\mu g\ g^{-1}$)	H-ORAC[d] (μmol of TE g^{-1})
Juzepczukii group					
702305-Chimi Lucki	W/W	1.50 ± 0.74	2.83 ± 0.63	456.43 ± 78.14	30.86 ± 10.52
703258-Laram Canchali	Pw/W	1.27 ± 0.01	2.99 ± 0.14	366.88 ± 67.77	33.37 ± 4.11
Phureja group					
701570-Chaucha	P/Y	2.82 ± 0.18	25.43 ± 2.60	322.12 ± 11.50	69.32 ± 4.68
705172-unknown	Py/Cr	1.62 ± 0.27	15.14 ± 1.05	307.64 ± 8.31	49.29 ± 17.59
Stenotonum group					
702472-Amarilla del Centro	Y/Y	1.49 ± 0.19	36.21 ± 1.47	474.64 ± 57.03	36.17 ± 5.21
702961-Garhuash Pashon	O/Y	1.94 ± 0.50	29.59 ± 3.99	425.03 ± 31.83	55.45 ± 3.61
703288-Yana Poccoya	Pr/W	1.66 ± 0.14	7.20 ± 0.46	330.99 ± 23.68	38.60 ± 3.62

[a] Data are expressed on a dry weight basis. The mean values represent analyses of three samples from three different plants ($n = 3$), each assayed in duplicate. [b] Primary (in capital) and secondary skin color/primary (in capital) and secondary flesh color. DP, dark purple; P, purple; R, red; O, orange; Y, yellow; C, cream; W, white. [c] Data expressed as mg gallic acid equiv (GAE) g^{-1} of dry weight. [d] H-ORAC, hydrophilic oxygen radical absorbance capacity. Data expressed as micromoles of Trolox equiv (TE) g^{-1} of dry weight.

gen phosphate (pH 4.6) and 5 mM hexadecyltrimethylammonium bromide (cetrimide) as described by Zapata et al. (*25*). It was filtered through a Millipore Isopore membrane filter (0.2 μm) and degassed under vacuum. Ascorbic acid was eluted isocratically at a flow rate of 1 mL min^{-1} and a column temperature of 40 °C. Ascorbic acid and isoascorbic acid were identified by their retention time and spectral data as compared to authentic standards. Quantification was accomplished at the maximum absorbance detected in the spectrum of ascorbic acid (265 nm) by comparing integrated chromatographic peak areas from the samples to peak areas of known amounts of ascorbic and isoascorbic acids. Total ascorbate content was expressed in micrograms per gram of DW.

Total Phenolic Analysis. Five hundred milligrams of powdered freeze-dried material was mixed with 10 mL of 80% (v/v) methanol in a 15 mL graduated tube. This mixture was homogenized using a vortex for 30 s and allowed to stand with intermittent shaking for 2 h in the dark at room temperature. After centrifugation at 5000*g* for 15 min at 4 °C, the supernatant was collected and evaporated to dryness in a Speedvac (Heto, Thermo Electron Corp., Waltham, MA). Phenolic compounds were resuspended in 5 mL of water and stored at −20 °C under a nitrogen atmosphere until analysis. Total phenolic concentrations, measured as gallic acid equivalents, were estimated using the Folin−Ciocalteu assay (*26*). Five hundred microliters of appropriately diluted samples, 1250 μL of a 7.5% sodium carbonate solution, and 250 μL of Folin−Ciocalteu reagent (1 N) were mixed in a test tube and allowed to react at room temperature for 30 min. Absorption at 755 nm was measured using a Beckman DU 800 spectrophotometer (Fullerton, CA). Total phenolic content was expressed as milligrams of gallic acid equivalents (GAE) per gram of DW from a gallic acid standard concentration curve.

Hydrophilic Antioxidant Capacity. The hydrophilic antioxidant capacity was determined using the ORAC assay. ORAC analyses were performed on the phenolic extracts in a 96-well microplate fluorometer (Ascent F.L. Fluoroscan, Labsystem, Vantaa, Finland) and were adapted from the procedures described by Ou et al. (*27*), Huang et al. (*28*), and Cao and Prior (*29*). AAPH, a water-soluble azo compound, was used as a peroxyl radical generator. Trolox, a water-soluble tocopherol analogue, was used as standard and fluorescein as fluorescent probe. Fluorescence filters were used for an excitation wavelength of 485 nm and an emission wavelength of 520 nm. Briefly, 25 μL of blank, Trolox standard, or diluted samples were mixed with 250 μL of 55 nM fluorescein and incubated for 10 min at 37 °C before automatic injection of 25 μL of AAPH solution (153 mM). The fluorescence was measured every minute for 50 min. All samples were analyzed in duplicate at three different dilutions. The final ORAC values were calculated using the net area under the decay curves and were expressed as micromoles of Trolox equivalents (TE) per gram of DW.

Calcium, Iron, and Zinc Analyses. Samples, 300−500 mg of DW, were subjected to acid digestion. Reagent (4.4 mL) (0.42 g of selenium, 14 g of Li_2SO_4, 350 mL of H_2O_2, and 420 mL of H_2SO_4) was added to the sample in a Kjeldahl flask. Acid digestion was performed by increasing temperature until the digest had cleared. At the end of the procedure, samples were diluted with H_2O up to 75 mL and kept at 4 °C prior to analysis. Blank digestions were performed in the same way. Samples were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Varian, Palo Alto, CA). Certified reference material (white cabbage, BCR-679) was used as quality control.

Statistical Analyses. Pearson correlation coefficients were determined on log-transformed data to evaluate relationships between variables. Principal component analysis (PCA) was performed on centered and standardized data to compare the micronutrient profile of the different potato genotypes. For that purpose, the computer program Canoco 4.0 for Windows and SigmaPlot 7.101 software were used. The Euclidean distance matrices from data on micronutrient analysis were calculated using the DARwin 4.0 software (CIRAD, Montpellier, France). Mantel tests were performed to determine the correlation between the genetic distance matrix and the Euclidean distance matrices from nutritional data using Genalex6 software (*30*).

RESULTS AND DISCUSSION

Antioxidants. The contents in total carotenoids, total vitamin C, and total phenolics are presented in **Table 1** for the 74 potato genotypes of the core collection. All mean values are expressed per gram of dry weight with standard deviations.

Total Carotenoid Content. The levels in total carotenoids varied greatly among the 74 potato genotypes of our core collection. The contents ranged from 2.83 to 36.21 $\mu g\ g^{-1}$ of DW, and the mean value was 11.77 $\mu g\ g^{-1}$ of DW. The highest ranking cultivar, 702472-Amarilla del Centro (Stenotonum group, formerly *S. goniocalyx*), was intensely yellow-fleshed and contained 13 times more carotenoids than the lowest ranking white-fleshed cultivar, 702305-Chimi Lucki (Juzepczukii group). These levels of carotenoids are consistent with the levels reported by Morris et al. (*11*) in stored potato tubers (1.8−34.3 $\mu g\ g^{-1}$ of DW).

A large variation in total carotenoid content was observed within the Andigenum group, which was the most largely represented group in our core collection (58 of 74 cultivars). Among the 74 potato cultivars, 8 genotypes (11%) contained >20 μg of carotenoids g^{-1} of DW. They were all highly yellow pigmented and included one genotype from the Phureja group and two from the Stenotonum group (formerly *S. goniocalyx*). On the other hand, five genotypes from the core collection (7%) showed <5 μg of carotenoids g^{-1} of DW in their tubers and included two genotypes from the Juzepczukii group. The high carotenoid contents of the Phureja and Stenotonum groups have already been pointed out in several studies as well as the strong correlation between carotenoid concentrations and yellowness (*31*, *32*).

The identification and quantification of individual carotenoids present in our samples have not been performed in the present study. Other studies reported that the major potato carotenoids

Table 2. Iron, Zinc, and Calcium Contents of the 74 Native Cultivated Potato Genotypes of the CIP Core Collection[a]

genotype	moisture (%)	iron (μg g^{-1})	zinc (μg g^{-1})	calcium (μg g^{-1})
Ajanhuiri group				
702683-Laram Ajawiri	71.3	70.98 ± 22.95	18.76 ± 4.34	551.23 ± 93.73
702802-Jancko Ajawiri	70.1	98.35 ± 26.23	20.42 ± 5.59	746.08 ± 137.95
704229-Jancko Anckanchi	74.6	154.96 ± 49.14	24.59 ± 1.68	1092.93 ± 442.76
Andigenum group				
700141-Wiishilla Paqui	74.1	53.62 ± 5.87	14.50 ± 2.40	598.17 ± 127.81
700347-SS-2613	78.3	56.26 ± 19.86	20.61 ± 2.73	399.01 ± 112.84
700815-Sale Papa	79.0	50.58 ± 13.81	17.57 ± 2.13	371.94 ± 93.63
701127-Ojo De Buey	78.6	47.43 ± 7.86	14.49 ± 0.94	665.06 ± 325.72
701589-Muro Chaleco	77.9	51.16 ± 16.34	15.72 ± 3.14	360.97 ± 142.65
702316-Pulu	75.2	75.31 ± 29.26	19.75 ± 4.60	750.67 ± 394.71
702408-Huatay Runi	74.6	55.64 ± 15.47	18.92 ± 2.74	454.81 ± 195.82
702477-Yana Puma Maqui	78.8	68.54 ± 13.28	21.27 ± 5.91	728.66 ± 77.32
702535-Sipancachi	73.8	42.06 ± 12.94	17.35 ± 1.89	452.17 ± 15.97
702568-Pichea Papa	72.1	37.71 ± 1.72	12.60 ± 2.27	340.02 ± 62.08
702599-unknown	74.3	44.91 ± 9.49	13.30 ± 2.14	404.18 ± 69.05
702829-Alcca Tarma	69.2	29.87 ± 4.39	17.58 ± 1.46	271.09 ± 22.15
702867-unknown	74.8	55.28 ± 10.24	15.61 ± 1.70	737.00 ± 68.50
703248-Wila Huaka Lajra	77.2	64.37 ± 13.37	20.74 ± 1.82	407.85 ± 36.07
703346-Huaycha Pacena	76.5	50.38 ± 13.96	20.66 ± 2.60	441.16 ± 133.37
703365-Holandesa	76.0	36.14 ± 3.74	16.87 ± 2.39	318.22 ± 95.31
703370-unknown	71.1	52.25 ± 6.30	15.66 ± 1.63	436.90 ± 56.22
703426-Wacapa Naguin	77.7	43.85 ± 6.27	21.46 ± 3.43	444.14 ± 99.35
703428-Samba	76.8	69.49 ± 14.49	24.19 ± 3.45	599.75 ± 158.13
703462-unknown	72.2	49.43 ± 31.23	22.75 ± 2.38	304.83 ± 86.99
703499-Higos	71.4	38.61 ± 7.54	13.45 ± 1.13	377.93 ± 21.90
703505-Puca Papa	74.4	32.98 ± 4.85	14.23 ± 1.82	392.44 ± 38.14
703558-Tuquerrena	75.6	45.33 ± 18.27	23.59 ± 7.18	313.95 ± 24.13
703578-Quincha	76.0	60.33 ± 3.46	20.94 ± 2.84	563.63 ± 9.29
703721-Jallga Huarmi	72.5	60.86 ± 9.39	14.86 ± 0.78	594.47 ± 162.08
703739-Lisan	78.1	67.88 ± 10.21	16.30 ± 1.96	544.58 ± 117.19
703750-Carganaca	78.7	45.51 ± 6.45	20.10 ± 3.09	570.50 ± 151.42
703759-Chiar Imilla	81.5	76.74 ± 22.34	21.38 ± 3.49	528.86 ± 75.74
703905-Huata Colorada	79.2	62.65 ± 24.94	22.94 ± 4.61	776.12 ± 365.04
703988-Canchillo	78.0	42.87 ± 10.04	22.12 ± 3.84	502.78 ± 109.92
704078-Malcachu	79.2	110.68 ± 14.59	19.41 ± 3.39	957.17 ± 91.22
704152-Runa Bola	75.3	64.48 ± 13.99	14.87 ± 1.22	667.77 ± 163.77
704201-Curipamba	75.3	37.93 ± 5.80	22.21 ± 3.22	452.68 ± 94.06
704338-Violeta	75.2	37.83 ± 4.50	13.75 ± 2.14	451.27 ± 81.05
704353-Puma	74.3	42.44 ± 4.87	16.56 ± 2.19	564.47 ± 53.00
704354-unknown	69.9	49.94 ± 15.99	19.02 ± 2.32	422.63 ± 107.05
704429-Guincho Negra	75.8	55.20 ± 5.36	16.05 ± 1.15	934.70 ± 150.29
704437-Chata Colorada	75.9	44.43 ± 8.89	20.09 ± 3.26	280.64 ± 14.04
704469-Wuiclush	76.1	52.94 ± 3.26	18.88 ± 1.78	739.32 ± 48.08
704497-Huaccoto	77.9	58.00 ± 7.08	24.29 ± 3.48	447.28 ± 61.17
704504-Puca Huato	77.7	55.05 ± 6.19	20.38 ± 4.34	418.87 ± 96.63
704592-Yurac Putis	75.2	49.65 ± 14.10	19.91 ± 4.94	427.91 ± 161.82
704647-unknown	76.9	59.81 ± 3.52	23.80 ± 5.02	593.01 ± 47.83
704828-Wila Immilla	72.0	56.85 ± 15.95	15.37 ± 1.71	452.65 ± 122.84
704864-Koli	79.4	45.77 ± 10.04	20.42 ± 2.71	473.93 ± 231.62
704865-Holendesa	70.1	35.23 ± 7.55	18.10 ± 3.16	279.72 ± 10.74
704903-Keny Luky	77.2	47.55 ± 12.80	22.41 ± 5.33	298.45 ± 22.95
704916-Coyu	77.3	38.27 ± 3.00	19.16 ± 0.94	415.93 ± 51.90
704964-Sutumari	73.9	52.87 ± 10.13	16.06 ± 2.84	482.41 ± 69.39
705082-Tocana Rosada	76.6	50.99 ± 4.94	19.87 ± 2.84	457.10 ± 124.54
705191-unknown	80.8	67.20 ± 10.13	15.91 ± 2.68	510.74 ± 212.14
705214-Morada	77.5	51.18 ± 7.19	16.87 ± 4.84	442.44 ± 61.19
705264-Roscalena	73.7	59.85 ± 9.34	28.83 ± 2.75	572.63 ± 106.93
705424-Chatilla	75.8	67.75 ± 8.95	18.67 ± 2.24	482.12 ± 30.58
705428-San Jose	75.0	82.18 ± 13.80	21.44 ± 4.26	405.69 ± 12.45
705445-Uqi Nawi	73.5	51.90 ± 13.68	21.49 ± 1.65	581.24 ± 140.27
705556-Wayru	75.9	59.76 ± 6.54	19.11 ± 1.92	608.92 ± 50.12
705601-Yana Palta	76.1	44.26 ± 5.74	15.45 ± 0.81	375.89 ± 96.29
Chaucha group				
700145-Chimbina Colorada	74.3	35.80 ± 11.07	15.26 ± 2.11	327.72 ± 134.10
702196-Mauna Huaman Uma	73.9	39.58 ± 11.14	20.58 ± 2.28	327.32 ± 82.38
703305-Chiar Surimana o phinu	69.8	49.69 ± 8.43	18.07 ± 2.15	405.38 ± 166.87
Chilotanum group				
703610-Papa cacho	74.5	57.78 ± 10.40	18.51 ± 0.99	686.88 ± 80.57
703671-Negrita	73.9	59.02 ± 1.21	17.42 ± 1.48	390.71 ± 89.29
Curtilobum group				
702455-Yuraq Ocucuri o Wana	72.6	41.32 ± 11.06	16.82 ± 1.96	361.89 ± 105.75
Juzepczukii group				
702305-Chimi Lucki	76.3	61.61 ± 13.95	14.94 ± 0.35	769.03 ± 190.85
703258-Laram Canchali	68.9	49.10 ± 11.25	20.32 ± 2.43	617.09 ± 209.77
Phureja group				
701570-Chaucha	79.1	58.38 ± 5.87	20.97 ± 3.63	670.47 ± 133.22
705172-unknown	65.0	58.24 ± 21.07	19.39 ± 1.50	361.80 ± 52.54
Stenotonum group				
702472-Amarilla del Centro	72.2	42.76 ± 10.52	18.92 ± 2.86	444.44 ± 128.66
702961-Garhuash Pashon	72.7	40.15 ± 2.19	17.43 ± 2.60	412.08 ± 89.19
703288-Yana Poccoya	71.5	50.45 ± 7.56	16.13 ± 1.85	341.19 ± 72.36

[a] Data are expressed as mg g^{-1} of dry weight, and the moisture content of the tubers is given in percent. For each genotype, the mean value represents analyses of four samples from four different plants ($n = 4$).

are zeaxanthin, antheraxanthin, violaxanthin, and lutein in different ratios depending on genotype and storage conditions (*11*, *32*, *33*). In humans, these carotenoids have no provitamin A activity but have important antioxidant and biochemical properties. For instance, lutein and zeaxanthin have been identified as key compounds to maintain the anatomy and function of the retina and may have a protective effect against age-related macular degeneration, a major cause of loss of vision in the elderly (*34*). An epidemiological study in a Spanish population (with an average potato consumption of 70.4 g day^{-1}) estimated that potato contributed 13% to the dietary zeaxanthin intake and 2% to the dietary lutein intake (*35*). The contents of zeaxanthin and lutein in the potato tuber used for these estimations were 20 and 15 μg 100 g^{-1} of fresh weight (FW), respectively. According to the studies of Morris et al. (*11*) and Breithaupt and Bamedi (*33*), the levels of zeaxanthin and lutein in yellow-fleshed tubers vary among cultivars and may account for 6−43 and 9−27% of the total carotenoid content, respectively. Therefore, the tubers of the highest carotenoid-ranking potato cultivar of our core collection, namely, 702472-Amarilla del Centro, may contain 60−430 μg 100 g^{-1} of FW of zeaxanthin and 90−270 μg 100 g^{-1} of FW of lutein. Thus, including these tubers in the Spanish diet could increase by 20−81% the total dietary zeaxanthin intake and by 8−24% the total dietary lutein intake, without changing the usual consumption level of potato. The way the tubers are processed before eating (peeling, cooking methods) may also affect these values downward or upward (*16*). The contributions to the dietary intake presented here represent therefore the starting potential of raw potato tubers stored for 4 months.

Total Vitamin C Content. The range in ascorbic acid levels within the potato germplasm under investigation was lower than for the total carotenoid contents. There was a 3-fold difference between the lowest [703705-Puca Papa (Andigenum group) with 217.70 μg g^{-1} of DW] and the highest ranking cultivar [701589-Muro Chaleco (Andigenum group) with 689.47 μg g^{-1} of DW]. No cultivar group effect could be noted. Total ascorbate contents observed are consistent with the contents reported for stored potato tubers (variation from 290 to 1180 μg g^{-1} of DW) (*24*, *36*). Dale et al. (*24*) found that vitamin C losses after 4 months of postharvest storage at 4 °C ranged from 20 to 60% in 33 potato genotypes and that variation between genotypes appeared to be lower following storage, suggesting that the variability in ascorbic content within our potato core collection would have also been higher at harvest than after a 4 month postharvest storage. However, as already stressed by Dale et al. (*24*), ascorbic acid content during storage is important to consider when studying the contribution of potato to the vitamin C intake in the human diet. Potatoes are indeed usually consumed after a certain period of storage. The identification of high vitamin C ranking potato cultivars should therefore be performed on stored tubers, as we did in this study.

The FAO's Reference Nutrient Intake (RNI) for vitamin C in adults is estimated as 45 mg day^{-1} (*3*). The tubers of 701589-Muro Chaleco, the highest vitamin C ranking potato cultivar of our core collection, contained 15.2 mg of ascorbic acid 100 g^{-1} of FW. Therefore, the consumption of 150 g from this genotype could meet 50.5% of the recommended daily intake. Cooking may, however, decrease the ascorbic acid levels in tubers to an extent that depends on the genotype and the method used (*37*), reducing then this high potential contribution of potato to the daily vitamin C intake.

Total Phenolic Content. Phenolics are the most abundant antioxidants in potatoes. A large range of total phenolic content was observed among the 74 potato genotypes of the core collection, ranging from 1.16 mg of GAE g^{-1} of DW for 702568-Pichea Papa (Andigenum group) to 12.34 mg of GAE g^{-1} of DW for 704429-Guincho Negra (Andigenum group). There was an 11-fold difference between the lowest and the highest ranking cultivar. These values are in general agreement with those reported in the literature (*9*, *10*, *15*, *38*). A large intracultivar group variation was found within the Andigenum group, whereas no significant intercultivar group influence was observed. Three genotypes from the Andigenum group (704429-Guincho Negra, 702477-Yana Puma Maqui, and 702316-Pulu) (**Table 1**) presented remarkably high levels of total phenolics. It is noteworthy that all of them are at least partially purple-skinned and -fleshed. Using an HPLC methodology, Lewis et al. (*10*) also reported higher concentrations of phenolic acids and flavonoids in purple- or red-skinned (and -fleshed) tubers than in their white counterparts. In that study, phenolic acids (mainly chlorogenic acid) were represented to a large extent in every potato genotypes, accounting for 45−90% of the total polyphenolic content. The phenolic profile in two white-fleshed varieties has also been recently analyzed using a high-throughput HPLC method (*39*). Red- or purple-fleshed tubers contained also significant amounts of anthocyanins (*10*). Interestingly, besides their antioxidant attributes in human, acylated anthocyanins present in red- and purple-fleshed potatoes represent promising natural colorants as these pigments may impart desirable color and stability in food (*40*).

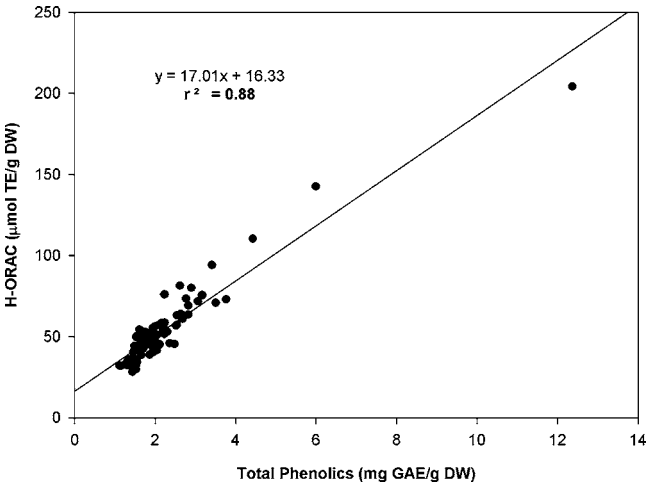

Figure 1. Relationship between hydrophilic antioxidant capacity and total phenolic content in the 74 native cultivated potato genotypes of the CIP core collection. Hydrophilic antioxidant capacity (H-ORAC) is expressed in μmol of Trolox equiv (TE) g^{-1} of DW and total phenolic content in mg of gallic acid equiv (GAE) g^{-1} of DW.

Hydrophilic Antioxidant Capacity. The antioxidant capacity of the phenolic extracts, representing the major antioxidants present in potato tubers, was evaluated using the ORAC assay. The range of the hydrophilic ORAC (H-ORAC) values was large among the 74 potato genotypes of the core collection (28.25−204.41 μmol of TE g^{-1} of DW), with a mean value of 55 μmol of TE g^{-1} of DW (**Table 1**). Our values are consistent with the ones obtained by Wu et al. (*41*), who reported a value of 58.62 μmol of TE g^{-1} of DW for a raw unpeeled Russet Burbank potato. In the present study, the ORAC value for the purple-fleshed 704429-Guincho Negra cultivar was 2.5 times higher than that of the best ranking yellow-skinned cultivar, namely, 700347-SS-2613 cultivar.

A scatterplot of the total phenolic content versus H-ORAC is presented in **Figure 1**. The spread of the values within the

potato collection can be observed, as well as the high correlation between both measurements ($r = 0.91$, $p < 0.01$). This linear correlation suggests that the presence of the phenolic compounds largely accounts for the hydrophilic antioxidant capacity of the potato tubers. Moreover, the peroxyl radical reaction in the ORAC assay involves hydrogen atom transfer (HAT) mechanisms (*42*) and the phenolic compounds are known to be the principal hydrophilic antioxidants that easily transfer one hydrogen to the peroxyl radical (*43*). Thus, H-ORAC of potato extracts may be estimated by a simple measurement of total phenolics. H-ORAC values and total vitamin C contents were not significantly correlated ($r = 0.19$), suggesting that the contribution of vitamin C to H-ORAC was low. Indeed, considering an ORAC value of 5.4 μmol of TE mg^{-1} for vitamin C (*27*), the antioxidant capacity from vitamin C in the potato tubers may vary from 1.17 to 3.72 μmol of TE g^{-1} of DW of potato. Therefore, the contribution of vitamin C to the hydrophilic antioxidant capacity could be calculated and was <10% (between 1.33 and 9.44%).

A recent study of the U.S. diet has shown that the contribution of potato to the daily total phenolic and antioxidant intake from fruits and vegetables was third after orange and apple due to its high daily consumption (171.4 g day^{-1}) (*44*). The method used for the determination of the total phenolics was similar to the one described in the present work. In that study, a total phenolic content of 35.28 mg of GAE 100 g^{-1} of FW was reported, and we obtained a mean value in our potato core collection cultivated in Peru of 55.19 mg of GAE 100 g^{-1} of FW. The consumption of Andean potato tubers may thus significantly increase the intake of dietary antioxidants. Moreover, considering the value of 298.98 mg of GAE 100 g^{-1} of FW observed in the highest-ranking potato cultivar of our core collection (704429-Guincho Negra), the contribution of potato to the daily total phenolic intake could be increased by 800%. Following the example of carotenoids and vitamin C, the cooking methods used will affect the levels of phenolic compounds persisting in potato tubers (*16*).

Minerals. Table 2 shows the concentrations of calcium, zinc, and iron in the tubers of the core collection. The iron content in the 74 potato cultivars varied from 29.87 to 154.96 μg g^{-1} of DW, with a mean value of 54.95 μg g^{-1} of DW. The calcium content ranged from 271.9 to 1092.93 μg g^{-1} of DW, with a mean value of 504.81 μg g^{-1} of DW. The lowest ranking cultivar for both elements was 702829-Alcca Tarma (Andigenum group), and the highest ranking for both was 704229-Jancko Anckanchi (Ajanhuiri group). In a more general approach, Pearson correlation coefficient on log-transformed results regarding iron and calcium showed a high relationship between both contents ($r = 0.67$; $p < 0.01$). A lower range of values was observed for zinc, ranging from 12.6 μg g^{-1} of DW in 702568-Pichea Papa (Andigenum group) to 28.83 μg g^{-1} of DW in 705264-Roscalena (Andigenum group). A weak but significant correlation was found between zinc and iron contents ($r = 0.35$, $p < 0.01$), whereas there was no significant correlation between zinc and calcium contents. It is noteworthy that all of the Ajanhuiri group cultivars under investigation showed high contents of the three minerals.

In general, the contents in calcium and zinc are similar to those reported by other authors for unpeeled raw potatoes (*45*−*47*). The contents in iron are in the same range as those published by Anderson et al. (*48*) (11.71−131.05 μg g^{-1} of DW) for unpeeled potatoes from the United States and Canada, but our mean value (54.95 μg g^{-1} of DW) is slightly higher than those reported in the food composition table of the U.S. Department of Agriculture (37.754 μg g^{-1} of DW) (*46*). Differences in metal concentrations could be explained by several factors. First of all, the potato sampling carried out can be of major importance. Indeed, the elemental distribution may vary within the potato tuber. There is evidence that some elements may be more concentrated in the potato skin relative to the potato flesh (*49*). Variations might also exist between the stem end and the distal end of the potato tuber (*9*). To overcome these aspects and process each cultivar in the same way, whole unpeeled tubers were ground, freeze-dried, and mixed before analysis. A uniform peeling of all the odd-shaped tubers (typical for Andean cultivars) was indeed nearly impossible. As a result, the ratio of skin to flesh may vary between the samples, according to the tuber size and shape, but may be attributed to a genotypic characteristic. This could partly explain certain high iron values. A weak but significant correlation ($r = -0.36$, $p < 0.01$, data not shown) was found between tuber weight and iron content. A determination coefficient of 0.13 indicates that the tuber size may explain 13% of the variability in iron contents. Second, it is recognized that the mineral composition of fruits and vegetables is a reflection of the mineral composition of the soil and environment in which the plants grow (*48*). Our potato core collection was cultivated in a very specific environment (Huancayo, Peru) with a very low soil pH (3.6), which is known to increase the availability of iron in soils (*50*) and, therefore, may increase the iron content of potato tubers.

Adequate dietary intake of iron, zinc, and calcium is essential to human health. More than 2 billion people worldwide are anemic, and this can be mainly attributed to iron deficiency. Iron deficiency during childhood and adolescence impairs physical and mental development. In adults, it reduces the capacity for physical work (*3*). Dietary iron requirements depend on numerous factors, for example, host factors (age, sex, physiological status, ...) and diet composition. Cereals, fruits, and vegetables such as potatoes contain non-heme iron, which is poorly absorbed. Non-hemic iron absorption may be enhanced by ascorbic acid, meat, and fish, whereas phytate, calcium, and polyphenols may inhibit the absorption. The FAO's RNI for iron depends therefore on the bioavailability of the mineral. In developing countries (assumed bioavailability of 5%), the RNI ranges from 27 (for men) to 59 mg day^{-1} (for women), and in developed countries (assumed bioavailability of 12%) the RNI ranges from 11 to 24 mg day^{-1}. Cultivar 704229-Jancko Anckanchi (Ajanhuiri group) contained on average 6 mg 150 g^{-1} of FW. Consequently, a high-iron potato tuber of 150 g of FW from the Jancko Anckanchi genotype could contribute from 10 to 54.5% to the dietary iron intake.

Zinc is an essential micronutrient, and deficiency has serious consequences for health. Zinc deficiency may cause stunted growth. Randomized controlled trials showed that zinc supplementation can reduce the severity of morbidity from common childhood infections (*51*, *52*). In addition, zinc plays an important role in protecting cellular components from oxidation, and dietary deficiencies may enhance the risk of cancer (*53*). Following the example of iron, zinc bioavailability depends on the overall composition of the diet. Dietary proteins may facilitate zinc absorption, whereas, in contrast, organic compounds such as phytate-forming stable and poorly soluble complexes with zinc can impair absorption. The FAO's RNI assuming a high zinc bioavailability (50%) ranges from 3 (for women) to 4.2 mg day^{-1} (for men), whereas the RNI assuming a low zinc bioavailability (15%) ranges from 9.8 to 14 mg day^{-1}. Considering that the highest ranking cultivar, 705264-Roscalena (Andigenum group), contained 1.13 mg of zinc 150 g^{-1} of FW,

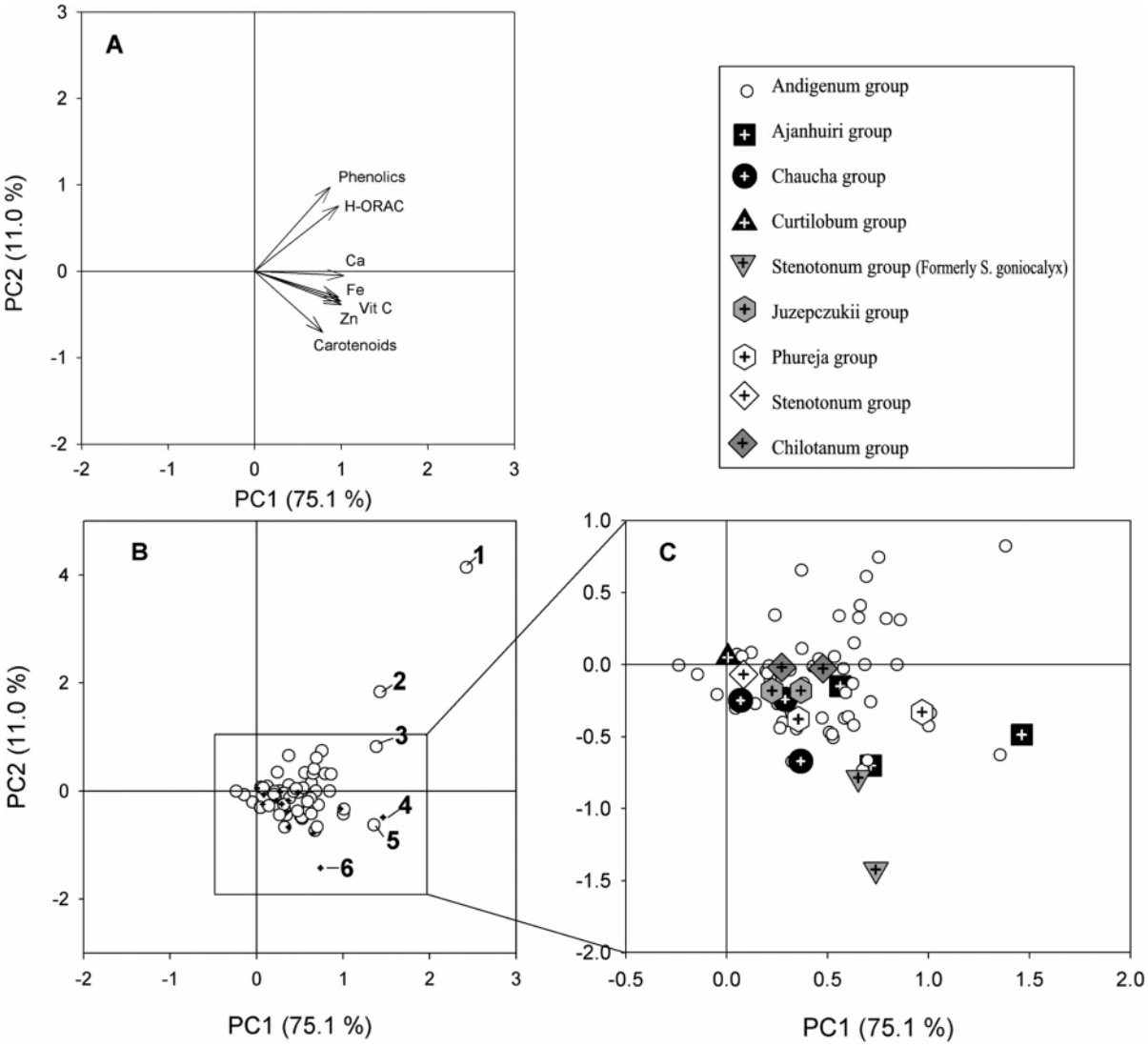

Figure 2. PCA of studied nutritional contents and hydrophilic antioxidant capacity in 74 native cultivated potato genotypes: (**A**) relationships between variables; (**B**) 74 observations representing each genotype. Significance of numbers in panel **B** is defined in the text. The region in the black frame is enlarged in **C**. H-ORAC, hydrophilic antioxidant capacity; Vit C, total vitamin C content.

the consumption of one tuber from this genotype could contribute from 8 to 37.5% to the dietary zinc intake.

Calcium plays a crucial role in providing rigidity to the skeleton and is involved in neuromuscular function, blood clotting, and many metabolic processes. Calcium deficiency may lead to rachitism and osteomalacy and is involved in osteoporosis. Sodium and protein intakes are presumed to increase the calcium requirement. In contrast, vitamin D could promote calcium absorption (*3*). The RNI (assuming a bioavailability of around 40%) for calcium in adults is 1000 mg day^{-1}. The highest calcium-ranking cultivar, 704229-Jancko Anckanchi (Ajanhuiri group), contained 39 mg 150 g^{-1} of FW. Thus, a single potato tuber from this genotype could contribute only 3.9% to the dietary calcium intake. Regarding the potato production, increased calcium content in tubers may also be beneficial because it increases the tuber quality and storability (*54*).

Losses of minerals during tuber cooking being minimal (*55*), certain potato cultivars should be regarded as a significant source of iron and zinc in the human diet. By contrast, potato cannot be considered as a relevant source of dietary calcium.

Principal Component Analysis. PCA was performed on the 74 potato genotypes of the core collection, and the following variables were included in the test: H-ORAC, total phenolic, total carotenoid, total vitamin C, iron, zinc, and calcium contents. The first two principal components (PC) accounted for 86.1% of the total variability, PC1 (75.1%) and PC2 (11.0%) (**Figure 2**).

The PCA plot demonstrated a low variability of the micronutrient profile. The similarity in vector length and direction suggests that no micronutrient was present at the expense of another. Total phenolics and H-ORAC appeared to be highly correlated, whereas orthogonality between these two measurements and the total carotenoid content indicated an independence of these variables (**Figure 2A**). A weak separation could be observed between the cultivars, indicating that most potato genotypes balanced in terms of antioxidant and mineral contents (**Figure 2B**). However, certain genotypes could be distinguished from the cluster and were statistically unbalanced (numbers 1−6 in **Figure 2B**; 1, 704429-Guincho Negra; 2, 702477-Yana Puma Maqui; 3, 702316-Pulu; 4, 704229-Jancko Anckanchi; 5, 703-905-Huata Colorada; 6, 702472-Amarilla del Centro). A large intracultivar variation was found within the Andigenum group, for which a large number of data existed. Some patterns related to the other cultivar groups (**Figure 2C**) confirmed the trends observed in the previous sections. Some cultivars from the Ajanhuiri group showed particularly high tuber mineral contents,

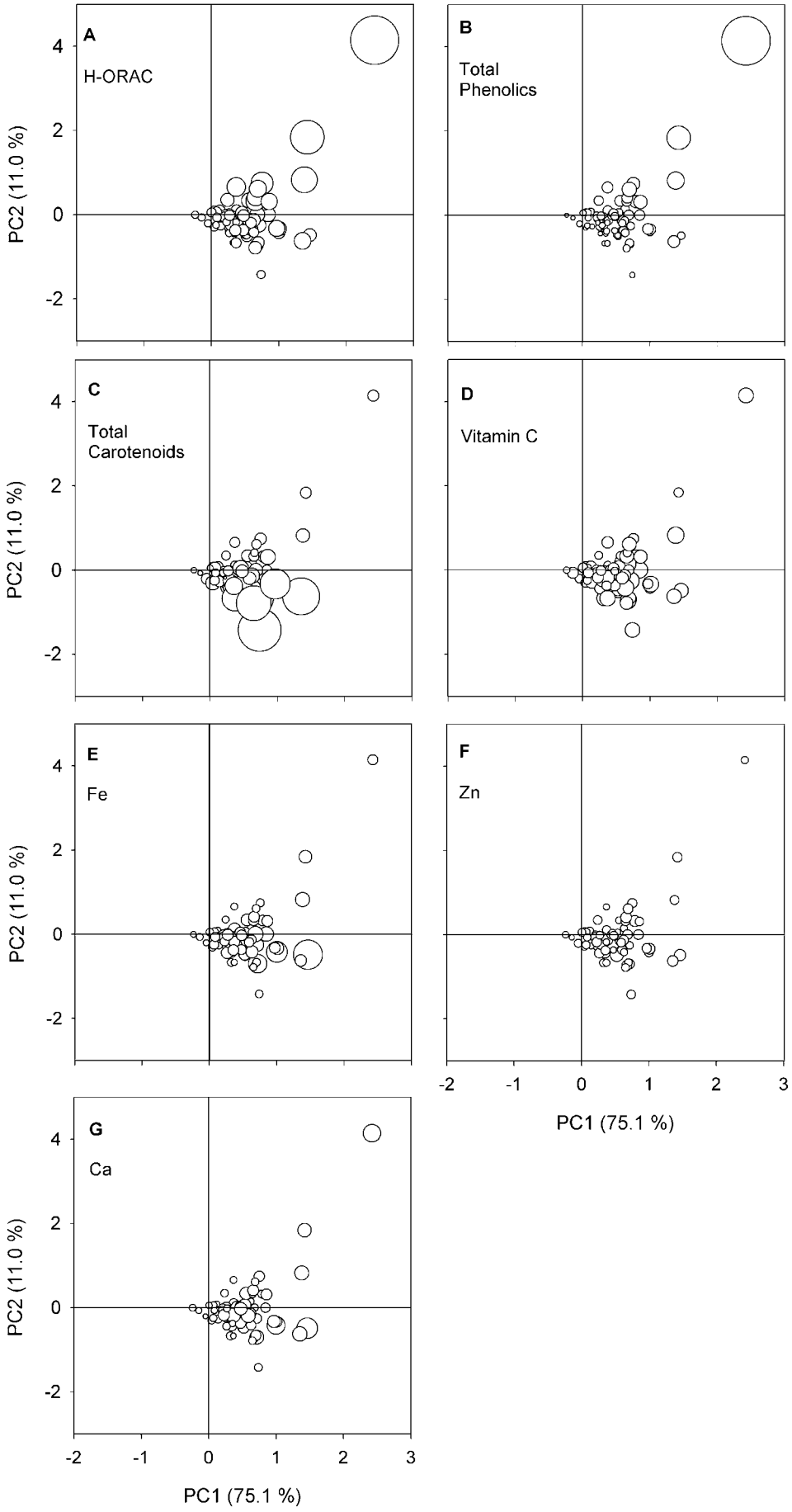

Figure 3. Bubble plots of the PCA performed on the 74 native cultivated potato genotypes of the CIP core collection, emphasizing quantitative variability in specific micronutrients among the potato germplasm.

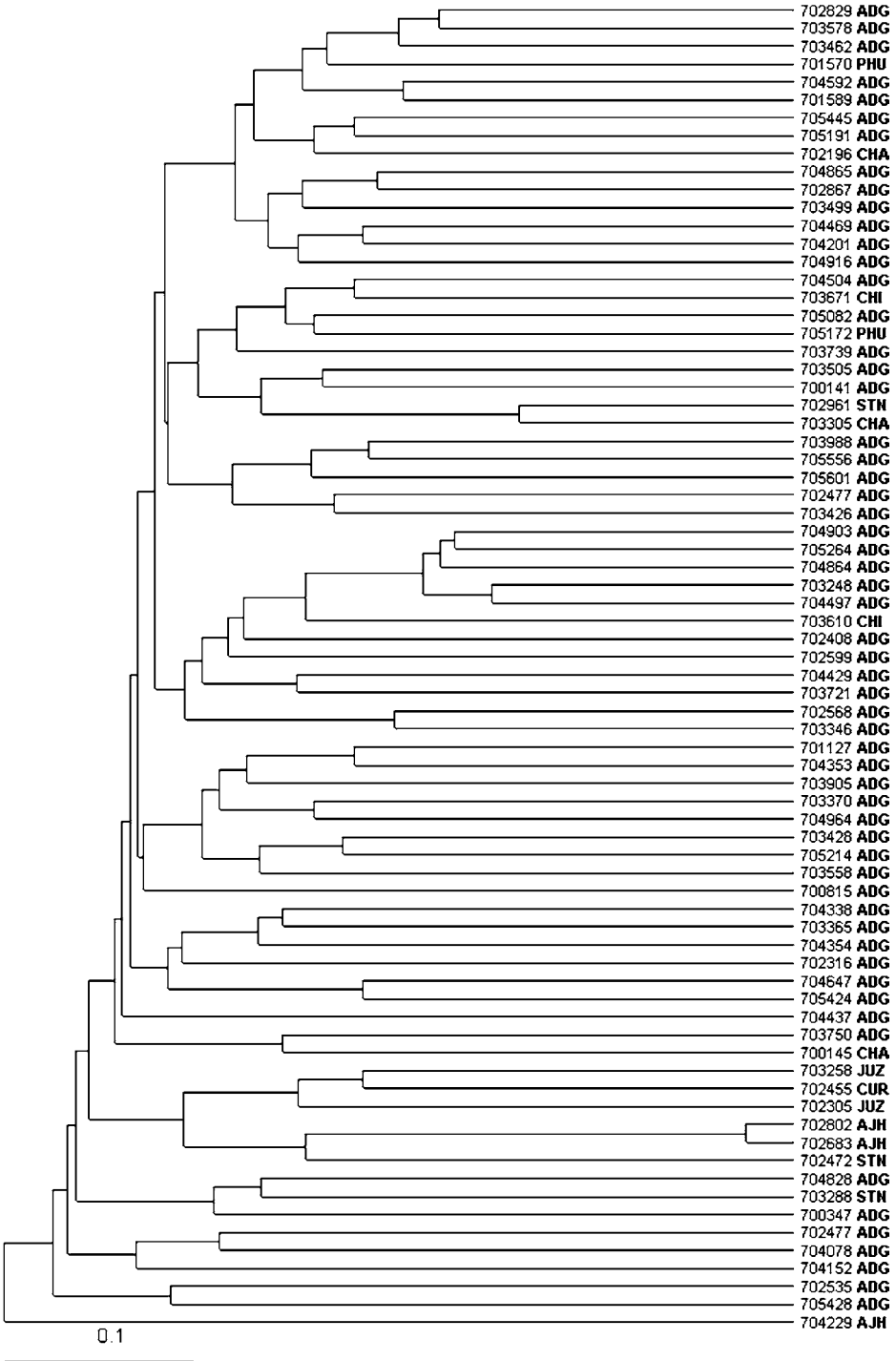

Figure 4. Dendrogram (UPGMA method) of 74 native potato landrace built from genetic distance estimates from 10 microsatellite markers. The scale bar represents the pairwise genetic distances between genotypes. Numbers refer to the CIP accessions as indicated in **Tables 1** and **2**, whereas abbreviations represent cultivar groups as follows: ADG, Andigenum; AJH, Ajanhuiri; CHA, Chaucha; CHI, Chilotanum; CUR, Curtilobum; JUZ, Juzepczukii; PHU, Phureja; STN, Stenotonum.

whereas some tubers from the Stenotonum groups were high in carotenoids content.

The variability in specific micronutrients among the potato germplasm was graphically emphasized using bubble plots (**Figure 3**). The area of the bubble is proportional to the concentration of the concerned variables. As a consequence, 704429-Guincho Negra, 702477-Yana Puma Maqui, and 702316-Pulu were clearly characterized by their high total phenolic contents and H-ORAC (**Figure 3A**,**B**). On the other hand, 703905-Huata Colorada and 702472-Amarilla del Centro were identified for their high total carotenoid contents (**Figure 3C**), and 704229-Jancko Anckanchi was identified for its high iron content (**Figure 3E**). Total vitamin C, zinc, and calcium contents did not show any particular spatial pattern (**Figure 3F**,**G**). Variations within the potato germplasm were lower for these variables than for the others. The PCA suggests that no potato genotype had a particularly high content of both antioxidants and minerals or even had a particularly high content in every antioxidant. However, a high content of a specific antioxidant did not negatively affect the level of the other antioxidants, suggesting independent control pathways between antioxidants.

Table 3. Correlation Coefficient between SSR and Nutritional Data from the 74 Native Cultivated Potato Genotypes of the CIP Core Collection Using the Mantel Test

	Correlation between SSR and Combined Nutritional Data		
	total studied micronutrients	total antioxidants	total minerals
SSR	0.16[a]	0.01	0.17[a]
	Correlation between SSR and Selected Antioxidant Content Data		
	total phenolics	total carotenoids	total ascorbate
SSR	0.02	0.03	−0.01
	Correlation between SSR and Selected Mineral Content Data		
	iron	zinc	calcium
SSR	0.23[a]	−0.09	0.17[a]

[a] Significant at the 0.01 level.

Comparison of the Nutritional Data with the SSR-Based Genetic Diversity. As described above, the reclassification of landrace populations of cultivated potatoes by Huaman and Spooner (*21*) recognizes eight cultivar groups within a single species, *S. tuberosum*. This taxonomic system relies mainly on morphological data, ploidy level, and likely origins. The PCA performed on the micronutrient data did not show any pattern related to the cultivar group (**Figure 2**). The large predominance of genotypes from the Andigenum group in the core collection over the other groups might be the main cause. In contrast to the taxonomic classification, our core collection was selected on the basis of molecular data (*20*). In particular, SSR markers were used to reveal genetic differences among the potato genotypes (**Figure 4**). Therefore, the genetic distances obtained using molecular markers were compared with the results obtained with the studied nutritional data. The relationships between the genetic distances, on the one hand, and distinct or combined nutritional parameters, on the other hand, were studied using the Mantel test. The correlation values ranged from −0.09 to 0.24 (**Table 3**), suggesting a low level of relationship between SSR-based genetic diversity and nutritional diversity under investigation. For instance, the correlation coefficient between the genetic distance matrix from SSR data and the Euclidean distance matrix from the total studied nutritional data was low ($r = 0.16$) but significant ($p < 0.01$). The determination coefficient was 0.025, indicating that the SSR-based genetic diversity may explain only 2.5% of the observed nutritional variability. In particular, the iron and calcium contents were significantly correlated with the SSR data, but the coefficients were also very low. Interestingly, the dendrogram analysis revealed that the genotype 704229-Jancko Anckanchi from the Ajanhuiri group was clearly outside the cluster made up of all the remaining genotypes (**Figure 4**). This cultivar presented also the highest iron and calcium contents. The two other genotypes from the Ajanhuiri group were also rich in iron and calcium and clustered close to the previous one, pointing out a certain genetic predisposition for this group to accumulate iron and calcium. Furthermore, the lowest ranking cultivar for both elements (702829-Alcca Tarma from the Andigenum group) is located on the opposite side of 704229-Jancko Anckanchi in the dendrogram, highlighting a high SSR-based genetic distance between both. However, as expected with such correlation coefficients, no other clear cluster could be brought out from the dendrogram according to their selected or combined nutritional data. These results led us to conclude that SSR probably targets regions of the genome different from the ones involved in the production of the antioxidants or in the accumulation of minerals, resulting in different estimates of the genetic diversity. SSR markers are indeed totally neutral markers targeting usually noncodant regions. However, our core collection allowed us to observe a large variation in health-promoting micronutrient contents and identify particularly high-ranking potato genotypes, but these outcomes were weakly linked to the SSR-based genetic diversity. It is also important to stress that a number of factors, besides genetics, are known to affect the levels of micronutrients. The environmental factors may play also a major part in the variability of the micronutrient profile of the potato tubers. Furthermore, the ripeness stages, storage conditions, and processing and cooking conditions may have a more or less important impact on micronutrient contents as well. These effects are also genotype-dependent.

This study was performed on stored uncooked potato tubers, which were cultivated in the highlands of South America. We showed a wide variability in micronutrient levels among the 74 potato genotypes of the genetically diverse core collection, indicating genetic differences in the control of these components. These variations within the potato germplasm offer the consumer the option of choosing a high-ranking cultivar in terms of phenolics, or carotenoids, or minerals within his diet. The values obtained for micronutrient contents, when discussed in terms of contribution to the dietary intake, highlight that potato tubers could significantly contribute to the dietary antioxidants, zinc, and iron intake on an extent depending on the genotype. Cultivars from the Ajanhuiri group showed particularly high tuber iron and calcium contents. A certain SSR-based genetic distance between this group and the other remaining groups could also be identified on the basis of a dendrogram. Some tubers from the Phureja and Stenotonum groups were remarkably high in carotenoids content, whereas the genotypes from the Juzepczukii group were particularly low-ranking cultivars. The wide variability in the studied nutritional contents of the Andigenum group confirms the high level of polymorphism shown in several studies (*22*).

Including nutritional information (e.g., the ones we presented in this study) besides that concerning disease resistances or glycoalkaloids and heavy metal contents in potato cultivar selection could reduce to some extent the risk of mineral deficiencies and chronic diseases in certain populations. This could help to improve their nutritional status without changing their potato consumption habits. The identification of potato cultivars with high polyphenolic, carotenoid, or iron content adds value to potato consumption and might open new market niches for native cultivated species. In addition, these results support the investment in new breeding programs for improvement of health-promoting micronutrients in modern potato cultivars using the Andean landraces as a source of useful alleles.

ABBREVIATIONS USED

SSR, simple sequence repeat; ORAC, oxygen radical absorbance capacity; TE, Trolox equivalents; GAE, gallic acid equivalents; DW, dry weight; FW, fresh weight; BHT, butylated hydroxytoluene; DTT, dithiothreitol; AAPH, 2,2-azinobis(2-amidinopropane) dihydrochloride; CIP, Centro Internacional de la Papa; RNI, reference nutrient intake; PCA, principal component analysis; UPGMA, unweighted pair-group method with arithmetic averaging.

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