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Abstract: Andean potatoes (Solanum tuberosum andigenum) are a staple food for Andean population; there is great biodiversity but only few varieties are cultivated nowadays. In order to contribute to biodiversity conservation of andean potatoes, information about their morphological, nutritional and functional characteristics was generated. In gene bank (INTA-Balcarce), varieties collected from regional producers were preserved. Forty four genotypes were multiplied and characterized. Morphological characteristics; proximate composition and functional compounds were analyzed. Cluster analysis separated them into 3 groups according to distinguishing characteristics, which define industrial or nutritional applications. Group2 was characterized by higher content of macronutrients and Group3 with the highest antioxidant activity, both would be advisable for direct consumption. Genotype CS 1418 had big size and oval form so it could be destined to potato chips industry. Knowledge on nutritional and functional properties of genotypes contributes to promoting the cultivation depending on properties and also to preserve biodiversity.

Cover Letter

Dear Editor

We submit to Food Chemistry our manuscript entitled " **Biodiversity of Andean potatoes: morphological, nutritional and functional characterization**", in which we determined morphological, nutritional and functional characteristics of 44 genotypes of Andean potatoes.

This was selected for oral presentation at the 11ºIFDC. We appreciate that it be considered to be published in Food Chemistry as the original article.

We believe that the knowledge generated is important because the conservation of biodiversity must be one of the priority issues among nutritionists, biologists and food technologist. On the other hand Andean potato is a staple food for Andean communities, especially for lower-income and a potential source of income.

Quantification and identification of functional properties of different genotypes of Andean potatoes can improved the added value of the food chain of this important Andean tuber, situation that could improve the socioeconomic conditions of the Andean communities of South America.

Thank you very much for your attention.

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Title page

Biodiversity of Andean potatoes: morphological, nutritional and functional characterization

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***Response to Reviewers**

Ms. Ref. No.: FOODCHEM-D-16-01889R1
Title: Biodiversity of Andean potatoes: morphological, nutritional and functional characterization

Reviewers' comments:

Reviewer #2: The search for new potatoes with antioxidant activity and of industrial interest is an important task. However, I still believe the paper and content lacks novelty to be published in Food Chemistry

The authors are convinced that the study of new varieties of Andean potatoes and determining the nutritional composition, antioxidant activity, physical and morphological characteristics allow to obtain novel results regarding the possibilities of use of each variety and also to conserve its biodiversity promoting its production according to the applications industrials or in health, and not only for their agronomic productivity.

Some comments:

- L-192- Level of 5%

Correction was done (Line 189)

- TAC: why did authors use the pH differential to measure the anthocyanins content? This method is usually applied for monomeric anthocyanins and not dimers, etc…. is there a plausible justification for this?

The term "total anthocyanins" was changed to "total monomeric anthocyanins" because effectively the method used is applied to these compounds. The actual level of anthocyanins has probably been underestimated with the method used, but it is still high. (See lines 121 - 122; 253-254).

In general it has been found that anthocyanins are mostly found as monomers, this statement is based on determinations made by other authors (Kalbasi et al., 2007; Cevallos-Casals et al., 2003) who determined that anthocyanins polymerization in commercial red sweet Potatoes imported from Peru was lower than 20%.

Kalbasi, A. & Cisneros-Zevallos, L. (2007). Fractionation of Monomeric and Polymeric Anthocyanins from Concord Grape (Vitis labrusca L.) Juice by Membrane Ultrafiltration. Journal of Agricultural and Food Chemistry. 55, 7036-7042.

Cevallos-Casals, B. & Cisneros-Zevallos, L. 2003. Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweet potato. Journal of Agricultural and Food Chemistry, 51, 3313-3319.

- Authors should use these papers to discuss their data:

1. Chemistry, Volume 133, Issue 4, 15 August 2012, Pages 1131-1137. Gabriela Burgos, Walter Amoros, Elisa Salas, Lupita Muñoa, Paola Sosa, Carlos Díaz, Merideth Bonierbale

2. Journal of Food Composition and Analysis, Volume 22, Issue 6, September 2009, Pages 613-616. M.E. Jiménez, A.M. Rossi, N.C. Sammán
3. Carotenoid profile and retention in yellow-, purple- and red-fleshed potatoes after thermal processing. Food Chemistry, Volume 197, Part A, 15 April 2016, Pages 992-1001
Zora Kotíková, Miloslav Šulc, Jaromír Lachman, Vladimír Pivec, Matyáš Orsák, Karel Hamouz
4. Development of a potentially probiotic food through fermentation of Andean tubers. LWT - Food Science and Technology, Volume 71, September 2016, Pages 184-189
Ana Laura Mosso, Manuel Oscar Lobo, Norma Cristina Sammán
5. Development of a potentially probiotic food through fermentation of Andean tubers. LWT - Food Science and Technology, Volume 71, September 2016, Pages 184-189
Ana Laura Mosso, Manuel Oscar Lobo, Norma Cristina Sammán

The discussion was expanded, including comparison between the results obtained in this work with the papers suggested by the evaluator and others; some of these were included in References. Also the codifications used in tables were added in the text to facilitate reading (See lines 172-176; 178-185; 253-254; 265-274; 277-283).

Reviewer #4:

The manuscript has been greatly improved now and the suggestions made have been answered to my satisfaction except References list, where references are not in the format of 'Food Chemistry'.

References list were corrected with the format of Food Chemistry and actualized (See lines 356-461).

***Highlights (for review)**

- Morphological, nutritional and functional properties allowed characterize Andean potato biodiversity
- Morphological descriptors are good indicators of functional compounds
- Clustering of genotypes determined specific uses for each group
- Andean potato varieties could contribute to food security

Introduction

Biodiversity loss of organisms, species and populations is a highly topical subject. In the world, species are becoming extinct rapidly and most of the reasons are related to human activity (Chapin et al., 2000). Modern crops contain less than 1% of the genetic diversity available in wild species. The biodiversity of wild species and subspecies could play a key role in global nutrition and food security because different varieties of the same species can provide different amounts of nutrients and functional compounds. Therefore, it is extremely important to generate this information (Toledo & Burlingame, 2006).

Burlingame, Mouillé and Charrondiere(2009) in a review about the potato nutritional composition found differences in nutritional profile due to its great biodiversity. It shows that nutritional content should be one of the criteria for the promotion of cultivars and that nutrient analysis and its disclosure should be conducted systematically.

Other researchers emphasize the need of studies about the characterization of local varieties and promote the conservation and recovery of regional biodiversity (Rodriguez Galdón et al., 2012). Potatoes are one of the crops with the greatest genetic diversity, which is displayed in their ability to grow in very different environments (Navarre, Goyer & Shakya, 2009).

Andean potatoes (*Solanum tuberosum andigenum*) are native of South America; Peru and Bolivia contain the greatest genetic biodiversity of this crop, therefore, these countries are considered the center of origin and domestication of these species (Navarre et al., 2009). Andean potatoes are also found in north of Argentina, Ecuador, Colombia and South of Venezuela (Spooner, 2013). The geographical area of origin of Andean potatoes in Argentina is confined to Quebrada de Humahuaca, Puna and high valleys in Jujuy and Salta provinces. These environments are characterized by abrupt changes in altitude and precipitation patterns. Andean potato is a food staple of the Andean population.

These tubers represent a valuable genetic resource since Andean farmers have historically selected those varieties with appropriate nutritional characteristics and resistant to diseases and pests. Even

though there is a high diversity, only few varieties are grown and there is risk of many of them are becoming extinct (Tapia & Fries, 2007).

The potato provides energy due to its high carbohydrate content; also, contains minerals, fiber, proteins and antioxidant compounds such as polyphenols and carotenoids, vitamins E and C, which contribute to nutrition and wellness of consumers. These properties are often underestimated or ignored (Burgos, Auqui, Amoros, Salas & Bonierbale, 2009). The Food and Agriculture Organization of the United Nations (FAO) pointed out that if the analysis of nutrients of diversity in different food species and intra-species were made systematically and these data were disseminated, the national information systems for food and agriculture would be strengthened and this could be useful to build the basis for setting priorities and national policy (FAO, 2008).

The morphological characterization of tubers can be used as a source of information to identify genotypes in gene banks. Madroñero, Rosero, Rodríguez, Navia and Benavides (2013) determined that the best qualitative variables to discriminate an Andean potatoes collection were primary and secondary skin color and secondary color of tuber pulp. Also this characterization allows the identification of "elite germplasm" to be used as parents in future breeding programs.

Potatoes have a high diversity of phenolic compounds. The quantity and quality present in the tuber depend on its genotype characteristics and may be affected by climatic and agri-management factors (Andre et al., 2009). Genetic biodiversity loss may not only result in food with lower content of functional compounds but it may also induce the loss of knowledge referred to the biosynthetic pathways of the tubers (Albishi, John, Al-Khalifa & Shahidi, 2013; Fernández Orozco, Gallardo Guerrero & Hornero Méndez, 2013).

Nonetheless, the variety of tubers and, therefore, biodiversity is lost because the agronomic and commercial selection of some varieties. Other factors that contribute to the loss of the crop genetic diversity are the replacement of local varieties for high-yielding species, the abandonment of the traditional lifestyle, phytosanitary problems, the lack of policies for primary production and development of post-harvest processes, changes of dietary patterns oriented towards cereals such as

rice and wheat and their by-products consumption and the low demand in the markets. All of the above mentioned leads to the production of a limited number of varieties of regional tubers (FAO, 2013).

Consequently, it is of the utmost importance to work in the recovery and study of Andean crops (Jiménez, Rossi & Sammán, 2007) to allow diversification of their production (Lutaladio & Castaldi, 2009). These actions would also support to inhabitants of the region, who still keep their manners respecting their ancestral knowledge. By working together with regional producers, science can achieve strategies for the preservation of agro-biodiversity (Burgos et al., 2013; Toledo et al., 2006). Greater awareness of the nutritional and functional properties of the different varieties of Andean potatoes will contribute to the preservation of the biodiversity, which is part of the Argentine regional heritage and will allow reintroducing these healthy foods in the population diet (Jiménez, Rossi & Sammán, 2009).

The aim of this work is to contribute to biodiversity conservation of Andean potatoes by generating information about the morphological, nutritional and functional characteristics of different genotypes in order to increase their production and application in food industry and nutrition.

2. Material and methods

2.1 Materials

Forty four genotypes of Andean potatoes stored in the Germplasm Bank of the National Agricultural Technology Institute (INTA Balcarce, Buenos Aires, Argentina) were used.

In practice, many of these varieties are not grown since many years, and therefore they were reintroduced in the Andean region for this study. Potatoes were sown in Hornillos, Jujuy (Argentina), all in the same place, planting date and agronomic conditions; the soil type in this region is sandy loam and gravel in all the topsoil.

2.2 Morphological characterization of potato tubers

Characterization was done according to the guide proposed by the International Potato Center (CIP). Nine descriptors were used: Skin predominant color, Intensity of the predominant color of the skin, Skin secondary color, Secondary color distribution of the skin, General and Secondary form, Pulp predominant color, Pulp secondary color, Pulp secondary color distribution and Eyes Profundity, following the codification listed in Table 1.

Weights of tubers were registered. Ten tubers from each genotype were weighted using an electronic scale. Sizes were rated according to established characteristics by the National Institute for Agricultural Research (INIAP) of Ecuador: small potatoes (20-40 g), medium (41-60 g), big (61-90 g) and very big (over 90 g) (Monteros, Yumisaca, Andrade-Piedra & Reinoso, 2011).

Tubers without damage, stains, cuts or with presence of worms were selected. All of them were characterized in the first week after harvest.

2.3 Chemical composition

All the analytical determinations were performed according to AOAC methods (AOAC, 1998). Moisture was determined in oven at 135 °C (AOAC 930.15). Total protein content was analyzed by Kjeldahl method (Buchi Digestion Unit K-435) with a nitrogen-to-protein conversion factor of 6.25 (AOAC 979.09). Total dietary fiber was assessed using the enzymatic-gravimetric method (AOAC 985.19). For ash analysis a carbonization at 550 °C (Mufle furnace Indef, M/07C2) was performed (AOAC 923.03).

Usable total carbohydrate was determined by the Clegg method (Clegg, 1956). Dried potato (1g) was digested with perchloric acid, and then anthrone solution was added. The hydrolyzed starches and soluble sugars were determined together colorimetrically at 630 nm. Results were expressed in g glucose/100 g. Standard glucose solutions (Sigma Aldrich) were used, for the layout of calibration curve.

2.4 Total phenolic (TP) determination

105 2.4.1 Sample preparation

106 The samples were weighed, washed and cut into slices (unpeeled) of 1 cm thick then were freeze-
107 dried using a Lyovac GT 2 (Leybold Heraeus – Germany). After lyophilisation and stabilization in
108 desiccators, they were ground in a laboratory mill and stored in zip-lock bags and kept refrigerated
109 at 4 °C until use.

110

111 2.4.2 TP quantification

112 TP content was determined according to Lachman, Hamouz, Orsak, Pivec and Dvorak (2008) using
113 the Folin-Ciocalteau reagent. TP extraction was performed from the lyophilized sample (2g) with
114 methanol solution (80%) for 24 h. Initially samples were sonicated for 15 min and stirred for 1 h in
115 a bath at room temperature. Sample was filtered and completed to 100 mL. Then, 5 mL Folin
116 Ciocalteau reagent were added to 5 mL of sample , after agitation followed by addition of 7.5 mL of
117 20 % sodium carbonate solution. After 2 h at room temperature, absorbance was measured in a
118 spectrophotometer (Mapada, model UV6300PC) at 765 nm against a blank. The results were
119 expressed as gallic acid equivalents (GAE) (Sigma Aldrich, Switzerland) per kg of dry matter.

120

121 2.5 Total monomeric anthocyanins (TMA)

122 TMA content was determined using the pH-differential method (Truong, Hua, Thompson, Yencho
123 & Pecota, 2012). Total anthocyanins extraction was performed from lyophilized sample (2g) with
124 25 mL of methanol containing 1% HCl. Samples were sonicated in pulses of 3 min every 20 min for
125 1 h. at room temperature followed by filtration through Whatman No. 1 paper. Crude anthocyanin
126 extracts were stored at -18 ° C until analysis. Two dilutions of the extract were made. The first one
127 was done using potassium chloride (0.025 M) at a pH 1, and the second, with sodium acetate (0.4
128 M) at a pH 4.5. After 15min absorbance at 530 and 700 nm was read, using distilled water as blank.
129 The differences between absorbance obtained at the different pH and wavelengths were calculated
130 as follows:

$$A = (A_{530\,nm} - A_{700\,nm})_{pH1} - (A_{530\,nm} - A_{700\,nm})_{pH4,5}$$

TMA concentration (mg/L) was calculated as

$$TMA = \frac{A \times MW \times DF \times 1000}{\varepsilon \times l}$$

Where: MW is the molecular weight of cyaniding-3-glucoside (449.2 g/mol); DF is the dilution factor; ε is the molar absorptivity (26900 L cm $^{-1}$ mol $^{-1}$) and l corresponds to the optical path (1 cm). Total amount of monomeric anthocyanins was expressed as mg of cyanidin-3-glucoside/100 g of fresh weight.

2.6 Total Carotenoids (TC)

TC was determined according to Rodríguez-Amaya and Kimura (2004). Lyophilized sample (4g) was homogenized with 30 mL of acetone for 1 min followed by filtration. TC was extracted with petroleum ether twice. TC content was determined spectrophotometrically at 450 nm, with a calibration curve of beta-carotene (Sigma-Aldrich Co). Concentrations were expressed as µg beta-carotenes/g fresh weight.

2.7 Antiradical activity (DPPH)

Antiradical activity was measured using the technique described by Brand-Williams, Cuvelier, and Berset, (1995), based on the reduction of the DPPH radical controlled through the decrease in the absorbance at 520 nm caused by the action of an antioxidant. Different aliquots of methanolic extract of samples were added to a DPPH solution in methanol (initial absorbance equal to 1 at 520 nm). The decrease in absorbance was determined by monitoring changes during 30 min. The following equation was used to calculate AAR %.

$$AAR(\%) = 100 - [\left(\frac{A_{30}}{A_0}\right) \times 100]$$

Where: A_{30} is the solution absorbance determined at 30 min and A_0 is the initial absorbance. Results were expressed using the average inhibition concentration (IC_{50}), which is the amount of sample extract able to inhibit 50% of DPPH radical.

2.8 Statistical analysis

Analyses were carried out in triplicate. Results were expressed as mean ± standard deviation. In order to group and select potatoes genotypes with similar qualities a cluster analysis was performed. For mixed data analysis with quantitative variables (macronutrients) and qualitative variables (morphological characteristics), the similarity coefficient of Gower (1971) and the model of linkage average were used. Variance analysis between groups was performed and Tukey's test at a significance level of α 0.05 was used. In order to determine correlations between morphological and functional characteristics a Pearson correlation was performed. XLSTAT software (4.04 version-2011, Addinsoft; New York, USA) was used.

3. Results and discussion

3.1 Morphological characterization

Morphological characteristics of 44 genotypes are listed in Table 2. Coding was based on Table 1. Morphological variability between genotypes and within a genotype is presented in Figure 1. Some genotypes showed more than one coding in different morphological characters as general shape of tuber (GSF), eyes depth (PE), predominant skin color (SPC), skin color intensity (I), skin secondary color (SSC) and skin secondary color distribution (SCD).

In morphological characters, the highest frequencies observed in GSF were round, followed by oblongs elongated and oval; medium for PE; yellow followed by purple and brown for SPC and SSC respectively; located in eyes and scattered spots for SCD; cream for pulp predominant color

(PPC)and distribution of secondary color of pulp (PSCD) was absent in most genotypes. Predominant sizes were very small (< 20 g) and small (INIAP).

The studied genotypes showed lower color diversity, both in skin and pulp, than those determined in varieties of Andean potatoes from Peru and Ecuador. Monteros et al. (2011) identified a great variety of colors as SPC but nevertheless the colors more frequent in PPC (cream and yellow) were similar to the studied genotypes in Argentina. There are 13 GSF defined, of which only 3 and the same are the most frequent for potatoes from Peru, Ecuador and Argentina although the percentage of occurrence of each one in the different regions was not the same. E.g in Peru GSF more frequent were oblong, followed by compressed and round, while in Ecuador were round, compressed and elliptical and in Argentina round, oblongs elongated and oval.

3.2 Chemical composition

Table 3 shows chemical composition and functional characteristics of 44 genotypes of Andean potatoes. Significant differences ($p < 0.05$) between nutrient content of different genotypes were observed. The variability between the content of bioactive compounds and functional characteristics studied was even greater. These results differ with other authors who postulated that nutrient content depends heavily on factors such as handling or cropping system, environment and soil (Rodríguez Galdón et al., 2012; Lombardo, Pandino & Mauromicale, 2012). On the other hand, these results are in accordance with the variability observed by Toledo and Burlingame (2006), who reported that genotype, is one of the most significant factors in the determination of nutritional characteristics of different crops.

Moisture content ranged from 70.36 to 81.97 g/100g, similar values to those reported by other authors for fresh potatoes. However, the range determined by Burlingame et al. (2009) was higher (63-87 g/100 g), this can be attributed to the great number of potato varieties studied. In this work, the lower range may be caused by low relative humidity of the growing area. Protein content showed a wide range (from 1.93 to 4.85 g/100 g). Similar variability was reported by other authors

(Jimenez et al., 2009; Burlingame et al., 2009) for Andean potatoes. Although protein content in potato is low, these proteins have high biological value (Karenlampi & White, 2009).This fact combined with the high consumption frequency in most households, results in the fact that potato contributes considerably to the protein daily intake (Romaguera, Samman, Farfan, Lobo, Pons & Tur, 2008). Ash content varied between 0.95 and 1.73 g/100g for fresh potato (Table 3). Similar values were found by other authors who studied some varieties of Andean tubers from the same region (Jiménez et al., 2009). Although other authors informed a wide range of ash content, Lombardo et al. (2012) found ash content values between 3.5 and 5.3 g/100 (DW) and mean value of 4.3 g/100 g for organic potato crops while Rodríguez Galdón et al. (2012) reported a range from 0.62 to 0.89 g/100 g (FW). These differences could be caused by the fact that content and composition of mineral in potatoes are affected by many factors such as altitude, type and pH soil, organic matter, fertilization, irrigation, climate, sampling (Burgos, Amoros, Morote, Stangoulis & Bonierbale, 2007). The differences found in this work are related to differences between genotypes.

The results showed fiber content from 2.60 to 5.86 g/100 g. In studies of peeled potatoes significantly lower values were reported (Liu, Tarn, Lynch & Skjodt, 2007), indicating that potato peel is a good source of fiber. A wide range of usable carbohydrates content (11.87 to 24.00 g/100 g) was found in the 44 genotypes of Andean potatoes. Some values were comparable to studies performed in potatoes grown in Argentina, Peru, USA, Spain, India, Canada and Italy, reported by other authors (Burlingame et al., 2009). Rodríguez Galdón et al., (2012) found a smaller range of usable carbohydrates (11.6 to 19.7%) and this difference was attributed to the negative correlation between moisture content and starch.

3.3 Total phenolics (TP)

Determination of polyphenols, anthocyanins and total carotenoids was performed on 25 potatoes genotypes with different skin and pulp color, most of them (20) had white and pale yellow pulp;

three had intense yellow pulp and the other two purple and red pulps, displaying different spots in pulp and skin.

Polyphenol content ranged from 100.7 to 190.9 mg GAE/100g FW (373.3– 745.7mg GAE/100 g DW). These values are consistent with those reported by other authors; Rodriguez Galdón et al. (2012) values ranged from 56.7 to 127.4 mg GAE/100 g FW; Lombardo et. al. (2012) reported a) for conventional crop 279 to 314 mg GAE/100 g DW, and b) for organic farming 295 to 440 mg/100 g DW; Lombardo, Pandino and Mauromicale (2013) reported values from 255.9 to 359.4 mg/100 g DW and Tierno, Hornero Méndez, Gallardo Guerrero, López Pardo and Ruiz de Galarreta (2015) informed values of 142-359 mg/100 g DW; Rumbaoa, Cornago and Geronimo (2009) found contents from 34.5 to 50.0 mg GAE/100g DW; Navarre, Pillai, Shakya and Holden (2011) reported values from 180 to 1100 mg/100 g DW in colored potatoes and 160-200 mg/100g DW in white-pulp potatoes; Burgos et al. (2013) found ranges from 596 to 4196 mg/100 g DW; Lombardo et al. (2013) reported values from 255.9 to 359.4 mg/100 g DW; André et al. (2009) informed values from 140 to 2740 mg/100gr DW. Total polyphenol content could increase by severe weather conditions such as low temperatures, high altitude field and low rainfall or drought and other conditions such as the use of organic fertilizers and organic production (Lombardo et al., 2012; Lachman et al., 2008; André et al., 2009). Environmental conditions actually affect the content of phenolic compounds, but not the phenolic profile, remaining stable and depending only on the genetic component (André et al., 2009).

Genotypes with colored pulps, such as CS1418, CL 658, CCS 1385 and BA (3) had TP content between 569.50 and 645.00 mg/100 g DW. Also, high values of TP were determined in genotypes with white pulp and colored skin (red, purple and black), which shows that the skin also contributes to TP. Navarre et al. (2009) reported that genotypes of white pulp gets to present content of TP close to 400 mg/100 g DW, lower value than those determined in this study for the genotypes of white pulp, which can be attributed to the contribution to TP content of colored skin of tubers.

253 3.4 Total monomeric anthocyanins (TMA)

254 Content of total monomeric anthocyanins (TMA) ranged from 0.02 in white-pulp potatoes to 21.46
255 mg of cyanidin 3-glucoside equivalent/100 g FW in purple potato pulp (0.07 to 89.44 mg of
256 cyanidin 3 glucoside/100 g DW). These values are lower than those determined by different
257 researchers (Burlingame et al., 2009; Lachman et al., 2008; Lachman, et al., 2009). These
258 differences could be attributed to instability of anthocyanins compounds, culture conditions or
259 because they are different genotypes (Tian, Chen, Ye & Chen, 2016; Lemos, Aliyu & Hungerford,
260 2012; Reyes & Cisneros Zevallos, 2007). The results show that genotypes with purple and red pulp
261 color or other similar have higher amounts of anthocyanins than potatoes with yellow pulp; this
262 results matches with Lachman et al. (2008) and André et al. (2009).

263

264 3.5 Total carotenoids (TC)

265 Total carotenes content ranged from 1.16 to 7.18 µg/g DW. In addition a positive and direct
266 relationship between the intensity of the yellow color of pulp and CT was determined (Table 5).
267 Similar results were reported by other authors (Burlingame et al., 2009; Tierno et al., 2015;
268 Fernandez Orozco et al., 2013). However, TC concentration in tubers of red and purple pulp was
269 higher in comparison with tubers of pale yellow pulp. This could be attributed to the masking of the
270 yellow color by the purple red pigmentation of anthocyanins. The same behavior was determined by
271 Tierno et al. (2015) in potatoes of different origins, in which a "purple" variety of red pulp had a
272 higher TC than the yellow pulp varieties. In addition, studies about the protective action of
273 anthocyanins, to avoid the degradation of carotenoids in different oxidative processes, have been
274 carried out (Kotikova et al., 2016).

275

276 3.6 Antioxidant activity

277 The antioxidant activity values are shown in Table 3; IC_{50} ranged from 5.59 to 11.86 mg DM. The
278 antioxidant activity can be attributed mainly to polyphenol and anthocyanin contents and in lesser

extent to total carotenes (Table 5). Rumbaoa et al. (2009) informed IC_{50} values ranging from 30.6 to 48.6 mg DM, for different varieties of potatoes from Philippine origin with a pre-bleaching treatment. The difference between the results can be attributed to the heat treatment applied, however the higher antioxidant activity of potatoes obtained in this work can also be attributed to genotypes and growing conditions, such as light, temperature and water availability.

3.7 Statistical analysis

Statistical analysis shows the hierarchical sequence of cluster formation, based on the study of mixed variables with quantitative (macronutrients) and qualitative (morphological) data of the 44 genotypes (Figure 1). The 0,49 distance coefficient determined 4 groups: G1 formed by 38 genotypes, G2 formed by the CL 641, CL 482 and CL621 genotypes; G3 formed by two genotypes BA (2) and BA (3) and a fourth group consisting of CS1418 genotype (an outlier case). The latter group recorded the highest distance coefficient. It is unique and different from other tuber genotypes, as it has the characteristic of PSCD with a vascular ring of purple color. This genotype has an irregular SCD, in some cases it becomes the primary color, showing the existing morphological variability within the same genotype. This genotype was different from the other groups also by its larger size.

Cluster analysis revealed differences between groups and showed relationships between morphological variables and macronutrient content. The variance analysis determined the qualitative and quantitative properties that significantly characterized each group (Table 4). In genotype differentiation, morphological characterization had prevalence above chemical properties. Furthermore, type of analysis allows the determination of existence of genotypes with similar morphological characteristics, if distance is close to 0. In this study no genotypes with these characteristics were found.

G1 significantly differed from other groups by absence of secondary color and secondary color distribution in pulp. Within the group most genotypes showed homogeneity by having a unique skin color and white pulp predominance.

In G2, genotypes of irregular shapes, with brown skin color and without secondary color of pulp were observed. This group did not have significant morphological characteristics, but it was differentiated by high nutritional values; the genotype CL641 has the highest protein and fiber contents.

G3 was characterized by intense red-purple as skin predominant color, elongated shape and high content of functional compounds.

3.7.1 Correlations

In order to find a practical use tool for producers, studies correlating properties of the 25 genotypes were performed. The correlation coefficients are shown in Table 5. Genotypes with brown skin and purple spots also showed significant positive correlation with TMA content. This explains that not only pulp could concentrate anthocyanins but also skin, with the features described, may contain a significant amount of this component. Genotypes with both brown skin and yellow pulp were the largest contributors of TC; these results agree with other authors (Lachman et al., 2008; Lachman et al., 2009; Burgos et al., 2009; Tierno et al., 2015).

The negative correlation between IC_{50} versus polyphenols and anthocyanins, was due to these metabolites contribute to the potatoes antioxidant activity. Therefore, this supported the IC_{50} negative correlation with tubers of purple and red pulp and skin. IC_{50} negative correlation with tubers with pulp secondary color intense yellow was also observed, which would mean a contribution of carotenoids with antioxidant activity, although to a lesser extent (Lachman et al., 2009). On the other hand, the positive correlation between IC_{50} and brown predominant skin color, with no pulp secondary color distribution, means that uncolored brown skin do not contribute to antioxidant activity of tuber.

TP content correlated with skin predominant color purple and secondary color brown. These results showed positive correlation between TP and TMA; this behavior was also observed by other authors (Tierno et al., 2015; Lachman et al., 2008; André et al., 2009).

4. Conclusions

Morphological and chemical characteristics provide a better knowledge of the diversity of Andean potatoes.

Cluster method was an appropriate tool in order to group the genotypes according to distinguish characteristics of each one, which define some industrial or nutritional applications:

- Group 2 characterized by higher content of macronutrients would be widely recommended for direct consumption; also its genotypes would be used for starch production.
- Group 3: correlations between color and functional compounds indicated that this group has the highest antioxidant activity; therefore, it would be advisable for direct consumption.
- CS1418: it had big size and oval form so it could be destined to potato chips industry. The purple vascular ring in pulp tuber makes it rich in functional components and with distinctive visuals characteristics.

Only the genotypes of Andean potatoes with high agronomic yield are a common food in the diet of the Andean rural population; the quantity and quality of nutrients and functional compounds in different genotypes and the variability between them, justifies including these as an important factor of food security.

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Table(s)

CODE	GSF	CODE	I	CODE	SCD
1	Round	1	Pale/light	1	Absent
2	Elongated oblong	2	Medium	2	In the eyes
3	Oval	3	Intense/dark	3	In the eyebrows
4	Characteristic oblong	CODE	SSC	4	Around the eyes
5	Compressed	1	Absent	5	Scattered spots
6	Flattened	2	White cream	6	Like eyeglasses
7	Elongated	3	Yellow	7	Sprinkled spots
8	Kidney-shaped	4	Orange	8	Few spots
9	Like tuberous	5	Brown	CODE	PPC
10	Concertinado elongated	6	Pink	1	White
11	Elliptical	7	Red	2	Cream
12	Concertinado	8	Red-purple	3	Light yellow
13	Clavado	9	Purple	4	Medium yellow
		10	Blackish	5	Intense yellow
CODE	SPC	CODE	PSCD	6	Red
2	Yellow	1	Absent	7	Purple
3	Orange	2	Few spots		
4	Brown	6	Vascular ring and cord	CODE	PE
6	Red	CODE	PSC	1	Outstanding
7	Red-purple	1	Absent	3	Superficial
8	Purple	6	Intense yellow	5	Medium
9	Blackish	8	Purple	7	Deep

GSF (General and Secondary Form), SPC (Skin Predominant Colour), I (Intensity of the predominant color of the skin), SSC (Skin Secondary Colour), SCD (Secondary Colour Distribution of the skin), PPC (Pulp Predominant Colour), PSC (Pulp Secondary Colour), PSCD (Pulp Secondary Colour Distribution), PE (Eye Profundity).

N	Code bank	GSF	PE	SPC	I	SSC	SCD	PPC	PSC	PSCD	Size
1	CCS 1350	1	3	2	1	1	1	1	1	1	small
2	CS 1418	3	5,7	8	1	4	4,3	1	8	6	big
3	CS 1432	12	7	2,8	2,3	3,9	5	2	1	1	big
4	CCS 1172	5	3,5	2	2	9	4	2	1	1	medium
5	CCS 1251	12	7	2,8	2,3	3,9	5	1	1	1	medium
6	CCS 1330	1	3	4	1	9	5,2	3	1	1	medium
7	CCS 1255	6	1,3	6	1	3	3	2	1	1	small
8	CCS 1307	2	5	8	3	10	7	5	1	1	small
9	CCS 1166	9	5	7	3	5	7,4	4	1	1	small
11	CCS 1199	3	3	2	2	1	1	1	1	1	very small
12	CCS 1349	2	3	7	3	3,2	2,3	2	1	1	very small
14	CCS 1201	2,4	3	8	3	3,2	3,2	4	1	1	very small
16	CS 1430	1	5	3	3	8	4	2	1	1	very small
17	CL 658	7	3	7	3	5	7	7	1	1	small
19	CCS 1295	3	3	6	1	3	3	2	1	1	big
21	CCS 1205	5	7	2	2	8	2,4	2	1	1	small
23	CL 621	3,8	7	4	3	10	5,2	2	1	1	very big
25	CCS 1271	1	5	2	2	6	4	3	1	1	small
26	CCS 1284	1	5,7	2	3	9	4	2	1	1	small
28	CCS 1327	1,3	7	2	2	9	4,5	3	1	1	medium
31	CL 728	1	7	9	2	9	2,7	5	1	1	medium
33	CL 482	4,13	7	4	1	8	5	3	1	1	very small
34	CCS 1383	1	5	2,6	1,1	7,3	2,6	1	1	1	small
35	CL 748	6	3	2	3	9	5	4	1	1	small
39	CCS 1374	3,4,6	3	8	3	3	5	1	1	1	very small
40	CL 631	1	5,7	8	3	1	1	1	1	1	very small
42	CCS 1385	6	3,5	9	3	5	7	7	1	1	very small

44	CL 516	2	5	9	1	3	7	2	1	1	medium
45	CL 650	3	3,5	4	3	3,6	2,5	1	1	1	medium
49	CL 641	3,8,13	5	4	3	8	7,4	2	1	1	big
51	CL 835	1,2	3	2	3	9	4	1	1	1	very small
52	CL 790	1	1,3	2	3	1	1	3	1	1	medium
53	CCS 1170	1	5	2	1	8	5	1	1	1	very small
54	CL 836	1,13	5,7	4	3	8	2	2	1	1	very small
56	CL 708	1,2	5	2	3	9	2,7	3	1	1	small
57	CL 820	12	5,7	2	3	9	5	1	1	1	medium
58	CCS 1309	1	5,7	2	3	1	1	2	1	1	very small
62	LC 348	5,6	3,5	9	3	5	3	1	1	1	small
74	CL 793	2,3	5	8	2	3	5	1	1	1	small
75	CL 814	1	5	4	2	3	2	4	1	1	very small
104	BA (1)	7	3,5	8	3	3	2,6	2	1	1	very small
105	BA (2)	2	3	7	2	5	3,8	3	1	1	very small
106	BA (3)	2	3	7	2	5	7	6	6	2	small
212	212	13	3	7	3	3	3	2	1	1	small

N: Code of grown GSF (General and Secondary Form), SPC (Skin Predominant Colour), I (Intensity of the predominant color of the skin), SSC (Skin Secondary Colour), SCD (Secondary Colour Distribution of the skin), PPC (Pulp Predominant Colour), PSC (Pulp Secondary Colour), PSCD (Pulp Secondary Colour Distribution), PE (Eye Profundity).

N	Bank code	Variety name	Moisture	Protein	Ash	Fiber	UCH	Polyphenols	Anthocyanins	Carotenes	IC 50
1	CCS 1350	BLANCA ALARGADA	76.41 ± 0.47	2.51±0.06	1.29±0.01	3.00±0.23	16.25±3.63	ND	ND	ND	ND
2	CS 1418	CHAQUEÑA	77.68 ± 0.50	2.34±0.00	1.30±0.04	2.87±0.14	15.41±1.54	149.50±0.05	6.54±3.75	1.81±0.87	6.50±2.03
3	CS 1432	COLLAREJA REDONDA	76.11 ± 0.31	2.52±0.03	1.55±0.06	3.51±0.19	16.27±2.03	ND	ND	ND	ND
4	CCS 1172	MORADITA REDONDA	79.51 ± 0.02	3.14±0.05	1.31±0.04	2.70±0.18	15.27±1.02	102.63±2.34	0.22±1.05	1.20±1.03	9.41±3.19
5	CCS 1251	CHACARERA	77.29 ± 0.07	2.74±0.01	1.44±0.01	3.26±0.12	16.91±0.98	ND	ND	ND	ND
6	CCS 1330	MORADITA	77.64 ± 0.45	2.30±0.01	1.53±0.04	3.14±0.04	17.26±1.34	112.49±0.36	0.02±0.04	1.85±0.93	11.86±1.03
7	CCS 1255	DESIREE	81.97 ± 0.09	2.01±0.02	1.13±0.01	2.77±0.09	14.89±1.56	ND	ND	ND	ND
8	CCS 1307	MORADITA	79.03 ± 0.08	2.41±0.04	1.31±0.04	2.94±0.17	15.50±3.20	ND	ND	ND	ND
9	CCS 1166	CUARENTONA COLORADA	80.49 ± 0.01	2.88±0.04	1.27±0.03	3.14±0.12	14.70±1.48	160.09±0.14	4.09±2.43	1.16±0.65	8.77±3.02
11	CCS 1199	TUNI BLANCA	73.88 ± 0.46	3.83±0.01	1.62±0.04	3.86±0.14	17.31±2.45	ND	ND	ND	ND
12	CCS 1349	COLORADITA	79.68 ± 0.34	2.97±0.09	1.31±0.06	2.70±0.11	15.07±1.39	122.24±5.56	2.32±1.08	1.93±1.65	7.39±2.04
14	CCS 1201	AZUL	78.40 ± 0.38	2.62±0.01	1.48±0.00	3.13±0.09	15.61±0.79	141.52±4.07	10.53±1.17	1.60±1.43	8.60±0.94
16	CS 1430	CUARENTONA	78.73 ± 0.29	2.57±0.01	1.29±0.02	3.31±0.13	15.27±0.48	128.53±0.27	1.46±0.43	2.43±1.17	8.57±1.48
17	CL 658	SANTA MARÍA	75.34 ± 0.44	2.43±0.08	1.36±0.04	3.84±0.13	15.97±0.85	152.66±14.02	16.36±1.32	2.96±1.25	8.50±1.46
19	CCS 1295	ROSADA	77.76 ± 0.04	2.56±0.05	1.33±0.03	3.67±0.05	14.45±1.20	114.43±1.03	2.78±1.12	2.31±0.74	11.08±2.04
21	CCS 1205	CHURQUEÑA	72.38 ± 0.07	2.65±0.05	1.53±0.03	3.63±0.04	18.55±2.04	ND	ND	ND	ND
23	CL 621	CHORCOYEÑA	79.42 ± 0.46	2.58±0.03	1.35±0.05	2.67±0.15	15.72±0.79	ND	ND	ND	ND
25	CCS 1271	BLANCA	77.47 ± 0.80	2.24±0.03	1.40±0.06	2.65±0.18	16.04±0.84	130.80±0.37	0.61±1.07	1.68±0.86	9.19±2.34
26	CCS 1284	SANI	77.60 ± 0.03	2.99±0.11	1.43±0.01	3.43±0.09	15.80±2.94	ND	ND	ND	ND
28	CCS 1327	BAYISTA	73.97 ± 0.53	3.36±0.12	1.55±0.13	3.15±0.20	19.32±3.06	114.21±6.31	0.54±0.3	1.79±0.99	10.90±1.57
31	CL 728	CUARENTONA	74.57 ± 0.08	2.84±0.13	1.52±0.03	3.33±0.45	19.38±2.34	ND	ND	ND	ND
33	CL 482	ROSADA	70.36 ± 0.06	3.71±0.01	1.73±0.03	4.67±0.20	20.00±3.29	ND	ND	ND	ND
34	CCS 1383	PERA O SEÑORITA	78.63 ± 0.91	1.94±0.04	1.30±0.01	2.96±0.05	16.95±0.58	ND	ND	ND	ND
35	CL 748	OVERA	78.92 ± 0.01	2.73±0.01	1.15±0.05	3.26±0.41	15.84±0.68	ND	ND	ND	ND
39	CCS 1374	MORADITA	81.71 ± 0.01	2.02±0.09	1.18±0.03	2.91±0.06	14.01±1.45	126.05±4.35	5.88±3.99	1.49±0.76	6.59±2.19
40	CL 631	ALLO	74.83 ± 0.24	2.85±0.01	1.37±0.02	3.11±0.08	18.02±0.63	163.73±1.84	6.65±4.7	2.03±0.87	7.64±0.57
42	CCS 1385	MORADITA	72.77 ± 0.16	3.07±0.13	1.59±0.01	4.48±0.23	19.07±2.37	190.90±0.39	21.47±0.63	2.93±1.35	6.07±0.58
44	CL 516	CHORCOYEÑA	77.90 ± 0.50	2.24±0.01	1.33±0.02	3.16±0.48	17.19±1.55	113.91±6.55	0.09±0.25	1.95±0.87	10.44±1.23
45	CL 650	COLORADA	76.51 ± 0.04	2.06±0.01	1.26±0.01	3.37±0.37	17.97±1.35	ND	ND	ND	ND
49	CL 641	RUNA	72.43 ± 0.06	4.85±0.03	1.60±0.02	5.86±0.39	16.42±0.68	112.14±0.83	0.06±0.05	1.77±0.69	10.35±2.94

51	CL 835	AIRAMPÍA	75.08 ± 0.00	2.23±0.01	1.45±0.03	2.96±0.46	19.37±2.60	ND	ND	ND	ND
52	CL 790	OVERA	77.27 ± 0.15	2.47±0.04	1.22±0.02	3.20±0.16	17.41±1.35	100.65±0.66	0.43±0.45	2.74±1.32	10.06±2.05
53	CCS 1170	OJOS COLORADOS	81.17 ± 0.47	2.63±0.04	1.25±0.03	2.63±0.06	11.87±0.27	ND	ND	ND	ND
54	CL 836	AIRAMPÍA	75.72 ± 0.80	2.33±0.00	1.56±0.07	3.95±0.51	17.44±2.05	121.25±1.79	2.01±1.80	7.18±3.11	10.61±1.38
56	CL 708	RUNA	75.35 ± 0.69	2.92±0.01	1.43±0.01	3.15±0.25	17.94±1.48	ND	ND	ND	ND
57	CL 820	NEGRA REDONDA	77.82 ± 0.56	2.48±0.01	1.19±0.02	3.69±0.29	15.54±0.37	113.74±0.40	4.09±2.79	1.47±2.04	10.12±2.04
58	CCS 1309	BLANCA REDONDA	72.88 ± 0.15	3.10±0.03	1.52±0.05	3.91±0.48	19.24±2.04	129.17±3.10	3.99±2.06	2.02±1.23	10.32±1.34
62	LC 348	IMILLA NEGRA	74.95 ± 0.54	2.69±0.06	1.35±0.06	3.75±0.34	19.24±3.75	125.76±0.20	4.84±1.81	6.02±2.05	8.82±0.87
74	CL 793	SALLAMA	76.95 ± 0.33	3.66±0.02	1.32±0.02	3.36±0.41	15.52±2.48	ND	ND	ND	ND
75	CL 814	HOLANDESA COLORADA	73.82 ± 0.09	2.74±0.01	1.54±0.00	3.43±0.18	17.76±3.48	106.24±0.83	2.43±2.04	4.80±2.01	10.25±2.34
104	BA (1)	AZUL	78.70 ± 0.53	2.53±0.01	1.38±0.01	2.60±0.11	16.48±1.38	137.89±2.26	10.70±4.85	1.42±0.96	7.49±2.14
105	BA (2)	SANTA MARÍA PULPA BLANCA	81.13 ± 0.87	2.22±0.13	1.20±0.03	3.18±0.12	14.24±1.53	109.74±3.31	3.75±0.40	1.72±0.78	9.01±2.03
106	BA (3)	SANTA MARÍA PULPA ROJA	81.51 ± 0.48	1.93±0.13	0.95±0.03	2.78±0.04	13.03±3.75	128.49±4.63	17.98±0.81	2.44±1.20	5.59±3.43
212	212	COLORADITA	79.46 ± 0.11	2.32±0.02	1.18±0.04	2.97±0.10	15.54±3.58	ND	ND	ND	ND

Values reported as mean ± standard deviation. ND: no determined; n= 44; UCH: usable carbohydrates g/100g Fw; N: Code of grown
Polyphenols in mg GAE/100g Fw
Anthocyanins in mg equivalent cianidin 3 glucósido/100 g Fw
Carotenes in µg/g Fw
IC 50 in mg/mL Dw

Group/genotype	Characteristics	p-value
G 1	PSC1: Pulp Secondary Colour- absent	<0.0001
	PSCD1: Pulp Secondary Colour Distribution-absent	<0.0001
G 2	GSF8: General and Secondary Form- Kidney-shaped	<0.0001
	GSF13: General and Secondary Form- clavado	0.0027
	SPC4: Skin Predominant Colour- Brown	0.0002
	PSC1: Pulp Secondary Colour- absent	<0.0001
	PSCD1: Pulp Secondary Colour Distribution-absent	<0.0001
	Protein: Variable quantitative	0.0021
	Ash: Variable quantitative	0.0041
	Fiber: Variable quantitative	0.0081
	Starch: Variable quantitative	0.0199
G 3	Moisture: Variable quantitative	0.0381
	GSF2: General and Secondary Form- Elongated oblong	0.0273
	SPC7: Skin Predominant Colour- Red-purple	0.0018
	PSC6: Pulp Secondary Colour- Intense yellow	<0.0001
	SSC5: Skin Secondary Colour- Brown	0.0018
	SCD8: Secondary Colour Distribution- Few spots	<0.0001
	PPC6: Pulp Predominant Colour- Red	<0.0001
	PSCD2: Pulp Secondary Colour Distribution- Few spots	<0.0001
CS1418	GSF3: General and Secondary Form- Oval	0.0281
	SCD3: Secondary Colour Distribution- In the eyebrows	0.0336
	S4: Size- big	0.0027

Variable (1)	Variable (2)	Pearson	p-value
TP: Total polyphenols	TMA	0.715	0.0001
PPC6: Predominant pulp color red		0.451	0.0237
PPC7: Predominant pulp color purple		0.699	0.0001
PSC6: Secondary pulp color purple		0.451	0.0237
PSCD2: Secondary color distribution: Few spots		0.451	0.0237
SCD7: Secondary color distribution: Splashed spots		0.467	0.0185
SSC5: Secondary skin color brown		0.604	0.0014
SPC4: Predominant skin color Brown	TC	0.446	0.0253
PPC5: Predominant pulp color intense yellow		0.494	0.0098
TMA: Total monomeric anthocyanin	IC_{50}	-0.712	0.0001
TP: Total polyphenols		-0.625	0.0008
PPC6: Predominant pulp color red		-0.417	0.0381
PSC1: Secondary pulp color absent		0.521	0.0075
PSC6: Secondary pulp color intense yellow		-0.417	0.0381
PSCD1: Distribution of pulp secondary color absent		0.521	0.0075
PSCD2: Distribution of pulp secondary color: few spots		-0.417	0.0381
SPC4: Predominant skin color brown		0.476	0.0162
SPC7: Predominant skin color purple		-0.450	0.0240
SPC8: Predominant skin color purple		-0.485	0.0140
PPC7: Predominant pulp color purple	TP	0.606	0.0013
SSC5: Secondary skin color brown		0.432	0.0310

n=25, $p<0.05$; TMA: Total Monomeric Anthocyanin; TC: Total Carotenes; TP: Total polyphenols; IC_{50}: Concentration Index, inhibit 50% of free radicals.

Figure(s)

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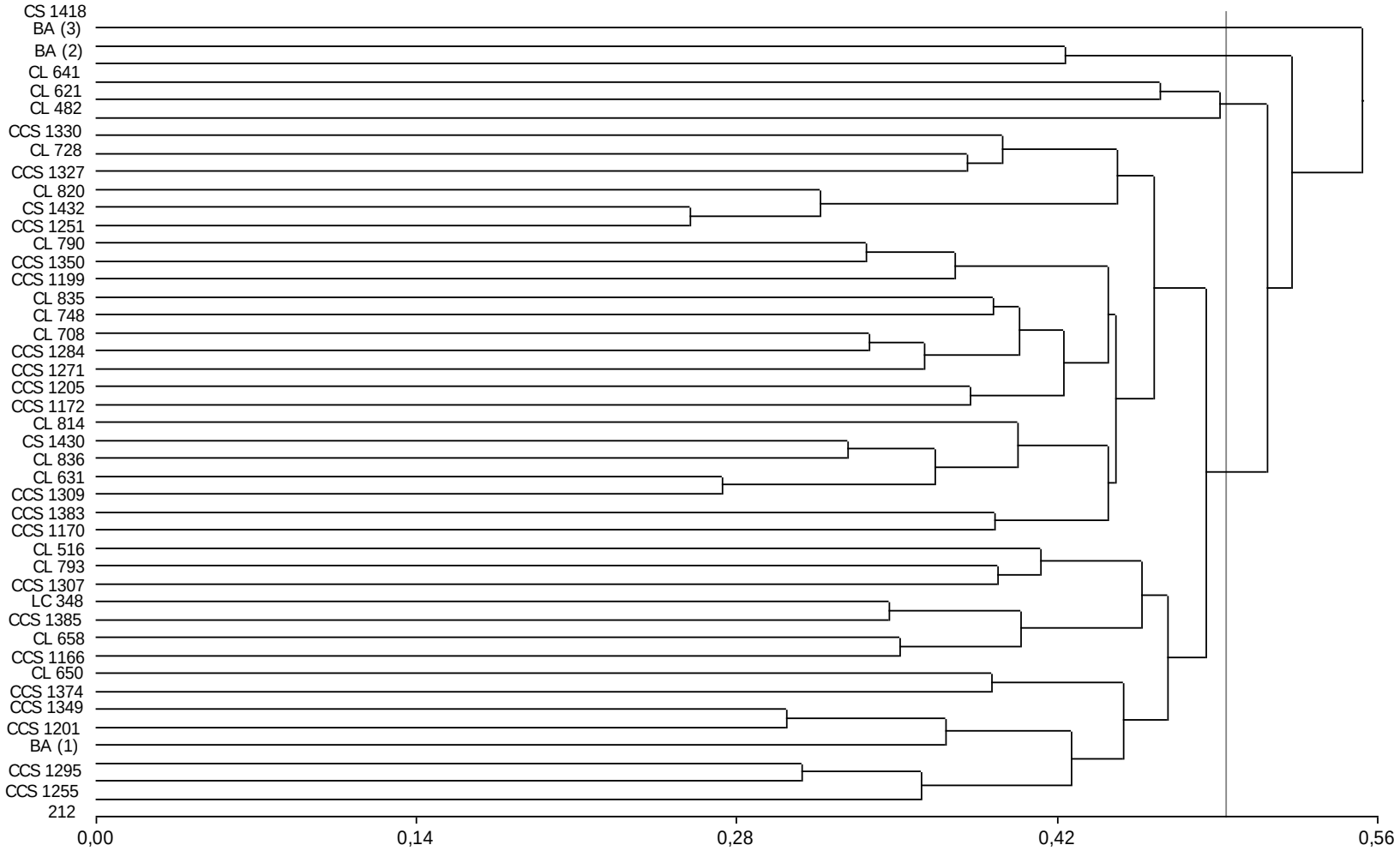
Figure 1. Cluster analysis for morphological characteristics and macronutrient content



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