Chemometric Studies of Chemical Compounds in Five Cultivars of Potatoes from Tenerife

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A statistical study of correlation and multivariate analysis on the chemical composition of five cultivars of potatoes harvested in Tenerife was carried out to establish the relationships between the chemical compounds and, therefore, to differentiate the samples according to traditional and recent importation potatoes, cultivars, and species/subspecies. A large number of significant correlations between the chemical compounds were found, which suggests biochemical relationships among them. After factor analysis, the dimension space was reduced from 24 variables to eight factors, accounting for 77.2% of the total variance. Starch, moisture, organic acids, and metals are the variables that make it possible to characterize the system without losing very much information. Total differentiation of potato samples according to the criteria species/subspecies and cultivars was obtained using discriminant analysis with all the variables. However, with only four variables (weight of tuber, starch, amylose, and glucose + fructose) it is possible to differentiate between the traditional and recent importation potatoes.

KEYWORDS: Chemical composition; multivariate analysis; potatoes

INTRODUCTION

Farming of potatoes in the Canary Islands, seven Spanish islands in the Atlantic Ocean near the African coast of Morocco, is very important due to its high consumption, tradition, and economic reasons. In the Canary Islands, there are about 20 000 persons who, direct or indirectly, are involved and depend on the farming of potatoes (*1*). After Galicia, the Canary Islands are considered the Spanish region with the highest per capita consumption of potatoes (estimated to be 143.2 g/person/day) (*2*). Many Canary typical foods include potatoes in their preparation. Therefore, potatoes are considered a traditional and basic food in the Canary diet, which contributes significantly to the intake of energy, fiber, vitamins included in group B, and ascorbic acid and minerals as K or Mg.

According to Gil González (*3*), approximately 20 to 25 cultivars of potato are produced in the Canary Islands, which can be grouped into two main types: (i) traditional potatoes or "*Papas antiguas de Canarias*", which were introduced in the islands several centuries ago. *Solanum tuberosum* ssp. *andigena* and *Solanum x chaucha* cultivars belong to this group. That is why it is supposed that they are closely related to the potatoes from the Andes; (ii) potatoes that have been imported from the British Islands during the last century. These cultivars belong to *S. tuberosum* ssp. *tuberosum*. Traditional potatoes show

peculiar sensorial characteristics such as sweet taste, firm texture, and special color of epidermis (black, violet, or red). Potatoes from Tenerife are mainly produced in two areas, located in the north and the south of the island. Climatic, soil, and crop conditions are similar in both areas.

The local government, according to European Union legislation, is trying to establish the criteria for quality, food labeling, and geographical origin that must be complied with to obtain the Certified Brand Origin "Denominación de Origen". Quality and Brand Origin Certified requires the establishment of sensorial, chemical, and genetical characteristics.

Multivariate techniques, such as factor and discriminant analysis, can be used to obtain information on major, minor, and trace components in foods. Research on the determination of the geographic origin or quality brand of food products is a very active area for the application of chemometric classification procedures (*4*). Chemical variables are normally used to perform this kind of classification. The chemical composition of potatoes is influenced by many factors, such as the production area, cultivars, soil and climate, agricultural practice, storage, and commercialization conditions (*5−7*). Therefore, it can be used as objective criteria to distinguish different groups of potatoes. So, a pattern recognition approach based on their elemental profile has been developed to classification rules for the authentication of Galician potatoes with certified Brand of Origin and Quality (*8*). Also, a method combining elemental analysis and neural network classification has been developed for determining the geographic origin of unprocessed potatoes (*9*)

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The main objective of this study was to develop several pattern recognition approaches that would confirm the authenticity of the traditional potatoes or "*Papas antiguas de Canarias*" and also differentiate them from other potatoes of recent importation. For this purpose, a statistical study of correlation, factor analysis, and discriminant analysis was carried out to differentiate the potato samples on the basis of the following criteria: traditional, recent importation, species/subspecies, and cultivars. The classification systems are based on the chemical composition. The chemical compounds analyzed were moisture, protein, starch, amylose, total and soluble fiber, ash, Na, K, Ca, Mg, Fe, Cu, Zn, Mn, fructose, sucrose, glucose, ascorbic acid, and other organic acids such as oxalic, fumaric, citric, tartaric, and malic acids.

MATERIALS AND METHODS

Samples. Forty-three samples of potatoes were provided by Mercatenerife (Central Market of Tenerife) from different regions of the island. Potato samples of each cultivar were collected from different farms to diminish the environmental influence on the results. They were harvested between March and July of 2000, and no more than two weeks was spent from harvest to analysis. Conditions of the storage were 12 °C and 80−90% of air moisture. The main characteristics of potato samples are shown in Table 1. Samples were authenticated by technicians of the Instituto Canario de Investigaciones Agrarias and of University of La Laguna. The cultivars analyzed were Cara ($n = 10$) and Kerr's Pink ($n = 10$) from *S. tuberosum* ssp. *tuberosum*, Bonita ($n = 5$) and Colorada ($n = 6$) from *S. tuberosum* ssp. *andigena*, and Negra ($n = 12$) from *S. × chaucha*.

Table 1. Distribution of Potato Cultivars According to Harvested Time, Production Area, and Irrigation

cultivar	tuber weight (g)	harvested time	location of farms		irrigation	
			north	south	yes	no
Bonita ($n = 5$)	35±14	March–July	3	2	3	2
Cara ($n = 10$)	94±39	April–June	5	5	8	2
Colorada ($n = 6$)	54±24	April–June	6	0	5	1
Negra ($n = 12$)	30±9	March–June	6	6	7	5
Kerr's Pink ($n = 10$)	97±19	March–July	5	5	7	3

Each potato was hand-rinsed under a stream of tap water for 15−20 s. Dirt was removed by gently rubbing by hand under the water stream. After rinsing, the potatoes were shaken to remove any excess of water, gently blotted with a paper towel, and placed in a lab dark place to air-dry prior to processing (1−2 h). Afterward, potatoes were weighed and immediately analyzed for moisture, ash, ascorbic acid, and length of tubers. Also, they were processed adequately for analyzing protein, starch, amylose, sugars, organic acids, total and insoluble fiber, and metals.

Analytical Methods. Between 3 and 6 fresh and whole tubers of each sample of potato was well homogenized using a Turmix (T-25 Basic, Ika). Approximately 100 grams of this homogenized mix was divided in four fractions: (i) 10 g were used for determining amylose, sugars, and organic acids; (ii) 3 g were used for each determination of moisture and ash; (iii) 50 g were desiccated to 55 °C (96 h) for determining starch, fiber, and metals; and (iv) 20 g were desiccated to 105 °C for determining protein. All the determinations were carried out in duplicate. The analysis of ascorbic acid was independently carried out on three tubers in duplicated subsamples.

Moisture was determined on three replicates by desiccation at 105 °C for 24 h, according to the method described in Association Official of Analytical Chemists (AOAC) (*10*). Ash was determined by triplicate ashing the residue of moisture determination at 550 °C for 24 h. The rest of the analysis also was performed in duplicate. Nitrogen content was obtained applying the Kjeldahl method (*10*), and the protein content

was calculated using a nitrogen factor of 6.25. Dietary and insoluble fiber was determined according to the methods proposed by Prosky et al. (*11, 12*). Starch was determined by polarymetric method according to Egan et al. (*13*). Amylose content was determined according to the method proposed by Hovenkamp-Hermelink et al. (*14*). Ascorbic acid was determined by the dichlorophenol indophenol titration procedure (*10*). Ascorbic acid was extracted using an acetic acid and metaphosphoric acid solution.

Organic acids analysis were performed by HPLC [Shimadzu chromatograph, with a UV−vis SPD-10AV detector and a Rspack KC-811 (250 × 4 mm) column (Shodex)]. Organic acids were extracted from 1.25 g of homogenized potato with 5 mL of an ethanol solution (80%), heated to 55 °C, and after the ethanolic extract, the sample was freeze-dried. The dried extract was then redisolved in 4 mL of ultrapure water and passed through a C_{18} Sep-pack. Finally, the sample was filtrated through a PVDF 0.45 μm filter. Organic acid concentrations were determined by injecting 20 μL of the standard solutions or sample extracts and eluting with H_3PO_4 0.1% (0.8 mL/min). Determination was carried out using a wavelength of 210 nm.

Sugar analysis were performed by HPLC [Shimadzu chromatograph, with a RID-6A detector and an Aminex HPX-87C (250 × 4 mm) column (BioRad)]. Sorbitol was used as internal standard. The extraction and separation processes for analysis of soluble sugars was similar to those processes described for organic acids. After eluting samples through a C_{18} Sep-pack, these were passed through a column with 1 g of Amberlite resine IRA-400 (BDH) (*15*). The columns were previously conditioned by passing 2 mL of methanol through them and then washed with 6 mL of water milli-Q. Glucose, fructose, and sucrose concentrations were determined by injecting 20 μL of the standard solutions or sample extracts and eluting with ultrapure water at a flow rate of 0.2 mL/min.

HPLC peaks were identified by comparing the retention times with those of commercial standards of the organic acids and sugars supplied by Sigma (Madrid, Spain).

Metal content was determined on three replicates using a Varian Spectra AA-10 Plus atomic absorption spectrometry equipped with a D_2 lamp background correction system using flame air-acetylene. Eight hundred milligrams of potato sample was weighed into digestion tubes, and 8 mL of HNO_3 Suprapur (Merck) was added. The mixture was heated into a digestion block in the following sequence: 100 °C/15 min, 125 °C/15 min, 150 °C/60 min, 160 °C/60 min, and 170 °C/15 min. After the sample was cooled at room temperature, 0.5 mL of HCl Suprapur (Merck) was added, and the sample was heated to 170 °C/5 min. Then, this solution was quantitatively transferred and adjusted to 10 mL with ultrapure water. For the determination of Na, K, Ca, and Mg, it was necessary to make a new dilution, taking 1 mL of the concentrated solution and adding ultrapure water up to 10 mL. Calcium, Mg, Fe, Cu, Zn, and Mn concentrations were determined by atomic absorption spectrometry, and Na and K concentrations were determined by atomic emission spectrometry using the adequate conditions for each metal.

Methods were validated with certified reference material (CRM) %. The Rye CRM-381 was used for protein, ash, soluble and total fiber. Starch values were not certified but recommended by CMR-381. Moisture was not certified. Wheat flour reference material (ARC/CL3, LGC Deselaers) was used for metals. The percent of recovery ranged from 97.5 to 101.5%. The percent standard deviation ranged from 0.68 to 5.62%.

High performance liquid chromatography methods and ascorbic acid, amylose/amylopectin methods had quality control samples, which were spiked and checked with standards from Sigma or Fluka. Spike recoveries and check standards for HPLC methods were typically within ± 10% of their true value and 5% for the rest.

Statistics. All statistical analysis have been performed by means of the SPSS version 10.0 software for Windows. The Kolmogorow-Smirnov's test was applied to verify if the variable had a normal distribution, $p < 0.05$. The mean values obtained in the different groups were compared by one-way ANOVA and *t*-test, if there were significant differences between mean values when statistical comparison gave $p < 0.05$. Simple linear and logarithmic correlation analysis was used to indicate a measure of the correlation and the strength of the relationship

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Table 2. Average Concentrations and Standard Deviations of Chemical Compounds for Different Cultivars of Potatoes[a]

	Bonita	Cara	Colorada	Negra	Kerr's Pink
moisture (g/100 g)	77.13 ± 1.21[a]	81.94 ± 1.81[b]	76.12 ± 2.52[a]	77.45 ± 2.03[a]	78.12 ± 1.99[a]
protein (g/100 g)	2.52 ± 0.38[a]	1.96 ± 0.34[b]	2.26 ± 0.41[ab]	2.44 ± 0.34[a]	2.29 ± 0.35[ab]
starch (g/100 g)	16.8 ± 1.4[a]	13.1 ± 1.5[b]	17.5 ± 2.7[a]	16.0 ± 1.7[a]	15.8 ± 1.5[a]
amylose (g/100 g of starch)	23.6 ± 13.1[ab]	26.6 ± 2.8[a]	22.3 ± 3.7[b]	23.9 ± 3.2[ab]	24.2 ± 2.7[ab]
total fiber (g/100 g)	1.62 ± 0.20[ab]	1.49 ± 0.28[a]	1.93 ± 0.34[b]	1.70 ± 0.23[ab]	1.66 ± 0.30[ab]
insoluble fiber (g/100 g)	1.14 ± 0.15[a]	0.81 ± 0.14[b]	0.96 ± 0.27[ab]	0.95 ± 0.19[ab]	0.93 ± 0.13[ab]
reducing sugars (mg/100 g)	108.0 ± 53.7[a]	85.8 ± 56.8[a]	171.4 ± 151.4[a]	83.1 ± 56.6[a]	44.1 ± 16.6[b]
sucrose (mg/100 g)	347.7 ± 223.4[a]	353.1 ± 182.4[a]	431.3 ± 220.0[a]	335.2 ± 49.2[a]	315.4 ± 42.4[a]
oxalic acid (mg/100 g)	28.98 ± 9.12[ab]	27.14 ± 11.91[a]	38.33 ± 8.69[b]	20.44 ± 9.00[a]	24.25 ± 9.25[a]
citric acid (mg/100 g)	116.0 ± 60.8[a]	428.9 ± 157.1[b]	312.1 ± 159.4[b]	379.8 ± 173.2[b]	350.5 ± 189.6[b]
tartaric acid (mg/100 g)	380.9 ± 347.6[a]	81.0 ± 130.1[b]	197.9 ± 186.8[ab]	82.6 ± 130.2[b]	223.4 ± 268.7[ab]
malic acid (mg/100 g)	57.1 ± 32.3[ab]	62.0 ± 33.7[ab]	65.5 ± 25.8[b]	43.0 ± 18.3[ab]	34.3 ± 18.3[a]
fumaric acid (mg/100 g)	3.55 ± 1.69[a]	2.23 ± 1.15[a]	3.42 ± 1.63[a]	3.89 ± 1.64[a]	3.30 ± 1.73[a]
ascorbic acid (mg/100 g)	21.60 ± 3.94[a]	25.70 ± 5.60[a]	21.43 ± 5.61[a]	24.23 ± 6.48[a]	24.92 ± 5.02[a]
ash (g/100 g)	1.07 ± 0.10[ab]	1.03 ± 0.12[a]	1.13 ± 0.15[abc]	1.18 ± 0.12[bc]	1.20 ± 0.08[c]
Na (mg/Kg)	64.7 ± 58.5[a]	66.6 ± 32.1[a]	38.0 ± 18.1[a]	76.7 ± 49.3[a]	49.1 ± 22.7[a]
K (mg/Kg)	6312 ± 1067[a]	4890 ± 814[b]	6044 ± 741[a]	5822 ± 814[a]	6233 ± 945[a]
Ca (mg/Kg)	43.4 ± 13.1[a]	63.6 ± 34.4[a]	41.9 ± 26.3[a]	58.5 ± 30.9[a]	50.6 ± 25.5[a]
Mg (mg/Kg)	219.9 ± 44.1[a]	228.9 ± 45.4[a]	209.6 ± 50.0[a]	242.1 ± 56.6[a]	245.0 ± 38.8[a]
Fe (mg/Kg)	7.48 ± 1.14[a]	7.19 ± 3.13[a]	8.06 ± 3.35[a]	8.82 ± 3.91[a]	7.78 ± 2.07[a]
Cu (mg/Kg)	1.08 ± 0.15[a]	0.54 ± 0.27[c]	0.64 ± 0.20[bc]	0.71 ± 0.24[bc]	0.88 ± 0.30[b]
Zn (mg/Kg)	3.24 ± 0.34[a]	2.18 ± 0.79[b]	2.91 ± 0.55[ab]	3.11 ± 0.95[a]	3.52 ± 1.12[a]
Mn (mg/Kg)	1.68 ± 0.96[abc]	1.43 ± 0.49[cb]	2.15 ± 1.01[a]	1.06 ± 0.30[c]	1.68 ± 0.49[ab]

[a] Results in the same horizontal line with the same superscript were not significantly ($p < 0.05$) different.

between two variables. Factor analysis, using principal components as the method from extraction of factors, was used to summarize the information in a reduced number of factors, and linear discriminant analysis was used to select the most useful variables in the differentiation among aggregations.

RESULTS AND DISCUSSION

To organize this section in a more comprehensive manner, it has been divided into four parts: chemical analysis, correlation study, factor study, and discriminant analysis.

Chemical Analysis. Table 2 shows the results of the chemical compounds analyzed in the samples corresponding to cultivars of potatoes studied. The results of one-way ANOVA for comparison are also included in this table. In general, it can be deduced that there are several chemical compounds that permit distinguishing among cultivars. The cultivar Cara presented higher ($p < 0.05$) moisture and lower ($p < 0.05$) starch content than the rest of cultivars considered. There are not significant differences among the rest of the cultivars for both parameters. The protein content of the cultivar Cara was lower ($p < 0.05$) than those of Bonita, Negra, and Kerr's Pink, which showed the highest levels of proteins. The cultivar Cara presented lower ($p < 0.05$) total fiber and insoluble fiber than those contents observed in the cultivar Colorada and Bonita, respectively. In relation to the reducing sugars, the cultivar Kerr's Pink had lower ($p < 0.05$) content than the rest of cultivars, presenting this cultivar with a relatively low variation among the samples. The cultivar Colorada presented higher ($p < 0.05$) mean contents of oxalic acid than the rest of cultivars, except Bonita. Similarly, the cultivar Colorada had the highest mean concentration of malic acid. The cultivar Bonita showed lower ($p < 0.05$) mean concentration of citric acid than the rest of cultivars considered, and higher ($p < 0.05$) content of tartaric acid than the cultivars Negra and Cara. With respect to inorganic compounds, the cultivar Cara presented the lowest content of ash. The mean concentration of K in the cultivar Cara was significantly lower than the mean concentrations obtained in the rest of cultivars. Analogously, the mean concentration of Zn in the cultivar Cara was the lowest, the differences being significant ($p < 0.05$) as

compared with the mean concentrations obtained in the rest of the cultivars except Colorada. The cultivar Colorada presented a mean Mn concentration higher ($p < 0.05$) than those concentrations obtained in the cultivars Cara and Negra, presenting the cultivar Negra lower Mn content than that observed in the cultivar Kerr's Pink. Most of the parameters did not present significant differences as a function of the production area. Moisture, Fe, and Mn showed higher concentrations ($p < 0.05$) in the north area as compared with those detected in the south area of the island. In contrast, the Na concentrations in the potato samples produced in the south area were higher ($p < 0.05$) than those contents observed in the north. Irrigation only affected the moisture contents of the samples, such that irrigated potato samples presented higher ($p < 0.05$) content of moisture than nonirrigated ones. Harvest time did not affect the chemical composition of the samples. Therefore, the environment had a small influence on the chemical composition of the potato samples analyzed by us.

Correlations. The matrix correlation (Table 3) indicates some associations between pairs of the measured variables. Potassium concentration showed significant correlation with all the metals except Na, pointing out the correlation with Mg, Cu, and Zn concentrations. Also, the K concentrations correlated ($p < 0.001$) positively with the content of protein and starch and negatively with moisture. The positive correlations of K—protein and K—starch agree with results found by Fuentes Yagüe (16), which indicates that K is associated with protein and starch. The protein content showed also a high number, 9, of significant correlation. Among them, one can emphasize the positive correlation observed with starch, total fiber, and ash, and negative correlation with moisture. The protein content was weakly ($p = 0.016$) correlated with the mean weight of the potatoes. A similar correlation ($p = 0.038$) was also observed between weight and total fiber content. This indicates that, when the weight of potato is increased the protein and total fiber contents decreased. This could be related to the fact that an important part of the protein and of the fiber is placed in the cortex of potato, which is in the surface (approximately 0.5 cm of thickness). As the size of the potato increases, the surface and the amount of cortex

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Table 3. Correlation Matrix for All the Samples[a]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1. Weight	-																					
2. Moisture		-																				
3. Ash			-																			
4. Starch		**-0.960**		-																		
5. Ascorbic acid					-																	
6. Amylose		**0.476**		*-0.466*		-																
7. Protein	-0.365	**-0.512**	*0.446*	*0.412*			-															
8. Total fiber	-0.317	**-0.542**		*0.407*		-0.425		-														
9. Insoluble fiber		*-0.467*		**0.525**					-													
10. Sucrose										-												
11. Glucose+fructose					*-0.431*					0.369	-											
12. Oxalic acid					*-0.483*						*0.454*	-										
13. Citric acid													-									
14. Tartaric acid													**0.770**	-								
15. Malic acid											*0.480*	*0.430*			-							
16. Fumaric acid	-0.323															-						
17. Na																	-					
18. K		**-0.560**	*0.489*	*0.479*			**0.622**	0.311	*0.414*									-				
19. Ca																	0.319		-			
20. Mg			0.388				0.346										**0.629**	*0.498*		-		
21. Fe							0.353										0.377	*0.430*	*0.445*		-	
22. Cu		-0.387	0.380				0.514						-0.323		*0.475*		**0.631**	0.372				-
23. Zn							*0.429*									0.362	**0.616**	**0.655**	*0.402*			**0.601**
24. Mn					-0.315						0.322					*-0.451*	0.304					

[a] When $p > 0.05$, values are not shown in table. Significance level: normal letter $p < 0.05$; italic letter $p < 0.01$; black letter $p < 0.001$.
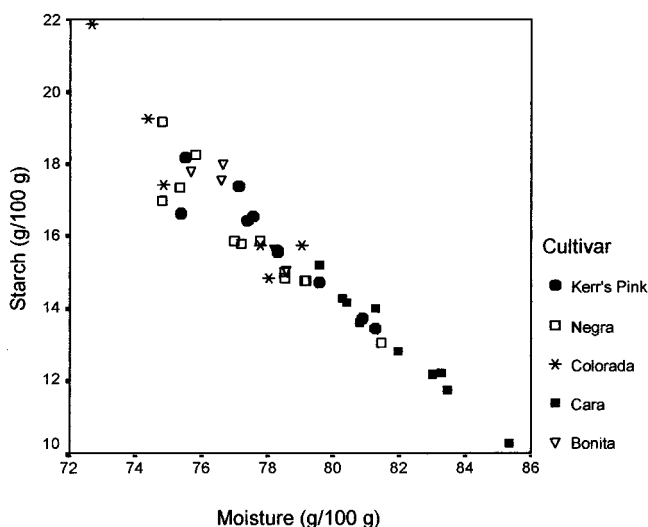

Figure 1. Plot of the correlation between starch and moisture.

decrease. The highly significant correlation ($r = -0.960$) between moisture and starch can be emphasized, which confirms the results obtained for other authors (*5*). This correlation (Figure 1) defines the following regression line, that permits the calculation of the content of starch in a sample of potato with a previous determination of its moisture:

$$[\text{starch (g/100 g)}] = 0.776[\text{moisture (g/100 g)}] - 1.158$$

Starch and total fiber are positively correlated ($r = 0.407$), which could be because both compounds are synthesized from the sucrose produced by photosynthesis. Whether the conditions are favorable to the photosynthesis, both metabolic paths increase their activity (*17*), and, as a consequence, both compounds increase their concentration. Sugars and organic acids presented a relatively low number of significant correlations. The negative correlation between ascorbic acid with glucose + fructose and with oxalic acid and the positive correlation between glucose + fructose and oxalic acid are interesting.

Factor Analysis. Factor analysis was applied to all the samples of potato studied to obtain a more simplified view of the relationship among the chemical compounds considered. The

Table 4. Results of the Factor Analysis of the Matrix of Data

component	eigenvalue	% variance	% cumulative variance
1	4.974	20.73	20.73
2	2.884	12.02	32.74
3	2.493	10.39	43.13
4	2.077	8.65	51.78
5	2.034	8.48	60.26
6	1.478	6.16	66.42
7	1.353	5.64	72.05
8	1.230	5.13	77.18
9	0.978	4.07	81.25
10	0.717	2.99	84.24
11	0.618	2.57	86.82
12	0.560	2.33	89.15
13	0.475	1.98	91.13
14	0.432	1.80	92.93
15	0.396	1.65	94.58
16	0.314	1.31	95.89
17	0.270	1.13	97.01
18	0.216	0.90	97.91
19	0.142	0.60	98.50
20	0.119	0.50	99.00
21	0.115	0.48	99.48
22	0.075	0.31	99.79
23	0.047	0.20	99.99
24	0.003	0.01	100.0

first eight principal components (PC) were chosen (77.2% of the total variance) because their eigenvalues were higher than 1 (*18*), and therefore, they explain more variance than the original variables (Table 4). All variables except protein, presented communality higher than 0.6, and therefore they are well represented by these eight factors. A Varimax rotation was carried out to minimize the number of variables that influence each factor and then to facilitate the interpretation of the results (Table 5). The first PC that explains the higher percentage of variance (20.7%) is mainly related to starch and moisture (positive and negative correlation, respectively), which are the major chemical compounds of the potato. This agrees with the correlation study, since both compounds are negatively and strongly correlated. The second PC is related to the Mg and, to a lesser degree, with the Zn contents. These variables showed a positive and significant correlation. The third and fourth PC are related to the organic acids: positively with oxalic and citric acid in the third and fourth PC, respectively, and negatively with ascorbic and tartaric acid in both PC, respectively. The

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Table 5. Factor Matrix Obtained after a Varimax Rotation

	components							
	1	2	3	4	5	6	7	8
weight	−0.059	0.072	−0.131	0.159	0.319	**0.767**	−0.279	0.028
moisture	**−0.891**	−0.150	−0.001	0.137	−0.156	0.238	−0.006	0.080
ash	0.091	0.529	−0.105	−0.106	−0.272	−0.156	−0.090	−0.501
starch	**0.933**	0.023	−0.020	−0.048	0.169	−0.143	0.031	−0.028
ascorbic acid	0.129	−0.210	**−0.761**	0.250	0.222	−0.164	0.008	0.035
amylose	−0.337	0.006	0.027	0.069	−0.395	0.685	0.033	0.031
protein	0.393	0.559	0.099	−0.129	0.142	−0.211	0.166	−0.086
total fiber	0.444	0.211	−0.076	−0.293	0.007	−0.576	−0.065	−0.055
insoluble fiber	0.698	0.092	−0.006	0.148	−0.228	−0.009	−0.029	0.502
sucrose	−0.022	−0.055	0.336	0.084	0.179	−0.048	−0.001	**−0.694**
glucose + fructose	−0.123	−0.077	0.738	0.027	0.295	−0.233	0.015	−0.132
oxalic acid	0.236	−0.066	**0.798**	−0.010	0.010	0.091	0.054	−0.153
citric acid	−0.103	0.140	−0.019	**0.859**	−0.061	0.216	0.022	−0.084
tartaric acid	−0.050	0.129	0.088	**−0.868**	0.253	−0.151	0.027	−0.085
malic acid	−0.071	−0.036	0.645	0.239	0.138	−0.243	0.321	0.387
fumaric acid	−0.029	0.309	0.206	0.166	−0.011	−0.142	**0.754**	−0.053
Na	−0.055	0.074	0.059	0.219	**−0.811**	−0.016	−0.064	0.094
K	0.533	0.696	0.081	−0.094	0.103	0.063	−0.122	0.022
Ca	−0.023	0.284	0.019	0.197	0.007	0.033	**−0.795**	−0.019
Mg	−0.086	**0.819**	−0.103	0.121	0.063	−0.061	−0.238	0.111
Fe	0.062	0.473	0.144	−0.106	0.392	−0.088	−0.245	0.521
Cu	0.359	0.470	−0.091	−0.623	−0.156	0.232	0.189	0.063
Zn	0.073	**0.749**	0.035	−0.068	0.049	0.183	0.424	0.053
Mn	0.163	0.252	0.191	0.007	**0.770**	0.004	−0.063	0.047

fifth PC is associated negatively and positively with Na and Mn, respectively. The sixth, seventh, and eighth PC are correlated with the mean weight of the potato sample, Ca, and fumaric acid, and sucrose, respectively. Consequently, it can be deduced that starch, moisture, organic acids, and metals are the variables that make it possible to characterize the system without losing very much information. If the scores of each potato sample are represented in the space generated by the first three PC (three-dimensional plot), there is no differentiation between the groups of potatoes considered (traditional−recent importation, species and cultivars). This is because the variance explained is only 43% of the total. Therefore, it would be necessary to include the rest of components in the representation to obtain a clearer separation of the samples.

Discriminant Analysis. Discriminant analysis (DA) is based on the extraction of linear discriminant functions of the independent variables by means of a qualitative dependent variable and several quantitative independent variables. There are two processes that can be applied in DA: (i) stepwise DA that selected the quantitative variables that enhance discrimination of the groups established by the dependent variable. For this purpose, the criterion for this selection is the Lambda of Wilks, which maximizes the ratio of variance between groups to variance within groups; and (ii) introduction of all variables independent. The objective of this process is not to lose information, although the system obtained is more complex. This is applied in those situations where the stepwise method cannot produce a good classification of the samples as a function of the qualitative variable. In this work, we have performed three studies of DA, each one considering different categories (traditional−recent importation, species/subspecies, and cultivars) and the same quantitative variables.

A stepwise DA to overall data was applied considering the criterion traditional−recent importation. If the number of values of the qualitative variable is *n*, the number of discriminant functions is *n* − 1. As the number of values of the qualitative variable is 2 (traditional or recent importation), one discriminant function was extracted which is a linear combination of the

Table 6. Results of Discriminant Analysis (Traditional–Recent Importation) Using the Stepwise Method[a]

			predicted group	
initial group		N	1	2
traditional	1	22	22 (100%)	0 (0%)
recent importation	2	19	0 (0%)	19 (100%)

[a] 41 samples well classified (100% of the potato samples).

quantitative variables. This function presented an eigenvalue of 3.909 and a coefficient of canonical correlation of 0.892. The discriminant function obtained is the following:

$$D_is = -1.173(\text{weight}) + 1.114(\text{starch}) + 0.612$$
$$(\text{amylose}) + 0.624(\text{glucose} + \text{fructose})$$

The classification of the samples into two groups is shown in Table 6. After the DA was carried out, 100% of the samples were correctly classified. Thus, it can be deduced that the traditional potatoes present a chemical composition relatively homogeneous, which permits one to classify them as a well-differentiated group with respect to the potatoes of recent importation with previous determination of four parameters (weight of tuber, starch, amylose, and glucose + fructose).

A subsequent analysis was carried out, using as criteria for comparison the species/subspecies, stepwise DA, and considering all the quantitative variables. The results of the classification applying both processes are shown in Table 7. When the stepwise DA was applied the variables selected were weight of tuber, starch, amylose, and glucose + fructose, so that the same variables that the below process. Two discriminant functions were obtained having eigenvalues of 4.289 and 0.216, and canonic correlation coefficients of 0.901 and 0.422, respectively, for both functions. In this way, 82.9% of the data were correctly classified. The samples of ssp. *tuberosum* were well classified (100%), and the samples of ssp. *andigena* and *S.* × *chaucha* were correctly classified 60.0 and 75.0%, respectively. Three samples of ssp *andigena* were associated with *S.* × *chaucha*,

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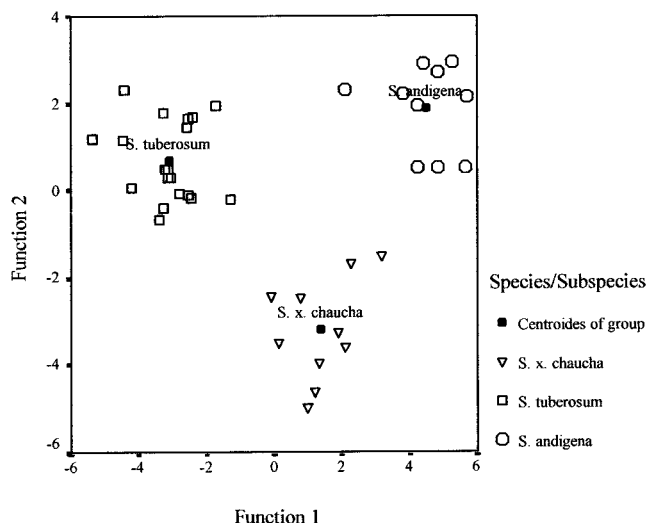*J. Agric. Food Chem.,* Vol. 50, No. 7, 2002 **2081**

Figure 2. Scatter diagram of the potato samples on the axes representing the two-function discriminant differentiating by species and subspecies.

Table 7. Results of Discriminant Analysis (Species and Subspecies)

				predicted group	
method	initial group		N	1	2	3
stepwise[a]	*ssp. andigena*	1	10	6 (60.0%)	0 (0%)	4 (40.0%)
	ssp. tuberosum	2	19	0 (0%)	19 (100%)	0 (0%)
	S. × chaucha	3	12	3 (25.0%)	0 (0%)	9 (75.0%)
all	*ssp. andigena*	1	10	10 (100%)	0 (0%)	0 (0%)
variables[b]	*ssp. tuberosum*	2	19	0 (0%)	19 (100%)	0 (0%)
	S. × chaucha	3	10	0 (0%)	0 (0%)	10 (100%)

[a] 34 samples well classified (82.9% of the potato samples). [b] 39 samples well classified (100% of the potato samples).

whereas four samples of *S. × chaucha* were included as of ssp. *andigena*. Therefore, it can be deduced that the ssp. *tuberosum* shows chemical characteristics more clearly differentiated than the other two groups. If a DA with introduction of all the variables was performed, then 100% of the potato samples were perfectly classified into three groups defined by the qualitative variable. In Figure 2, a scatter diagram of the two discriminant functions obtained from the 24 variables is represented, observing the separation of the potato samples into three original groups.

Similarly, a DA (stepwise and with all variables) in function of the cultivar was carried out. Table 8 shows the results of these classifications using both processes. So, with the stepwise DA, 81.4% of the potato samples were correctly classified. All
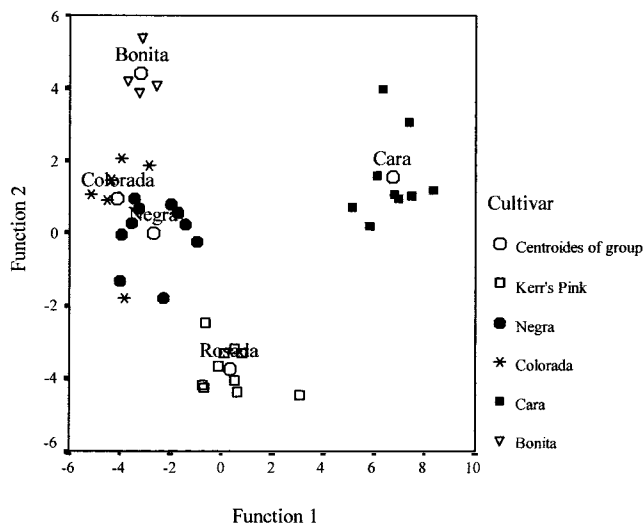

Figure 3. Scatter diagram of the potato samples on the axes representing the first two-function discriminant differentiating by cultivar.

Kerr's Pink samples were correctly classified (100%). For the samples of Bonita, Cara, Colorada, and Negra, 80.0, 80.0, 66.7, and 75.0% were correctly classified. Four discriminant functions were obtained, which are linear combinations of the following quantitative variables: Cu, weight of tuber, moisture, and ash, which discriminate more adequately the differences among the cultivars studied. When this study was performed with all the variables, 100% of the samples were correctly classified. The four discriminant functions obtained present high eigenvalues and values of canonical correlation close to 1. This indicates that the scattering of the data is due to differences among cultivars. A scatter diagram of two first-discriminant functions derived from the 24 variables is represented (Figure 3). It is observed that the samples are distributed in five differentiated groups that coincide with the five cultivars. The samples of cultivars Cara, Kerr's Pink, and Bonita were well separated; however, the samples of Negra and Colorada were slightly mixed.

In conclusion, analysis using only four variables (weight of tuber, starch, amylose, and glucose + fructose) makes it possible to distinguish between traditional and recent importation potatoes, and the determination of all the variables analyzed in this study allows the differentiation of the samples according to the other two criteria, species/subspecies and cultivars. However, the inclusion of other traditional and recent importation cultivars as well as a higher number of potato samples will be taken into account, in the future, to confirm these results.

Table 8. Results of Discriminant Analysis (Cultivar)

				predicted group				
method	initial group		N	1	2	3	4	5
stepwise[a]	Bonita	1	5	4 (80.0%)	0 (0%)	0 (0%)	1 (20.0%)	0 (0%)
	Cara	2	10	0 (0%)	8 (80%)	0 (0%)	0 (0%)	2 (20.0%)
	Colorada	3	6	0 (0%)	0 (0%)	4 (66.7%)	2 (33.3%)	0 (0%)
	Negra	4	12	0 (0%)	0 (0%)	3 (25.0%)	9 (75.0%)	0 (0%)
	Kerr's Pink	5	10	0 (0%)	0 (0%)	0 (0%)	0 (0%)	10 (100%)
all variables[b]	Bonita	1	4	4 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Cara	2	9	0 (0%)	9 (100%)	0 (0%)	0 (0%)	0 (0%)
	Colorada	3	6	0 (0%)	0 (0%)	6 (100%)	0 (0%)	0 (0%)
	Negra	4	10	0 (0%)	0 (0%)	0 (0%)	11 (100%)	0 (0%)
	Kerr's Pink	5	10	0 (0%)	0 (0%)	0 (0%)	0 (0%)	10 (100%)

[a] 35 samples well classified (100% of the potato samples). [b] 39 samples well classified (100% of the potato samples).

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