CLASSIFICATION OF POTATO CULTIVARS TO ESTABLISH THEIR PROCESSING APTITUDE

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Abstract

BACKGROUND: The commercial potato cultivars are diverse, not only in their physical characteristics but also in their nutritional compositions and their content of functional compounds (resistant starch (RS), total phenolic content (TPC) and antioxidant activity (AA)), but there is little information about these differences. The aim of this study was to characterise the nutritional value (focusing in carbohydrates and functional compounds) and instrumental parameters of eight potato cultivars consumed in Spain and to determine whether these parameters are useful for classifying the cultivars.

RESULTS: Significant Pearson's correlations were found due to the common and complex interactions between the constituents of potatoes and their properties ($p<0.05$). Principal component analysis (PCA) revealed the correlations among the physicochemical properties, and the first two principal components explained 56.84% of the variance among the cultivars studied.

CONCLUSIONS: The eight cultivars could be classified into three groups: (1) Red Pontiac, Caesar, Kennebec, Agria and Cherie cultivars; (2) Agata and Monalisa cultivars and (3) Spirit cultivar. Our results demonstrated that certain nutritional and functional parameters indicated the potential efficacy of different cultivars to satisfy the nutritional needs of consumers, improving the knowledge on the biochemical basis of potato processing to obtain higher quality products.

Key words: Total starch (TS); resistant starch (RS); total phenol content (TPC); reducing sugars; organic acids

INTRODUCTION

Potatoes（*Solanum tuberosum* L.）are a primary component of the human diet. More than 4000 varieties of potatoes are cultivated throughout the world. Despite the huge number of potato varieties available, few cultivars have been commercialised. These potato varieties were selected for their feasibility to be marketed and stored. A regular tuber size, high production ratio, good storage ability, multi-purpose use and consumer acceptance are the main characteristics of the potatoes that producers and sellers have chosen to improve their profits and reduce the waste of potatoes. In addition, the food industry prefers cultivars that can be stored for longer periods. In Spain, the rate of potato consumption is 23.13 kg per person per year and involves mainly stored potatoes with a white skin. The predominant variety of potato that is consumed is the Monalisa (26%) cultivar, followed by the Agata (16%) and Kennebec (16%) cultivars, and then the Caesar (8%), Agria (4%) and Red Pontiac (3%) cultivars [http://www.magrama.gob.es].[1]

Freshly harvest potato tubers contain approximately 800 $g \cdot kg^{-1}$ water and 200 $g \cdot kg^{-1}$ dry matter. The dry matter of potato tubers is composed of various substances, including starch, sugars, nitrogenous compounds, lipids, organic acids, phenolic compounds, mineral substances and non-starch polysaccharides. The starch content of potatoes varies with the cultivar and its growth stage. As a major constituent of potatoes, starch contributes to the texture, consistency and organoleptic qualities of foods prepared using them.[2] Starches are generally classified as a rapidly digestible, slowly digestible or resistant starch (RS), depending on the rate and extent of its digestion.[3] RS is not digested in the small intestine, therefore reaching the colon, resulting in the production of short-chain fatty acids, particularly butyric acid produced by the fermentation of resistant starch. RS was recently recognised as a valuable contributor to dietary fibre intake that is better tolerated than are other soluble fibres. The total sugar content of a potato is approximately 0.05 $g \cdot kg^{-1}$ of fresh weight, which is in the form of reducing monosaccharides, such as D-glucose and D-fructose, and non-reducing disaccharides, such as sucrose.[4] Low storage temperatures may cause an increase in the sugar content of most potato cultivars. The

59 organic acids in potato tubers are carbonaceous compounds with high metabolic activity, and
60 some of them are related to each other. The main organic acids in potato tubers are citric, malic,
61 tartaric, oxalic, fumaric and succinic acids. The content of citric acid in potato tubers is higher
62 than that of the other acids, and it plays an important role as an antioxidant by inhibiting the
63 oxidative enzymatic browning process.[5]
64 The phenolic compounds are members of a large group of minor plant products that play an
65 important role in determining the organoleptic properties. In potato tubers, the phenolic
66 compounds are located mainly in the skin and adhesive tissue cortex, and the concentrations of
67 phenolic components decrease toward the centre of the tuber.[6] However, potato skins are often
68 wasted as by-product of the potato-processing industry (i.e. the frying potato chips) or by
69 consumers. Lopez-Cobo et al.[7] studied the phenolic compounds of potato skin and stated that the
70 potato skin could be merit more attention. Physicochemical properties contained in potato tubers
71 that may act as antioxidants in the human diet have been intensively studied.[8,9] High positive
72 correlations between the level of antioxidant activity (AA) and the total phenol content (TPC)
73 were found by Reyes et al.[10] who stated that phenolic compounds were mainly responsible for
74 the antioxidant activity of potatoes. The antioxidant activities of potatoes vary among the potato
75 genotypes with varying flesh colours, and purple potatoes tend to be associated with a high level
76 of total antioxidant activity.[11]
77 In summary, potatoes are a healthy component of a varied diet because they are a relatively low-
78 calorie food containing a variety of dietary fibre nutrients and antioxidants. However, there is
79 scarce information about the correlations of textural parameters, carbohydrate components,
80 phenolics and antioxidant capacity of the potato cultivars commonly consumed. The main
81 purposes of this study were (1) to evaluate the instrumental parameters, carbohydrates and
82 functional content of eight commercial cultivars consumed in Spain, focusing on the starch
83 profile (RS, TS), the functional content (TPC, AA), colour and texture and (2) to establish
84 possible correlations between nutrients as a distinguishing feature of different potato varieties
85 for determining the aptitude of being processed.

MATERIALS AND METHODS

Chemicals

All the chemicals and solvents used were of analytical grade. Oxalic acid, fumaric acid, tartaric acid, malic acid, citric acid, lactic acid, D-(+)-fructose, D-(+)-glucose, sucrose, gallic acid 1-hydrate, Folin-Ciocalteu reagent, sodium dihydrogen phosphate, sodium carbonate anhydrous, HPLC-grade acetonitrile and 37% (v/v) chloridric acid were purchased from Panreac Applichem (IWT group, Barcelona, Spain). Methanol and anhydrous di-sodium hydrogen phosphate were supplied by Scharlau Chemie (Scharlab S.L. Barcelona, Spain). Thermostable amyloglucosidase (GOPOD) reagent buffer, GOPOD reagent enzymes, D-(+)-glucose standard solution, amyloglucosidase and pancreatic-α-amylase were purchased from Megazyme International (Ireland). Fluorescein, 2, 2-azobis (2-amidinopropane) dihydrochloride (AAPH) and 6-hydroxy-2, 5, 7, 8-tetramethylchromane-2-carboxylic acid (Trolox) were obtained from Acros Organics (Thermo Fisher Scientific Inc. Waltham, MA, USA).

Sample preparation

Potato samples

Potato tubers (*Solanum tuberosum* L.) of eight cultivars that are commercialised in Spain (Agata, Agria, Caesar, Cherie, Kennebec, Monalisa, Red Pontiac and Spirit) were obtained from Mercabarna (Mercados de Abastecimientos de Barcelona S.A., Barcelona, Spain). All the potatoes were grown in Europe and had the same post-harvest storage conditions. Randomly chosen samples of 10 kg of each potato cultivar were provided. Table 1 shows the physical characteristics of the potato cultivars. The average weight of the tubers ranged from 134 to 337 g, except for the Cherie cultivar, the weight of which was less than 100 g. The colour of the skin of the tubers was white-yellow, except for that of the Red Pontiac and Cherie cultivars, which was red. The flesh colour ranged from white to yellow. Two of the cultivars (Agria and Caesar) were defined as mealy, which might be due to their high starch content, and the rest (Agata,

Cherie, Kennebec, Monalisa, Red Pontiac and Spirit) were defined as multi-purpose (useful for boiled and baked products).

Each selected potato tuber was washed and then, potatoes were hand-peeled and the potato flesh was cut into small strips (1×1×5 cm). The potato flesh strips and the skin peels were lyophilised using a freeze-drying instrument, Cryodos-45 (Terrasa, Spain), and packed in plastic bags, and the lyophilised powders were maintained at -20 ℃ until further use.

Extraction of phenolic compounds, sugars and organic acids

Methanol extracts were obtained using the procedure described by Andre et al,[12] with slight modifications. In brief, the lyophilised powder of each sample was mixed and chilled, and 1 g was removed for extraction. Solid-liquid extraction was performed using 10 mL of acidified methanol/water (80:20 v/v) containing 0.1 g/L HCl by sonication (Bandeline Sonoplus GM70, Germany) for 14 min in an ice bath. After sonication, the extracts were centrifuged at 2.313 xg for 10 min at 4 ℃ (Selecta, Spain). The supernatant was filtered through Whatman No.1 filter paper, and the pellet was re-extracted as before. Two liquid extracts were mixed and were evaporated to dryness using a rotary evaporator at 40 ℃ (Laborata 4000 Efficient, Germany). The organic residue was brought to 5 mL with acidified water containing 0.1 g/L HCl and was stored at -20 ℃ until further analysis. All the samples were extracted in triplicate. The potato skin and flesh extracts were used for analysis of the phenolic compound content and antioxidant capacity. The flesh extracts were also used for the measurement of sugar and organic acid content.

Instrumental analysis

Colour evaluation

The colour of the potato samples was measured using a MINOLTA CR-400 colorimeter (Minolta camera, Osaka, Japan) in the CIE lab space. The L* (lightness), a* (greenness [-] to redness [+]), and b* (blueness [-] to yellowness [+]) values were evaluated at three different positions. The values for the parameters of hue angle (H°) and chroma (C*) were calculated as

follows: $H^{\circ}=\tan^{-1}(b^*/a^*)$ and $C^*= (a^{*2}+b^{*2})^{1/2}$. Six measurements were taken for each potato sample, and the results were expressed as the mean values ± standard deviation.

Texture analysis: Texture profile and shear force analyses

A texture profile analysis (TPA) of fresh samples was performed using a 75 mm diameter cylinder plunger probe (P/75). Six potato cylinders (length 10 mm, diameter 10mm) were analysed for each potato sample, The following parameters were set: test speed of 0.83 $mm \cdot s^{-1}$, a rest period of 5 s between the two cycles and a trigger force of 5 g. The maximum extent of deformation was 40% of the original length.[13] Four TPA parameters were determined from each curve as described by Bourne,[14]: hardness (peak force of the first compression cycle), cohesiveness (ratio of positive force area during the second compression to that during the first compression), springiness (ratio of the time duration of force input during the second compressing to that obtained during the first compression), and chewiness (hardness multiplied by cohesiveness multiplied by springiness). Six potato cylinders were analysed for each potato sample, and the results were expressed as the mean value ± standard deviation.

The flesh shear force of the potato cultivars was measured using a texture analyser (TA.XT plus, Stable Microsystems, Surrey, UK) equipped with a Wartner-Blazer probe, as previously described.[15] The test conditions were: test speed of 1 $mm \cdot s^{-1}$, target distance of 22 mm into the samples and trigger force of 2 g. The potato strips were cut vertically by the probe, and the shear force was set as the maximum force and expressed in N. Six potato strips were tested for each potato sample, and the results were expressed as the mean values ± standard deviation.

Potato component analysis

Dry matter and pH

The dry matter content was determined using the gravimetric method (AOAC 931.04). The results were expressed as $g \cdot kg^{-1}$. The pH was determined according to AOAC method 981.12. All the analyses were conducted in triplicate, and the results were expressed as the mean values ± standard deviation.

Determination of the total starch and resistant starch contents

The total and resistant starch contents were analysed through their enzymatic hydrolysis to D-glucose using the AOAC 996.11 (amyloglucosidase/α-amylase method) and AOAC 2002.02 methods, respectively. D-(+)-Glucose was oxidised to D-gluconate, which was quantitatively measured from the absorbance at 510 nm of a colorimetric reactant. The results of the total and resistant starch analyses were expressed as $g \cdot kg^{-1}$ of the lyophilised weight (LW). Each sample was analysed in triplicate.

Sugar analysis

The content of sugars in the potato samples was analysed using a high-performance liquid chromatography (HPLC) Hewlett Packard series 1100 instrument equipped with a Beckman 110B injector and a Beckman Refraction Index Detector (RID). The separation was performed using a Phenomenex Lunacolumn (250 x 4.6 mm i.d.), following the method of Rodriguez-Galdon et al.[16] Briefly, the liquid extracts were filtered through a 0.45 μm membrane filter, and 20 μL of each filtrate was injected. The mobile phase consisted of acetonitrile/water (78:22 v/v), and the flow rate was 1.2 $mL \cdot min^{-1}$. Individual sugars were identified by comparing their retention times with those of external standards, and the quantification was conducted through calibration using the external standard. Each extract was analysed in triplicate. The sugar contents were expressed as $g \cdot kg^{-1}$ of LW.

Organic acid analysis

The organic acid contents were determined using the same protocol used for analysis of the sugar contents, except that detection was conducted using a Beckman 166 UV-Vis detector set to 210 nm， as described by Rodriguez-Galdon et al.[16] The organic acid contents were expressed as $g \cdot kg^{1}$ of LW.

Total phenolic content analysis

The total phenolic content of the extracts of potato skin and flesh was determined using a modified version of the Folin-Ciocalteu assay.[17] Gallic acid was used as the standard and was diluted with distilled water to obtain the range of concentrations appropriate for a standard curve.

20 µL of sample extract, gallic acid calibration standard or the blank material was placed in a plastic cuvette with 1.58 mL of distilled water and 100 µL of Folin-Ciocalteu reagent. After 5 min of incubation, 300 µL of 200 $g \cdot L^{-1}$ sodium carbonate was added, and the solution was incubated for 2 h at room temperature. Then, the absorbance at 765 nm was measured using the Nicolet Evolution 300 spectrophotometer (Thermo electron Corporation, UK). The results were expressed as g Gallic acid equivalent per kg of LW (g $GAE \cdot kg^{-1}$ LW).

Analysis of the antioxidant activity of the potato skin and flesh extracts

The antioxidant activity of the extracts was evaluated using the oxygen-radical absorbance capacity (ORAC) assay, as described by Gorjanovic et al.[18] Briefly, 13.5 µL of each diluted sample or standard solution (Trolox at five different concentrations, ranging from 6.25 to 500 µM) was mixed with 135 µL of 9.57×10^{-2} µM fluorescein in a well of a 96 cell plate, and the plate was incubated at 37 ºC for 10 minutes; then, 50 µL of 153 mM AAPH (2, 2-azobis (2-amidinopropane) dihydrochloride) was added to each well to initiate the reaction. The fluorescence was measured every 2 min for 120 min at 37 ºC using emission and excitation wavelength of 485 and 530 nm, respectively, using a microplate fluorescence reader (Synergy™ Multi-detection Microplate Reader, BIO-TEK Instruments, USA) until the decay of the kinetic curve was completed. The area under the curve (AUC) and the net AUC ($AUC_{standard}$ - AUC_{blank}) was calculated for each standard or sample. A blank measurement was taken and a linear standard curve (5 standards) was created for every run. The results were expressed as g of Trolox equivalents (TE) per kg of LW. The reagents, standards and diluted samples were prepared using phosphate buffer, pH 7.40. Each extract was analysed in triplicate.

Statistical analyses

The data reported were the mean values of the results of triplicate analyses. The coefficient of variation of the chemical data was less than 5%. The variations among the contents of the potato components were evaluated using a one-way analysis of variance (ANOVA). The differences between mean values were evaluated using the HSD Tukey test with a 95% confidence interval.

Pearson's correlation analysis was conducted to study the relationships among the variables. Both analyses were conducted using Minitab 16 Statistical software (MINITAB Inc., State College, PA, USA). A principal component analysis (PCA) was conducted to determine the relationships among the variables that were analysed using STAT-ITCF statistical software (Bordeaux, France).

RESULTS AND DISCUSSION

Instrumental parameters

Colour characteristics

Colour is an important quality parameter for raw potato tubers that is affected by certain pre-harvest and post-harvest factors and by the type of cultivar. The chroma and hue-angle values of the tubers of the different potato cultivars varied considerably (Table 2). The chroma values of the yellow and light-yellow tubers were higher than those of the white tubers, with the exception of the Spirit tuber. The tuber chroma values increased from the Red Pontiac to the Agria (13.47 to 30.29, respectively) cultivars. Our results were similar to those of Cabezas-Serrano et al,[19] who found that the chroma values of the tubers of five industrial potato cultivars ranged from 17.1 to 31.0. Among the cultivars analysed, the highest Hue-angle value was obtained for Agata tubers (light yellow), followed by Monalisa (light yellow) and Spirit (white) tubers, and the lowest value was obtained for Cherie (yellow) tubers. The Hue-angle values of the tubers of the other cultivars were not significantly different ($p>0.05$).

Texture: TPA and shear force

The values obtained from the TPA of the raw potatoes varied considerably among the eight cultivars (Table 2). Their hardness ranged from 123.89 N to 156.80 N, and these results were consistent with those of Bordoloi et al.[20] Spirit showed a greater hardness and shear force, whereas Agata showed the lowest hardness and shear force of the tested cultivars. Therefore, significant correlation was found between the shear force and hardness ($r=0.838$; $p<0.05$). In addition, the Spirit cultivar also had the highest cohesiveness, springiness and chewiness values in all cultivars. The values of cohesiveness and springiness of all cultivars tested were smaller

than other parameters, but these values were significantly different ($p<0.05$). The shear force also significantly correlated with chewiness ($r=0.708$; $p<0.05$). The differences in this textural property among the potato cultivars may be due to their differing dry-matter content.[21] The texture is a very important parameter in cooking quality of potatoes. Mealiness was used to describe texture of boiled, baked and oven-fried potatoes, while hardness was also judged regarding quality.[22] According to Kaur et al,[23] potato cultivars with greater mealiness showed higher hardness and cohesiveness. The texture changes during the cooking are associated with the gelatinization and retrogradation behaviour of starch and with enzymatic and non-enzymatic changes of pectin. [22]

Dry matter and carbohydrate contents of the commercial potatoes

The dry-matter content of the potatoes ranged from 230 $g \cdot kg^{-1}$ for the Spirit cultivar to 184 $g \cdot kg^{1}$ for the Agata cultivar. All the cultivars, except the Agata variety, contained more than 200 $g \cdot kg^{-1}$ of dry matter, and significant differences in the dry-matter contents of the cultivars were found, as shown in Table 3 ($p<0.05$). Usually, commercial varieties of potatoes are selected according to their dry-matter content, but this parameter can be affected by the storage and growing area. S Stored Agata and Agria tubers from Italy had similar contents of dry matter,[19] but Agria tubers purchased in New Zealand had a higher content of dry matter.[20]

Starch is the main component of dry matter, with a concentration of approximately 600 $g \cdot kg^{1}$.[24] The content of total starch, which is also the major carbohydrate component of potatoes, ranged from 681 (Agata) to 752 $g \cdot kg^{-1}$ of LW (Spirit), as shown in Table 3. The cultivated potatoes had a mean content of 188 $g \cdot kg^{-1}$ of starch on a fresh weigh basis (FW) that ranged from 100 to 300 $g \cdot kg^{-1}$.[25] Among the studied potatoes with the starch content lower than that of the mean value, the tubers of the Spirit and Agata cultivars contained 173 $g \cdot kg^{-1}$ and 125 $g \cdot kg^{-1}$ of starch at FW. The total starch contents observed in this study were similar to those reported by Bordoloi et al.[20] for four commercial varieties.

The resistant starch in raw potatoes is defined as RS type 2 (RS2), which comprises

ungelatinised resistant granules that are slowly hydrolysed by α-amylase.[26] In this study, the content of resistant starch of the potatoes ranged from 482 (Agria) to 610 $g \cdot kg^{-1}$ (Cherie) of LW (Table 3). Previous reports noted that fresh potatoes contain 691-764 $g \cdot kg^{-1}$ of RS,[27,28] but there was scarce data about the differences among potato cultivars. Our results showed that the potatoes of the cultivars studied contained less RS than was previously reported and there were significant differences between the RS contents of the cultivars ($p<0.05$). Notably, the fraction of resistant starch comprised 65-85% of the total starch in the potatoes of the eight cultivars assessed.

Significant differences were found in the sugar content of the potatoes of the eight cultivars tested ($p<0.05$). The concentration of glucose (1.20-23.50 $g \cdot kg^{-1}$ LW) was slightly higher than fructose in all of the cultivar samples. Their fructose content ranged from 0.80 to 14.1 $g \cdot kg^{-1}$ LW, and sucrose content ranged from 1.40 to 4.5 $g \cdot kg^{-1}$ LW. Plata-Guerrero et al.[29] analysed the content of glucose, fructose and sucrose of the potatoes of four commercial potato cultivars, and they also found that the content of glucose (0.28-1.20 $g \cdot kg^{-1}$ FW) was higher than that of fructose (0.27-0.90 $g \cdot kg^{-1}$ FW) and sucrose (0.26-0.40 $g \cdot kg^{-1}$ FW). These results may be due to the high concentration of fructokinase in potatoes; this enzyme could redirect fructose into the hexose-phosphate pathway.[30] Our data showed that the reducing sugars (glucose and fructose) content of the tubers ranged from 0.20 to 37.6 $g \cdot kg^{-1}$ LW and the reducing sugars content of the Agata and Monalisa tubers were significantly higher than those of the other cultivars. Wegener et al.[31] analysed a variety of coloured potato cultivars and found that the content of reducing sugars in their tubers ranged from 0.26 to 0.75 $g \cdot kg^{-1}$ FW. Whereas the cultivar type and storage conditions had a notable effect on the equilibrium between free sugars and starch in tubers, Kumar et al.[30] did not observe changes in the concentration of reducing sugars in tubers during the first three days of storage at low temperatures (4-6 ºC). Endo et al.[32] observed that during storage at temperatures lower than 8 ºC, the content of reducing sugars increased markedly in all the cultivars studied. Furthermore, reducing sugars affect potato processing such that the higher the reducing sugars content, the higher the level of browning after frying. Additionally,

Muttucumaru et al.[33] proposed that in potatoes, sugars are more important than free asparagine as acrylamide precursors because other amino acids present in potatoes may play a role in the formation of this contaminant. Therefore, the tubers of commercialised cultivars that develop a high content of reducing sugars during storage may be a potential risk for acrylamide formation during cooking (i.e. baking or frying).

Correlations among the carbohydrate content, dry-matter content and texture of commercial potatoes

Pearson's correlations were calculated to evaluate the relationships among the components of the potatoes. The total starch content of the potatoes was highly positively correlated with their dry matter content ($r=0.722$; $p<0.01$), in agreement with the results of Bordoloi et al.[20] However, a less significant correlation was found between the dry matter and resistant starch content of the potatoes ($r=0.441$; $p=0.031$), which may be due to the content of resistant starch being dependent on the physicochemical properties of the starch.[34] Finally, the level of correlation between the contents of resistant starch and total starch of the potatoes ($r=0.417$; $p< 0.01$) was similar to that found for the RS and DM contents.

As expected, the glucose content was significantly positively correlated with the fructose content ($r=0.993$; $p<0.01$). There were negative correlations between the reducing sugar content and content of total starch ($r=-0.515$; $p<0.01$) and dry matter ($r=-0.727$; $p<0.05$).

The potatoes that had higher starch and higher dry-matter contents (such as Spirit potatoes) were observed to be much harder and more cohesive than those with low levels of these components. A significantly positive Pearson's correlation was found between the hardness and the shear force levels and the dry matter content of raw potato tubers ($r=0.824$; $p<0.05$ and $r=0.915$; $p<0.01$, respectively), whereas the correlations between the hardness and the shear force levels and the total starch content were also high ($r=0.700$ and 0.734, respectively; $p<0.05$).

Organic acids and pH

As Table 4 shows, the pH values of the tubers ranged from 5.89 to 6.30. The correlation between the organic acid contents and the pH level was significant ($r = 0.555$; $p=0.03$). The organic acids are biologically important because they participate in various metabolic processes, such as the Krebs cycle. These compounds affect the acidity and pH of potatoes, depending on their concentration and their pKa.[16]

The concentrations of the six most abundant organic acids (oxalic, tartaric, malic, lactic, citric and fumaric acids) in the potato tubers are listed in Table 4. Citric acid was the most abundant organic acid in all the tested potato cultivars. The ranges of the oxalic, tartaric, malic and lactic acids contents were similar; however, significant differences in the organic acid contents of the cultivars were found ($p<0.05$). Fumaric acid was the least abundant organic acid, and there were no significant differences in its content among the cultivars ($p>0.05$). Rovers and Guttman[35] reported citric acid contents ranging from 6.0 to 20 $g \cdot kg^{-1}$ DW, which is consistent with our finding of a range of 7.1 to 11.3 $g \cdot kg^{-1}$ DW; the malic acid content ranged from 1.0 to 6.0 $g \cdot kg^{-1}$ DW, which was slightly higher than our results (with a range of 0.7 to 1.3 $g \cdot kg^{-1}$ DW). The tartaric acid and oxalic acid contents found in our study are similar to those of Wichrowska et al.[5] and Rodriguez-Galdon et al,[16] respectively. None of the previous studies reported the presence of lactic acid.

The concentrations of individual organic acid differed among the potato cultivars. In general, Agata potatoes presented the higher content of citric and lactic acid, and Agria potatoes had the higher content of tartaric and oxalic acid. The higher content of malic and fumaric acids were found in Caesar potatoes. Organic acids (lactic acid, citric acid, oxalic acid, tartaric acid and fumaric acid) have been described as strong antimicrobial agents against psychrophilic, mesophilic microorganisms in fresh-cut fruit and vegetables (including potatoes).[36] The decreasing of citric acid in potato tubers, as well tendency of the boiled potatoes to darken, was due to the non-enzymatic process of the antioxidants.[37]

The Pearson's correlation analysis showed a positive and significant correlation between the

354 oxalic and tartaric acid contents (r=0.768; p<0.05), the citric and oxalic acid contents (r=0.661;
355 p<0.05) and the AA level and total acid content (r=0.565; p<0.05), but no significant
356 correlations (p<0.05) were found between the total organic acid content and the values of the
357 other parameters that were studied.
358
359 **Total phenolic content**
360 The phenolic content of potatoes depends primarily on the genotype and the growing location,
361 but certain methods of extraction and sample-preparation, such as vigorous extraction methods,
362 can lead to an apparent increase in the phenolic content.[38] According to Ji et al,[39] with the
363 exception of a few cultivars, the selected potatoes had higher concentrations of phenolic in the
364 skin than in the flesh, often twice as much. Potato skins are a rich source of phenolic
365 compounds, but much of the phenolic content of potatoes is wasted in the manufacture of some
366 potato products, such as potato chips. The effect of the cultivars on the total phenolic content
367 and the differences between the total phenolic contents of skin and flesh are shown in Table 5.
368 The total phenolic content (TPC) of the potato skins ranged from 3.8 to 6.7 g GAE·kg^{-1} LW.
369 These results were in accordance with those of Wu et al,[40] who reported that the total phenolic
370 content of potato skins ranged from 0.76 to 7.88 g GAE·kg^{-1} of dry weight. In general,
371 significant differences between the TPC of the cultivars were found (p<0.05). Apart from the
372 Caesar and Agata cultivars, the white-yellow skinned cultivars had a lower content of TPC
373 compared with that of the red-skinned cultivars, as expected. Several studies have reported that
374 red or purple skinned potatoes contained higher amounts of phenolic compounds (anthocyanins)
375 than the yellow-skinned cultivars.[41] The high phenolic content of some white-yellow skinned
376 cultivars (Caesar and Agata) may be explained by the differences in their phenolic compound
377 profiles.
378 As shown in Table 5, the TPC of the potato flesh ranged from 0.89±0.02 (Kennebec) to
379 1.73±0.04 (Agata) g GAE·kg^{-1} LW, which was lower than those reported by Ji et al (1.60 to 8.40
380 g GAE·kg^{1} DW).[39] Ah-Hen et al.[42] analysed Shepody and Desiree cultivars and found that the

TPC of peeled potatoes varied from 1.91 to 18.6 g GAE·kg^{-1} DW, which was also higher than the range we observed. The TPC of different potato cultivars clearly varied widely. According to Teow et al,[11] the purple-fleshed sweet potato clones had the highest total phenolic content, followed in order by the orange-, yellow- and white-fleshed clones. Negative correlations were found between the DM and TS contents and the TPC content (-0.585, $p<0.05$ and -0.456, $p<0.05$, respectively).

Antioxidant activity

There are some difficulties in measuring the true antioxidant status of food products in vivo. The antioxidant activities (AA) of foods or food components have been evaluated using in-vitro chemical models. There are two major mechanisms to explain how antioxidants deactivate free radicals (hydrogen-atom transfer and single-electron transfer).[42] Two assays of the AA are generally used, the ORAC (oxygen radical-absorption capacity) assay to determine the hydrogen-atom transfer activity and the FRAP (ferric reducing/antioxidant power) assay to determine the single-electron transfer activity. However, the ORAC assay is considered more closely related to a human biological assay.[43]

The antioxidant activities (AA) of the potato skin and flesh extracts are presented in Table 5. The AA in the flesh and skin extracts of the potato cultivars ranged from 4.83 to 10.79 and from 26.03 to 77.04 g TE·kg^{-1} LW, respectively, and significant differences between the values for different cultivars were found ($p<0.05$). The flesh extracts of the yellow and light-yellow cultivars exhibited significant higher AA compared with those of the white-flesh potato cultivars. The highest AA was found in the Agata flesh sample (10.79 g TE·kg^{-1} LW). Apart from the potato, other foods, such as sorghum and sweet potato, also show a similar relationship between the colour intensity and the AA .[11]

The Pearson's correlations between the total phenolic contents (TPC) and ORAC values of the skin and flesh samples were evaluated. The results showed positive correlations between the ORAC values of the potato skins and their TPC ($r=0.984$; $p<0.01$) and between the ORAC

values of the potato flesh samples and their TPC ($r=0.659$; $p<0.01$). High correlations between the TPC and AA have been reported for various food commodities, such as sorghum ($r=0.971$), cactus pear ($r=0.970$-0.990) and sweet potato cultivars ($r=0.937$).[11,44] These high correlations result from the contribution that the main phenolic compounds of potato tubers make to their hydrophilic antioxidant capacity. Additionally, phenolic compounds can transfer an oxygen molecule to the peroxyl radical, which is the basis of the peroxyl radical reaction evaluated in the ORAC assay, which involves a hydrogen-atom transfer mechanism.[12] Therefore, the TPC can be used as an indicator in assessing the AA of fruits and vegetables, including the tubers of potato cultivars.

Principal component analysis

Principal component analysis (PCA) revealed that fourteen principal components (PC1 to PC14) explained the variance among the data, and the first two principal components explained 56.84% of the total variance (Figure 1). The first principal component explained 38.31% of the total variance, and the second principal component explained 18.53% of the total variance, which indicated that the first two principal components concerned variables that differentiated the studied cultivars. The TS, DM, RS and texture parameters (Shear force (She), Hardness (Har), Chewiness (Che) and Cohesiveness (Coh)) had positive loadings and the AA, TPC, reducing sugar, total acid and colour parameter (Hue-angle) had negative loadings for the first principal component. The AA, DM and Har had negative loadings and other properties which showed in Figure 1 had positive loadings for the second principal component.

The scores of the eight potato cultivars for the first and second principal components are shown in Figure 2. The distribution of the cultivars along the first principal component reflected their DM, TS, She and Har. The tubers of the Spirit, Kennebec, Cherie and Caesar cultivars had positive scores for the first principal component, indicating their higher DM, TS, She and Har values. In contrast, the tubers of the Agata, Agria and Monalisa cultivars which had negative scores for the first principle component, had higher antioxidant activity and reducing sugar

content. Furthermore, the distribution of the cultivars along the second principal component reflected their Hue angle, springiness (Spr), Coh and Che. Regarding the first and second principal components, the Spirit cultivar had higher positive scores for both the first and second principle components, which indicated that the Spirit cultivars had the higher DM, TS, She, Har, Spr, Coh, Che and Hue angle values than that of other cultivars tested.

According to PCA, the eight commercial potato cultivars were classified into 3 groups: the Cherie, Kennebec, Agria, Caesar and Red Pontiac cultivars into group 1; the Agata and Monalisa cultivars into group 2 and the Spirit cultivar into group 3. The physical and chemical properties of different group cultivars were distinct. The cultivars of group 1 had higher dry matter, total starch content, shear force and hardness; the group 2 cultivars had higher antioxidant activity, reducing sugar content, Hue angle, springiness, cohesiveness and chewiness; the group 3 cultivar had higher dry matter, total starch, shear force, hardness, springiness, cohesiveness, chewiness and Hue angle. Certain nutritional and functional parameters of different group cultivars indicated the potential efficacy of different cultivars to satisfy the nutritional needs of consumers and industrial use. The group1 and group 3 cultivars were suitable for frying because of the higher dry matter and the lower reducing sugar content, enabling to obtain a less colored product and low levels of acrylamide content which was attributed to the Maillard reactions;[33] The group 2 cultivars were fit for boiling and baking because of higher value of springiness, cohesiveness and chewiness, and the cultivars without peeling during boiling and baking may increase the antioxidant properties due to health benefits.[10] The texture attributes are important for describing the variation of industrial use between the analyzed cultivars. As one of the textural parameters, the hardness could indicant the aptitude use of potato cultivars. Kreutzmann et al.[22] found that the frying potato cultivars with higher mealiness which significantly and positively correlated with hardness had higher scores; the boiling and baking potato tubers with lower mealiness had higher scores. As Figure 2 showed, the group 1 and group 3 cultivars had higher hardness than the group 2 cultivars, which also proved that the group1 and group 3 cultivars were fit for frying and group 2 for boiling and

462 baking. In general, our study showed that the physicochemical properties analysed enable to
463 classify the potato cultivars and predict the aptitude use of the potato cultivars.

464 ## CONCLUSIONS

465 A statistical study of correlations between all parameters analysed was conducted to discover
466 associations between measured pairs of these parameters. A significant ($p<0.05$) and positive
467 correlations were found which due to the common and complex interactions. The potato skin
468 recommended for use without removing during the cooking process (boiling and baking) was
469 due to the higher of total phenolics and antioxidant activity. The organic acids content was
470 similar to the previously reported, but the acid lactic was presented in all the cultivars studied.
471
472 The PCA results classified the eight cultivars studied into three groups: (1) Cherie, Kennebec,
473 Agria, Caesar and Red Pontiac; (2) Agata and Monalisa; (3) Spirit. The physical and chemical
474 properties of three group cultivars were notable different, which determined the aptitude of the
475 potato cultivars on being processing. The group 1and group 3 cultivars were suitable for frying
476 which was due to the higher hardness, dry matter and the lower reducing sugar content, while
477 group 2 cultivars were fit for boiling and baking because of the higher value of springiness,
478 cohesiveness and chewiness, and the cultivars without peeling increased the antioxidant
479 properties. These properties analysis and the groups may explain and reinforce the cooking type
480 of the cultivars proposed by the European Cultivated Potato database.

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484

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