



Evaluation of Genetic Diversity of *Solanum tuberosum* L. Cultivars by the Physiological and Biochemical Characteristics under Postharvest Conditions

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Abstract

Postharvest storage of potatoes may result in compositional and textural changes, which may differ among different genotypes. These changes have been less documented in the literature. Ten potato cultivars (“Picasso”, “Red Scarlet”, “Sifra”, “Challenger”, “Sante”, “Banba”, “Arinda”, “Agria”, “Fontane”, and “Innovator”) were evaluated in pre- and post-harvest experiments. In the pre-harvest experiment, tuber number, diameter, and fresh weight of the plants were evaluated. Later, the traits were evaluated in three stages, including at harvest time and 90 and 180 days after harvest during storage. Fresh weight, dry weight, volume weight, firmness, TSS and carbohydrates, phenolic and vitamin C content, antioxidant activity, beta-carotene content, POX activity, and protein and starch content of the tubers were assessed. All the traits were significantly different among cultivars at both pre-harvest and post-harvest stages. “Red Scarlet”, “Challenger”, and “Innovator” are suitable cultivars for fresh consumption, and some including “Picasso”, “Sante” and “Banba” are appropriate for processing such as chips production. It was also found that some cultivars, e.g., “Challenger” and “Sante”, had longer shelf-life and acceptable marketability after six months of storage.

Resumen

El almacenamiento poscosecha de las papas pudiera resultar en cambios en la composición y la textura, que pueden variar entre los diferentes genotipos. Estos cambios han sido menos documentados en la literatura. Diez variedades de papa (“Picasso”, “Red Scarlet”, “Sifra”, “Challenger”, “Sante”, “Banba”, “Arinda”, “Agria”, “Fontane” e “Innovator”) se evaluaron en experimentos previos y posteriores a la cosecha. En el experimento previo a la cosecha, se evaluó el número de tubérculos, el diámetro y el peso fresco de las plantas. Más tarde, los rasgos se evaluaron en tres etapas, incluso en el momento de la cosecha y 90 y 180 días después de la cosecha durante el almacenamiento. Se evaluaron el peso fresco, el peso seco, el peso volumen, la firmeza, el TSS y los carbohidratos, el contenido fenólico y de vitamina C, la actividad antioxidante, el contenido de betacaroteno, la actividad POX y el contenido de proteínas y almidón de los tubérculos. Todos los rasgos fueron significativamente diferentes entre los cultivares tanto en las etapas previas a la cosecha como después de la cosecha. “Red Scarlet”, “Challenger” e “Innovator” son variedades adecuadas para el consumo fresco, y algunas como “Picasso”, “Sante” y “Banba” son apropiadas para el procesamiento, como la producción de chips. También se encontró que algunas variedades, como “Challenger” y “Sante”, tenían mayor vida de anaquel y comerciabilidad aceptable después de seis meses de almacenamiento.

Keywords Potato · POX activity · Starch · Beta-carotene · Processing · Storage

Introduction

Potato (*Solanum tuberosum* L.), which belongs to the Solanaceae family, is the fourth important food crop in the world. Potatoes can be grown in a variety of environments so that they are currently produced in more than 100 countries (Barker and Pilbeam 2015). There are many potato

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cultivars in the world. Potatoes are genetically very diverse and can be classified by several attributes, such as the morphology and quality of tubers. The yield and quality of potato tubers are stabilized at the pre-harvest stage in the field and should be preserved at the post-harvest period until consumption. Factors affecting tuber maturity, i.e., genotype and climatic conditions, have a great effect on the tuber yield and quality (Alamar et al. 2017). It has been reported that 31%, 30%, and 12% of potatoes are used as fresh, fried, and chips, respectively (Miranda and Aguilera 2006). Naturally, fresh crops require low temperatures and high relative humidity during storage and transportation for the preservation of their quality. Potatoes are semi-perishable crops but can be stored in controlled conditions at 3–4 °C for about 6 months. However, the decreased quality of potato tubers, including the loss of their firmness and softness incidence, has been reported as a result of some physiological and biochemical reactions (Gupta et al. 2015).

Nemš and Peška (2018) reported that there were changes in the potential antioxidant activity during three months of potato storage and that the activity depended on the storage period and potato variety. Several factors, such as culture methods, genetic differences, growth stage, and post-harvest storage conditions, were reported to affect total phenolics and vitamin C content, as well as antioxidant activity in plants. The amount of water loss of potato tubers during storage is proportional to the difference between water vapor pressure in potato skin cells and air vapor pressure. Evaporation does not occur when the pressure in the skin cells of tubers and that of the air vapor around them are the same, which occurs when the relative humidity of the air is 97.8% (Kibar 2012). The amount of vitamin C was reportedly in the range of about 0.29–1.18 g/kg in different potato cultivars during storage, while it reached 0.22–0.69 g/kg after storage (Tamasi et al. 2015).

Starch is the main dry matter component in potato tubers, making up about 70% of their total solids. Some storage conditions can lead to the conversion of starch into sugar and cause the accumulation of other types of sugars including glucose, fructose, and sucrose (Rose et al. 1991).

The present experiment studied ten potato cultivars commonly cultivated by growers during storage to identify the best ones for different uses such as fresh consumption and chips production and to determine the diversity between the cultivars and correlation among the evaluated traits. The findings would trigger and accelerate future experiments on postharvest genetic diversity and related breeding programs of potatoes.

Material and Methods

In this experiment, ten potato cultivars (“Picasso”, “Red Scarlet”, “Sifra”, “Challenger”, “Sante”, “Banba”, “Arinda”, “Agria”, “Fontane”, and “Innovator”) were studied and evaluated in two pre-harvest and post-harvest experiments (Table 1). The research farm was located at the University of Maragheh (37.3892°N, 46.2534°E, and 1290 m above sea level). Field preparations were carried out in early autumn using deep plowing, disking, and leveling the field. In late April, ridges and furrows measuring 0.6 × 9 m were created. The required nutrients were added based on the results of a soil analysis test (Table 2). The tubers were placed at a depth of 10 cm at the top of the ridges at a distance of 35 cm from each other. Drip irrigation was done evenly and usually once every three to five days. Weeds were controlled manually in two stages during the growing season, first when the plants had three or four leaves and second almost one month later. Also, to prevent and fight fungal diseases, the plants were sprayed twice using benomyl and ridomil-MZ 58WP fungicides. The results of soil analysis are presented in Table 1.

Table 1 Some characteristics of the ten evaluated cultivars including the traits related to shape, skin, eye, sprout, and resistance to bruising of tubers (Van Diepen 2011)

Cultivars	Shape	Skin	Eyes or sprouts	Resistance to internal bruising
Picasso	very large, oval, uniform in shape	yellow skin	red eyes, rather shallow eyes	fairly good
Red Scarlet	large, oval to long oval, uniform in shape	red skin	shallow eyes	good
Sifra	large, round-oval, uniform in shape	yellow skin	rather shallow eyes	good
Challenger	large, oval to long oval, uniform in shape	yellow skin	shallow eyes	fairly good
Sante	large, oval round-oval, uniform in shape	yellow skin	rather shallow eyes	good
Banba	large, long-oval, uniform in shape	yellow skin	shallow eyes	good
Arinda	large, long-oval, very uniform in shape	yellow skin	shallow eyes	fairly good
Agria	large, long-oval, uniform in shape	yellow skin	shallow eyes	good
Fontane	large, oval, uniform in shape	yellow skin	rather shallow eyes	good
Innovator	large, long-oval, very uniform in shape	reddish brown skin	shallow eyes	fairly good

Table 2 Some physical and chemical characteristics of soil

Depth (cm)	acidity	EC (ds/m)	OC%	P (ppm)	K (ppm)	Clay (%)	Silt (%)	Sand (%)	Soil tissue
0–30	8.08	0.688	0.41	7.61	220	10.20	29.88	59.82	Sandy loam

After harvest, the tubers were counted, graded, and isolated for every cultivar. Then, the tubers were packaged and stored at 4 °C and 70–80% relative humidity. Traits were measured in three stages, including at harvest time and three months (90 days) and six months (180 days) after storage.

Morphological Traits

Tuber diameters were measured using a digital caliper, and the average diameter was recorded for each cultivar. Tuber yield was estimated by calculating their fresh weight per plant. Two tubers were randomly selected and placed in a beaker with a certain amount of water. The weight of the initial beaker was recorded with water (W1), and its weight was recorded again after the tubers were placed (W2). Finally, the volumetric weight was determined as the difference between W1 and W2. It was repeated four times for each cultivar. In other words, eight tubers were used to measure volumetric weight. The firmness of the tuber flesh was measured using a penetrometer (LUTRON FR-5120) with a 3-mm probe. Firmness was determined at nearly the same position on each tuber. No tests were made at spots close to the eyes. Prior to testing, a section of the skin was eliminated at the spot of testing on each tuber. Three readings per tuber were done. Eight tubers were selected for each replication, and the mean was calculated and stated in newtons per square centimeter ($N.cm^{-2}$).

Tuber fresh weight (g) was measured on tubers randomly selected and labeled as at harvest time, 90 days after storage, and 180 days of storage. The tubers were oven-dried at 70 °C for 48 h and then, the dried tubers were weighed to calculate the dry weight percentage.

Biochemical Traits

Total Soluble Solids

Total soluble solids (TSS) were measured with a digital refractometer (USA Inc. Kirkland, designated ATAGO PR-32) and expressed in degrees Brix.

Total Protein Content

Total protein content was measured by Bradford's (1976) procedure for which 0.5 g of tubers was grounded in liquid nitrogen and homogenized in 1.5 mL of 50 mM Na buffer phosphate (pH:7.8), including 1 mM of EDTA and 2% (w/v) polyvinylpyrrolidone (PVPP). The homogenate was

centrifuged at 10,000 rpm at 4 °C for 15 min. Supernatants were used for total soluble protein and peroxidase enzyme activity (POX). Finally, 1000 μ L of the Bradford reagent was added to 50 μ L of protein buffer phosphate samples, incubated for 5 min, and the absorbance was then read at 595 nm with a spectrophotometer (model 100, Cary, Richmond, VA).

Peroxidase Activity

POX activity was measured by the method of Mencarelli et al. (1995) for which 1000 μ L of 100 mM phosphate buffer at pH 7, 250 μ L of 0.1 mM EDTA, 1000 μ L of 15 mM hydrogen peroxide, 1000 μ L of 5 mM guaiacol, and 50 μ L of the enzyme extract were mixed. The absorbance was recorded at 470 nm for 180 s. The specific activity of this enzyme was calculated based on the UA. mg protein.

Total Carbohydrates Content

To Measure total carbohydrate content, 0.2 g of tubers was heated with 10 ml of 95% ethanol in a water bath at 80 °C. Then, 1 ml of 0.5% phenol and 5 ml of 98% sulfuric acid were added to 1 ml of the heated sample. The absorbance was read at 483 nm (Schlegel 1956). Total carbohydrate concentrations were calculated in mg. g^{-1} fresh weight (Schlegel 1956).

Starch Extraction

The residues from the carbohydrate assay were used and 5 ml of distilled water was added to it, which was then followed by adding 6.5 ml of 52% per-chloric acid. The samples were kept in a refrigerator for 20 min and then filtered through Whatman filter paper #1, washed 3 times with per-chloric acid (3.5 ml), and made up to 50 ml with distilled water. Next, 1 ml of 5% phenol was added to 2 ml of the prepared extract. Then, 5 ml of 98% sulfuric acid was added and kept constant until the stabilization of their color. The starch content was read at 485 nm (Rose et al. 1991).

Vitamin C Measurement

To measure vitamin C content, 1 g of the tuber was extracted with 3 ml of 1% metaphosphoric acid and centrifuged at 6000 rpm at 4 °C for 15 min. Then, 200 μ L of the extract was mixed with 1800 μ L of 2,6-dichlorophenolindophenol

(DCIP) and read at 520 nm and vitamin C content was calculated in mg. g⁻¹ FW (Bor et al. 2006).

Total Antioxidants Activity

The antioxidants activity content was determined by 2,2-diphenyl-picryl hydrazyl (DPPH). So, 1 g of the tuber was extracted with 2 ml of 80% methanol and centrifuged at 15,000 rpm for 15 min. Then, 100 µl of the extract was mixed with 1900 µl of 0.1 M DPPH and after 30 min, the absorbance was read at 517 nm (Chiou et al. 2007). The percentage of DPPH scavenging activity was calculated as follows: $[1 - (\text{absorbance of sample} / \text{absorbance of blank})] \times 100$.

Total Phenol Content

To determine total phenol content, 20 µl of the methanolic extract, 1.59 ml of distilled water, 100 µl of 10% Folin-Ciocalteu, and 300 µl of 7.5% sodium carbonate were added to the solution, which was kept in the dark at room temperature for 2 h. The absorbance was read at 765 nm (Singleton and Rossi 1965).

Beta-Carotene Content

One gram of the fresh tuber was crushed for 2 min and mixed with 5 ml of acetone. Then, the extracts were centrifuged for 10 min, the supernatant was separated, and the above steps were performed again on the residue. The supernatants of the above two steps were mixed, and then beta-carotene content was measured by reading the absorbance at 449 nm (Biehler et al. 2010).

Statistical Analysis

The experiment was arranged as a factorial study based on a completely randomized design with three replicates. The cultivar was the first factor and the storage time was considered the second factor. Data were subjected to ANOVA in a general linear method (GLM) using the MSTATC software (ver. 2.10 Michigan University). Correlation analysis, principal component analysis, and cluster analysis were done by the SPSS (ver. 23) and Minitab (ver. 17) software packages.

Results

Morphological Traits

ANOVA results showed that the effect of cultivars was significant at $p \leq 0.01$ on tuber diameter, number, and yield (Table 3). Also, the interactions between cultivar and storage were significant for all of the postharvest evaluated

Table 3 The ANOVA analysis of some pre-harvest characteristics of potato cultivars

Mean Square				
Source of variation	df	Tuber diameter	Tuber number	Tuber yield
Block	2	0.416 ^{ns}	0.700 ^{ns}	15.329 ^{ns}
Genotype	9	40.295 ^{**}	116.152 ^{**}	2781.156 ^{**}
Error	18	4.893	2.107	67.589
C.V. (%)		4.13	10.30	14.49

ns, ** significant at $p \leq 0.01$

traits (Tables 4, 5, 6). There was a significant difference between potato cultivars at $P \leq 0.01$. The highest tuber diameter belonged to “Innovator” (62.94 mm) (Fig. 1a). The highest and lowest number of tubers per plant were observed in “Sifra” (28), “Red Scarlet” (7), and “Banba” (8), respectively (Fig. 1b). The highest and the lowest tuber yields were obtained from “Sifra” (2571 g. plant⁻¹) and “Banba” (579.5 g. plant⁻¹), respectively, with different yields recorded by “Red Scarlet” (644.2 g. plant⁻¹), “Fontane” (722.1 g. plant⁻¹), and “Challenger” (740.3 g. plant⁻¹) (Fig. 1c).

The results of ANOVA showed that the effect of cultivar was significant at $p \leq 0.01$ on tuber fresh weight, tuber dry weight, volume weight, tuber firmness, and TSS (Table 4). The fresh weight of the tubers decreased significantly versus the control during 6 months of storage. The highest fresh weight belonged to “Arinda” (113.2 g) in the control and the lowest was measured in “Picasso” (23.60 g), “Arinda” (27.45 g), “Fontane” (27.55 g), and “Agria” (28.20 g) cultivars. The results also revealed that the lowest and the highest decreases in tuber fresh weight occurred in “Banba” (36%) and “Arinda” (75%) during storage, respectively (Fig. 1a). Tuber dry weight increased significantly compared to the control during storage. The highest tuber dry weights were observed in the third time of “Banba” (28.98) and “Picasso” (27.98) and the lowest in the first time in “Arinda” (14.92). “Arinda” (60%) and “Innovator” (14%) presented the highest and the lowest increments of tuber dry weight compared to the control, respectively (Fig. 2b).

The results revealed a significant decline in the volume weight compared to the control in most cultivars during storage for 180 days. The highest values of the volume weight were observed in “Sifra” (95.38 g), and “Banba” (92.73 g) in the control, and the lowest belonged to the third time of “Innovator” (46.63 g). In addition, the highest and the lowest diminution of tuber volume weight were observed in “Innovator” (31%) and “Arinda” (6%) compared to control, respectively (Fig. 3c).

After 180 days of storage, the firmness of all cultivars decreased significantly compared to the first time or to the

Table 4 The ANOVA analysis of some post-harvest characteristics of potato cultivars

	df	Mean Square				
		Tuber fresh weight	Tuber dry weight	Volume weight	Tuber firmness	TSS
Genotype	9	795.737**	49.870**	1145.182**	20.226**	3.904**
Time	2	20,712.359**	240.164**	1008.104**	119.809**	36.236**
Genotype × Time	18	366.026**	7.697**	51.497**	3.653**	0.495**
Error	60	92.880	2.915	19.920	0.776	0.166
C.V. (%)		17.60	7.55	6.03	5.26	10.22

**significant at $p \leq 0.01$

Table 5 The ANOVA analysis of some post-harvest biochemical parameters of potato cultivars

	df	Mean Square			
		Carbohydrate	Phenol	Vitamin C	Antioxidant activity
Genotype	9	2.850**	5600.854**	432.499**	499.353**
Time	2	73.548**	732,099.892**	28,504.299**	8746.390**
Genotype × Time	18	1.059**	5232.667**	166.126**	241.023**
Error	60	0.360	981.154	39.613	24.208
C.V. (%)		17.09	12.98	15.50	17.74

**significant at $p \leq 0.01$

Table 6 The ANOVA analysis of some post-harvest biochemical parameters of potato cultivars

	df	Mean Square			
		Beta-Carotene	POX activity	Protein	Starch
Genotype	9	0.591**	0023**	0.016**	0.041**
Time	2	4.168**	0.162**	0.367**	0.093**
Genotype × Time	18	0.345**	0.007**	0.004**	0.018**
Error	60	0.019	0.001	0.001	0.003
C.V. (%)		39.37	23.16	18.96	1.88

**significant at $p \leq 0.01$

control. The highest and the lowest amounts of firmness were observed in the control of “Challenger” (20.36 N. cm^{-2}) and “Arinda” (10.94 N. cm^{-2}) after 180 days of storage, respectively. The highest and lowest reductions in firmness during storage were noticed in “Arinda” (up to 41%) and “Innovator” (up to 11%), respectively (Fig. 3a).

Biochemical Traits

TSS increased in cultivars during storage compared to the harvest time. After 180 days, the highest and lowest TSS values were recorded in “Banba” (6.073 Brix) and in the control of “Red Scarlet” (1.950 Brix), respectively. On the other hand, “Agria” and “Arinda” showed the highest and lowest increments of up to 119% and 21% during 180 days of storage, respectively (Fig. 3b).

The amount of total carbohydrates increased during storage. It was significantly different among the cultivars, indicating that the increase rate was completely genotype-dependent. The highest and lowest total carbohydrate contents were observed in “Innovator” (6.93 mg. g^{-1} FW) and the control of “Picasso” (1.670 mg. g^{-1} FW), “Sifra” (1.830 mg. g^{-1} FW), “Challenger” (1.873 mg. g^{-1} FW), and “Banba” (1.960 mg. g^{-1} FW) after 180 days, respectively. “Innovator” and “Fontane” displayed the highest and the lowest increments of 213% and 71% versus the control, respectively (Fig. 3c).

Total phenol content was uppermost in the control of “Innovator” (534.3 mg gallic acid. 100 g^{-1} FW) and the lowest belonged to “Challenger” (77.59 mg gallic acid. 100 g^{-1} FW) after 180 days of storage. It was also observed that the total phenol content decreased significantly compared to the control during storage for 180 days, with “Challenger” and “Sifra” showing the highest and lowest reductions of up to 82% and 48% versus the control, respectively (Fig. 4a).

Based on the results, vitamin C content significantly decreased during 180 days of storage. The highest and lowest reductions occurred in “Sifra” (98%) and “Innovator” (74%) compared to the control, respectively. Besides, the highest content of vitamin C belonged to the control of “Fontane” (80.74 mg. g^{-1} FW), “Challenger” (78.65 mg. g^{-1} FW), “Innovator” (78.39 mg. g^{-1} FW), “Sifra” (76.78 mg. g^{-1} FW), and “Arinda” (76.66 mg. g^{-1} FW). On the other hand, “Sifra” (1.507 mg. g^{-1} FW), “Picasso” (1.710 mg. g^{-1} FW), “Arinda” (1.927 mg. g^{-1} FW), “Agria” (2.177 mg. g^{-1} FW), “Red Scarlet” (3.327 mg. g^{-1} FW), “Sante” (4.307 mg. g^{-1} FW), and “Fontane” (4.307 mg. g^{-1} FW) contained

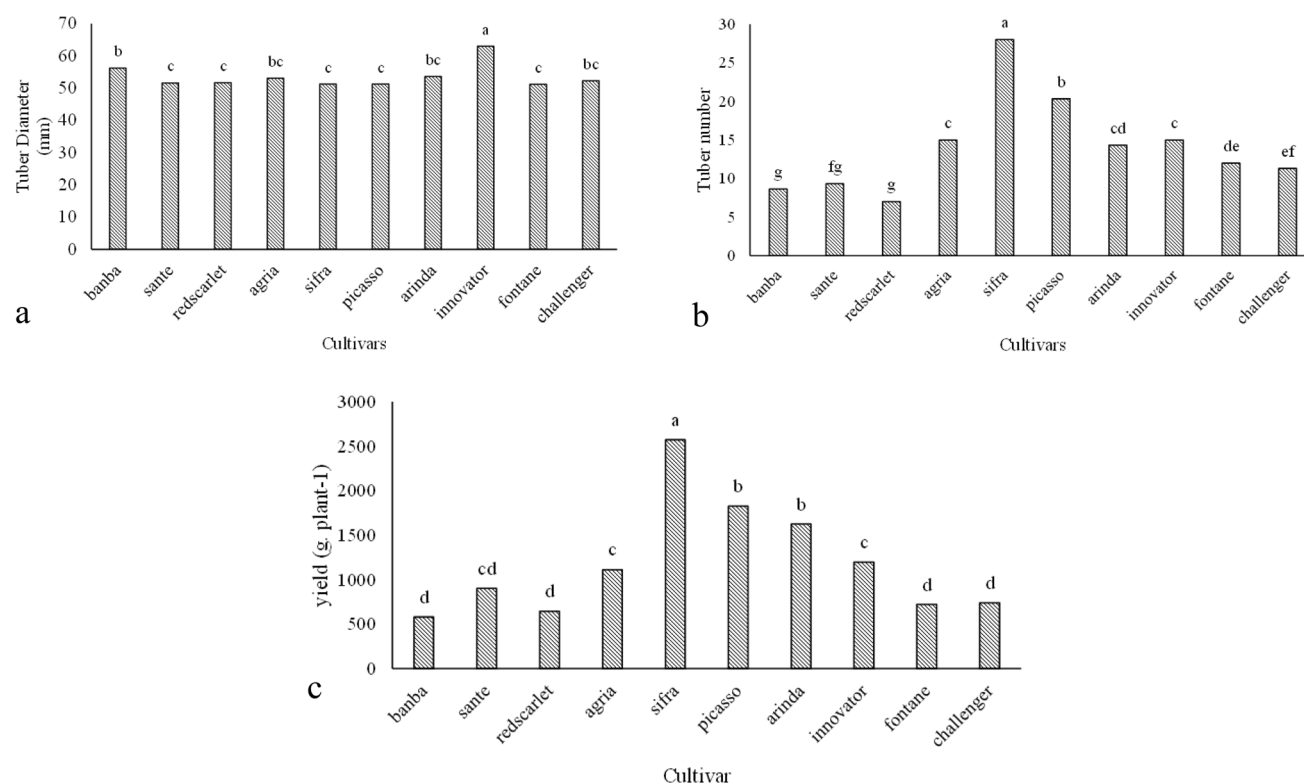


Fig. 1 The effects of cultivars on tuber diameter (mm) (a), tuber number (b), and yield (g. plant⁻¹) (c). Different letters are significantly different based on Duncan's multiple range test ($p \leq 0.05$)

the lowest amount of vitamin C after 180 days of storage (Fig. 4b).

Total antioxidant activity decreased significantly during 6 months of storage, with the highest levels observed in “Agria” (72.05%) and “Sante” (70.64%) and the lowest in “Challenger” (5.980%). The highest and lowest decreases belonged to “Agria” (83%) and “Red Scarlet” (45%) versus the control, respectively (Fig. 4c).

The results of ANOVA showed that the effect of cultivars was significant at $p \leq 0.01$ on beta-carotene, POX activity, protein, and starch content (Table 6). Beta-carotene content increased significantly in all cultivars, except for “Innovator” during 180 days of storage, with the highest and lowest increments observed in “Fontane” (15.61 times) and “Agria” (4.73) compared to the control, respectively. After 180 days of storage, beta-carotene content was the uppermost in “Fontane” (2.077 $\mu\text{g} \cdot \text{g}^{-1}$ FW) and the lowest in the control of “Innovator” (0.013 $\mu\text{g} \cdot \text{g}^{-1}$ FW) (Fig. 5a).

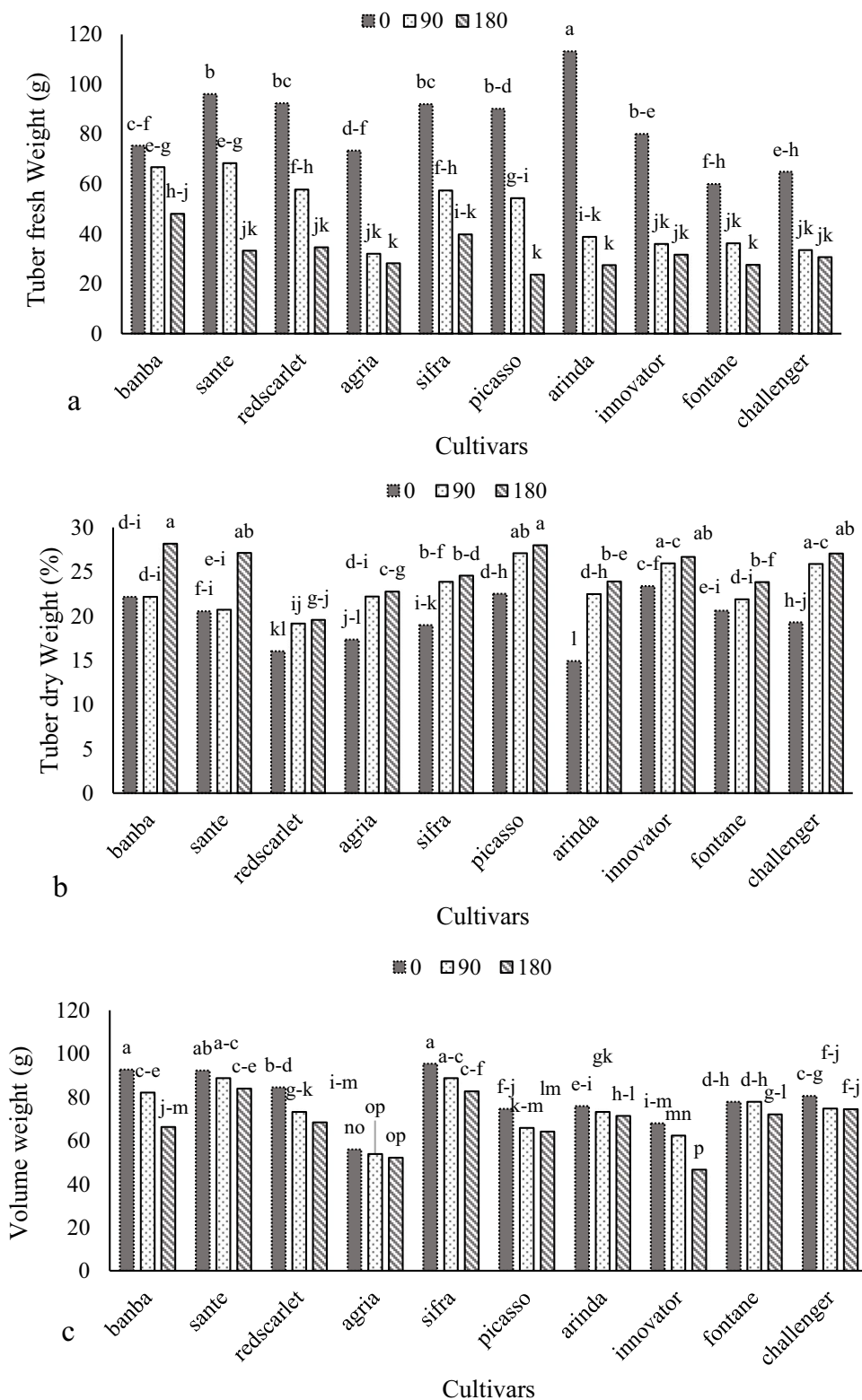
Based on the results, a significant increase was observed in POX activity in all cultivars, except for “Red Scarlet”, during 180 days of storage. After 180 days of storage, the highest and lowest POX activities were detected in “Arinda” (0.380 $\mu\text{mol} \cdot \text{Min}^{-1} \text{mg}$ FW) and the controls of

“Banba”, “Red Scarlet”, “Picasso”, “Arinda”, “Innovator”, and “Challenger”, respectively while the highest and lowest percentage increases were observed in “Arinda” by up to 7.6 times and “Red Scarlet” by up to 3.8 times compared to the control, respectively (Fig. 5b).

According to the results, the protein content of different potato cultivars decreased significantly compared to the control during the 6 months of storage. At the harvest time, “Agria” (0.386 $\text{mg} \cdot \text{g}^{-1}$ FW) contained the highest protein content and the lowest levels were observed in “Fontane” (0.013 $\text{mg} \cdot \text{g}^{-1}$ FW), “Picasso” (0.016 $\text{mg} \cdot \text{g}^{-1}$ FW), and “Sifra” (0.026 $\text{mg} \cdot \text{g}^{-1}$ FW) after 180 days of storage, while the highest and the lowest decreases belonged to “Fontane”, “Picasso”, and “Innovator” by up to 92 and 67%, respectively (Fig. 6a).

Starch content decreased in different potato cultivars with a significant difference compared to the control during 180 days of storage. The highest and lowest reductions were up to 16% and 0.3% observed in “Red Scarlet” and “Sifra”, respectively. The controls of “Banba” (28.9 $\text{mg} \cdot 100 \text{g}^{-1}$ FW) exhibited the highest starch content whereas the minimum level was observed in “Red Scarlet” (22.9 $\text{mg} \cdot 100 \text{g}^{-1}$ FW) after 180 days of storage (Fig. 6b).

Fig. 2 The effects of cultivars on tuber fresh weight (g) (a), tuber dry weight (%) (b), and volume weight (g) (c) at harvest time (0), 90 days after storage, and 180 days after storage. Different letters are significantly different based on Duncan’s multiple range test ($p \leq 0.05$)

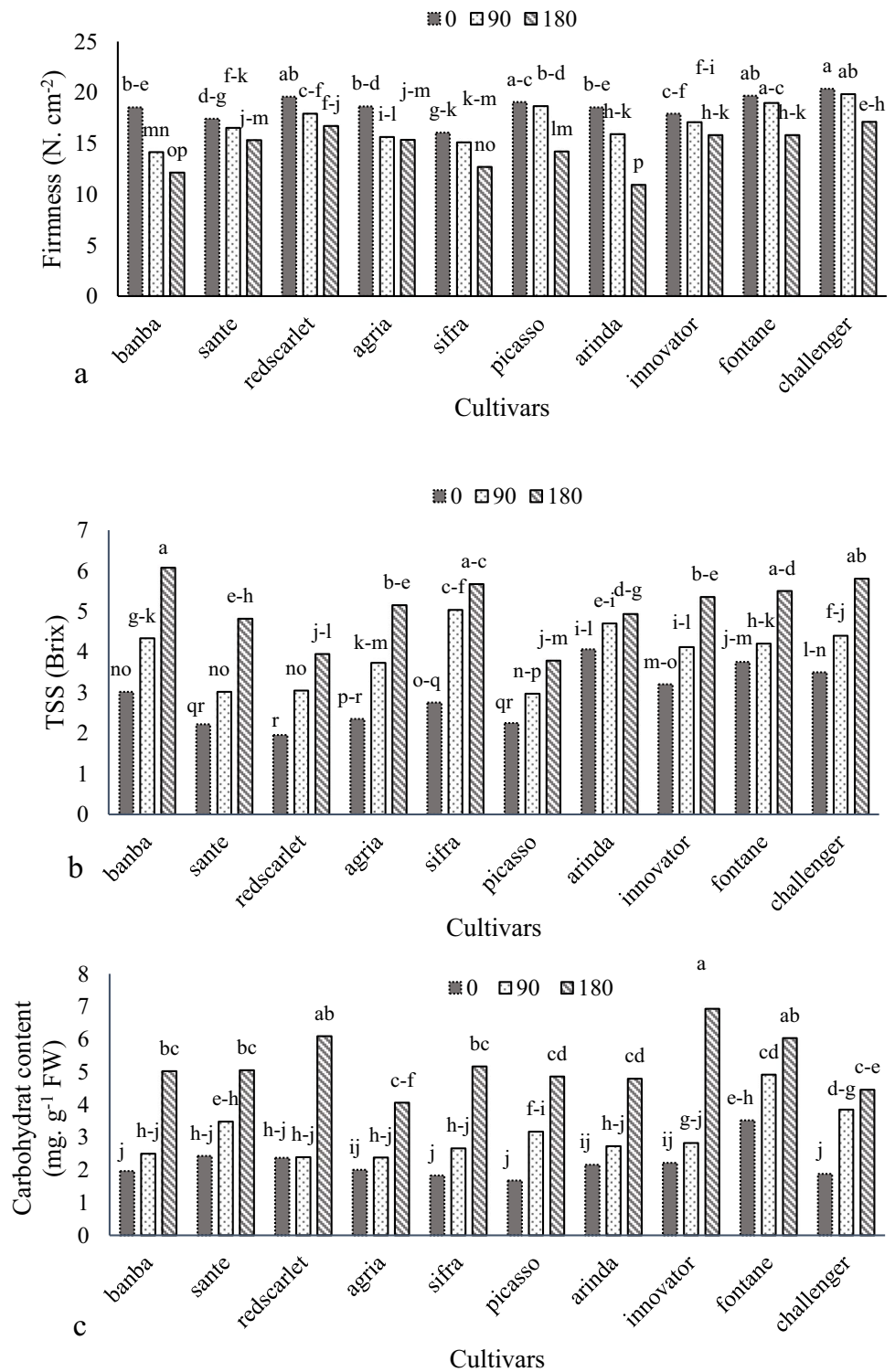


Correlations, Principal Components, and Cluster Analyses

Bivariate Pearson’s correlation analysis showed significant

positive and negative correlations among the assessed traits at the 5% and 1% probability levels. A high significant positive correlation was represented between tuber fresh weight with phenolics, vitamin C, antioxidant activity, and protein

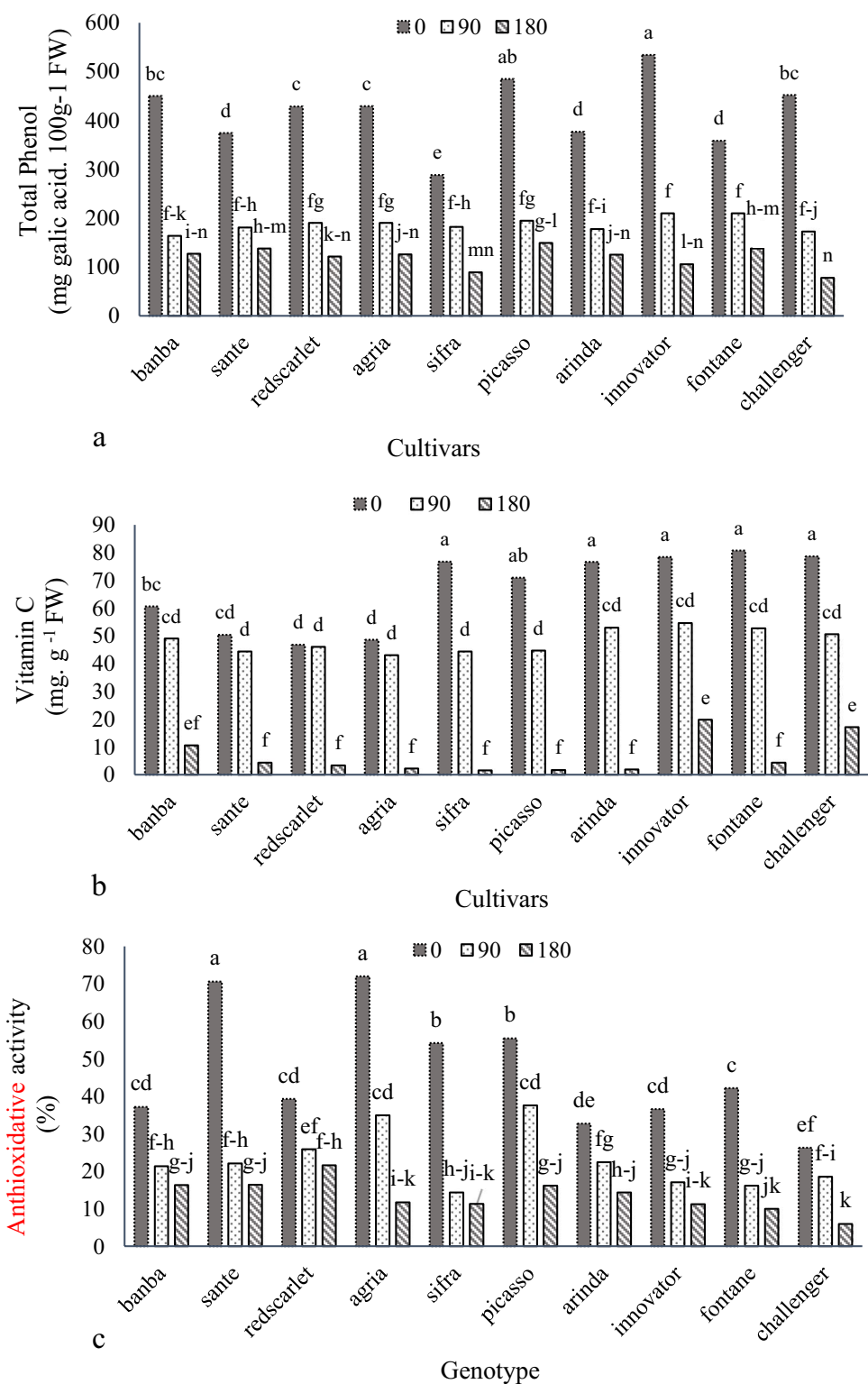
Fig. 3 The effects of cultivars on tuber firmness ($N. cm^{-2}$) (a), TSS (Brix) (b), and total carbohydrate content ($mg. g^{-1}$ FW) (c) at harvest time (0), 90 days after storage and 180 days after storage. Different letters are significantly different based on Duncan’s multiple range test ($p \leq 0.05$)



content while it was negatively correlated with TSS, carbohydrate, and POX activity. Moreover, firmness was positively correlated with carbohydrates, phenolics, and protein content. Similarly, TSS was positively correlated with carbohydrates and POX activity, while it was negatively correlated with phenolics, vitamin C, protein, and antioxidants activity.

In the same way, phenolics represented significant positive correlations with antioxidant activity and protein, while it was negatively correlated with POX activity. Moreover, vitamin C was correlated with phenolics, antioxidant activity, and protein content positively and with carbohydrates, beta-carotene, and POX activity negatively, while proteins

Fig. 4 The effects of cultivars on total phenol (mg gallic acid. 100 g⁻¹ FW) (a), Vitamin C (mg. g⁻¹ FW) (b), and total antioxidant activity (%) (c) at harvest time (0), 90 days after storage and 180 days after storage. Different letters are significantly different based on Duncan’s multiple range test (p≤0.05)

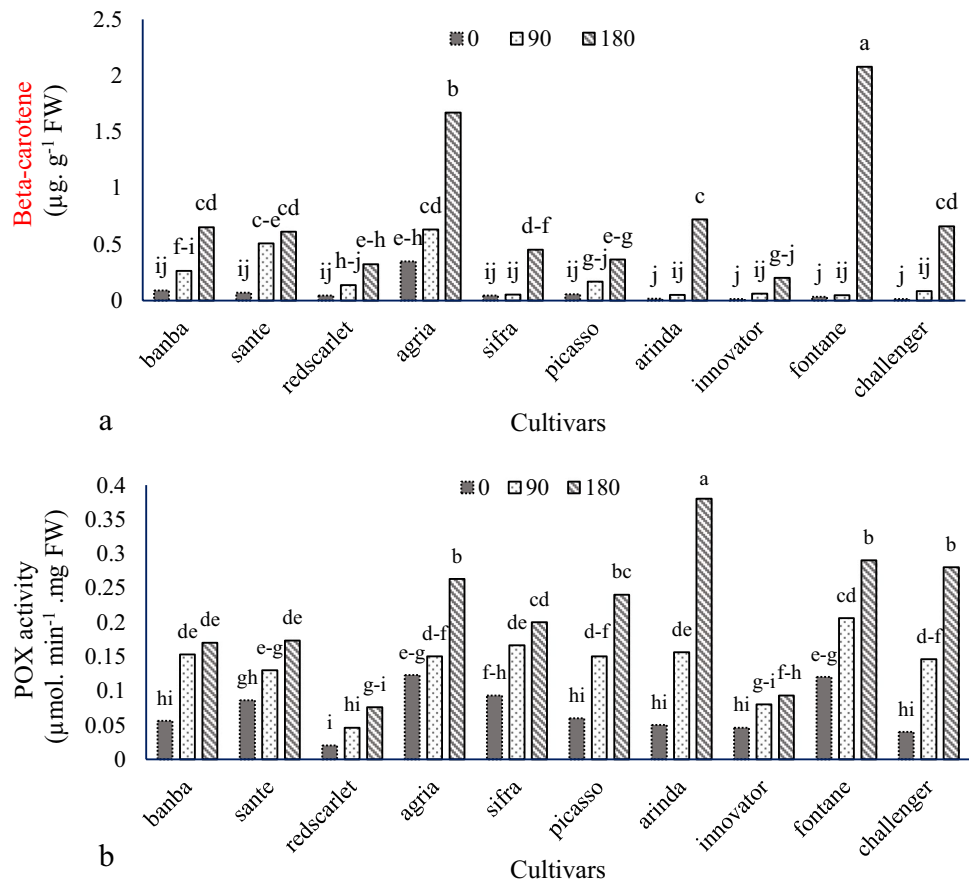


and POX activity had a significant positive correlation with each other (Table 7).

The principal component analysis (PCA) tries to disclose the pattern of variations among the measured morphological and biochemical traits and to record a more applicable

understanding of the value of each characteristic in accounting for the variations. In this study, among 13 principal components (PC), three PCs captured 71.48% of the total variance (Table 8). PC1 was the principal and most efficient component, responsible for nearly 54.49% of the exploited

Fig. 5 The effects of cultivars on Beta-carotene content ($\mu\text{g. g}^{-1}$ FW) (a), POX activity ($\mu\text{mol. Min}^{-1}\text{mg FW}$) (b) at harvest time (0), 90 days after storage and 180 days after storage. Different letters are significantly different based on Duncan's multiple range test ($p \leq 0.05$)



total variance. In PC1, tuber fresh weight, firmness, phenolics, vitamin C, and antioxidant activity were noticeable and the most effective variables or traits that played the major role in the observed variations in the cultivars during storage. Nevertheless, PC2 and PC3 explained 9.18% and 7.80% of the total variance, respectively. Volume weight had the main role in PC2, and starch played a major role in PC3 (Tables 8 and 9).

The loading plot of the investigated traits along with PCA revealed that the correlated characteristics were located on the plot with close distances (Fig. 7). The correlations were also shown in Pearson's correlation.

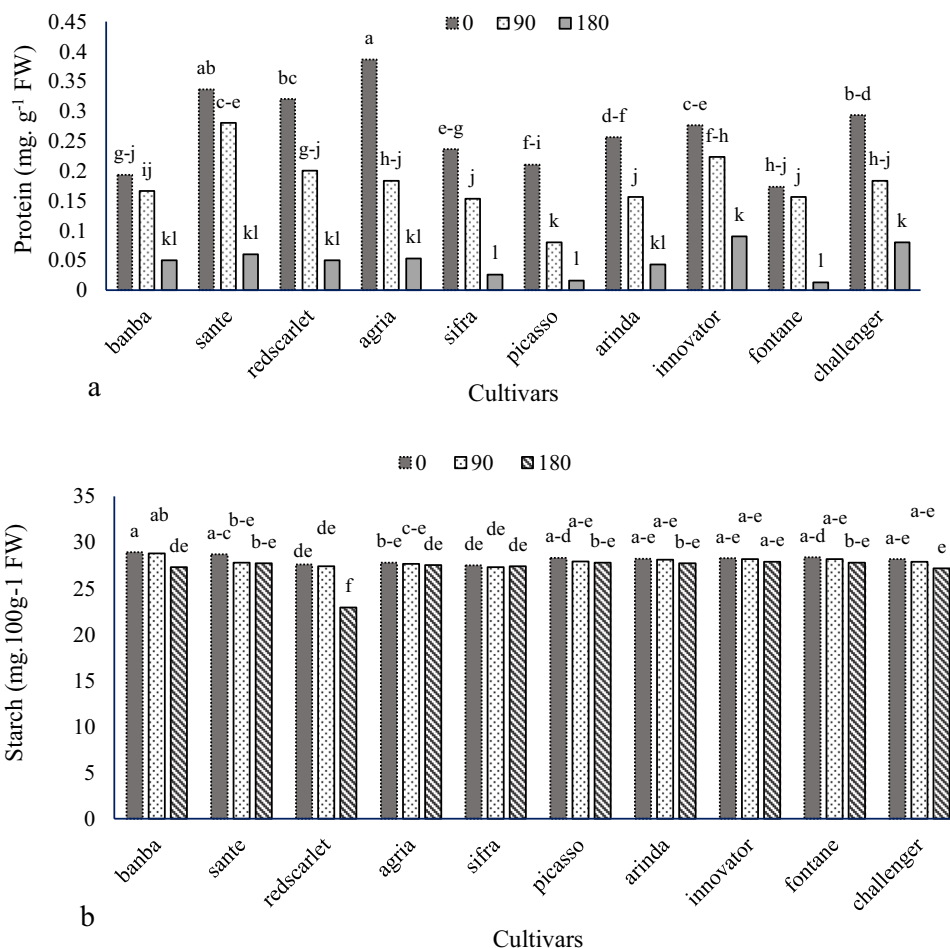
Discussion

The results revealed significant differences among the studied cultivars based on the evaluated morphological and biochemical traits. The differences could be used in breeding programs and environmental control of storage. The difference in the number of tubers depends on the differences among genotypes, canopy development, environmental conditions, and management practices (Eaton et al. 2017). Tessema et al. (2020) reported that the environment and genetic diversity affected tuber weight. According to

Gebreselassie et al. (2016) in Eastern Ethiopia, potato cultivars and the environment had a high effect on the tuber weight. In a 6–8-month storage period, 10% and about 90% of the total weight loss were due to respiration and water loss, respectively. Therefore, it can be assumed that water evaporation is the main reason for weight loss recorded in our study. Variances in weight loss between cultivars may be due to different genotypes (Arifa et al. 2018). Differences in the yield between cultivars may be related to genetics, tuber seed quality, and better adaptation of cultivars to the climatic conditions (Eaton et al. 2017).

Due to the relationship between changes in dry matter and respiration rate, as well as water loss during storage, dry matter is a crucial factor in stored fruits and vegetables so that its changes differ among crops and even among different cultivars of a crop. Similarly, a study on the difference in dry matter of diverse banana cultivars and in different periods revealed that the high dry matter might be described as a reason for the longer shelf life and better fruit quality (Hailu et al. 2014). In our research, the dry matter increased in all cultivars after 3 and 6 months, but the enhancement was significantly different among the cultivars. Ozturk and Polat (2016) stated that changes in dry matter in different potato cultivars were not uniform at the end of storage so that the dry matter of “Marfona”, “Tuscan”, “Binella”, “Granola”,

Fig. 6 The effects of cultivars on protein content (mg. g⁻¹ FW) (a), starch content (mg. 100 g⁻¹ FW) (b) at harvest time (0), 90 days after storage (90) and 180 days after storage (180). Different letters are significantly different based on Duncan’s multiple range test (p ≤ 0.05)



and “Natascha” declined, but that of “Banba” and “Aslani” increased.

Water loss during storage is a major attribute that differs among cultivars remarkably (Hailu et al. 2014). Kibar (2012) reported that the increase in dry weight through water loss due to evapotranspiration was greater than respiration during storage. It was found that dry weight and its components increased relatively during the storage period.

Volumetric weight is different among cultivars of crops due to the differences in both biochemical compositions and the amount of moisture reduction during storage. Tuber density reduction due to moisture loss during storage and weight loss were reported in various cultivars (Ghafir et al. 2009). Genotype differences were observed in weight loss during postharvest storage of plums (Salazar et al. 2020).

One of the most important post-harvest characteristics of crops is the firmness of the edible parts. Pectin degradation due to enzymatic and non-enzymatic reactions, degradation of cell wall polysaccharides due to hydroxyl radicals, and loss of moisture during ripening reduce the strength of fruit tissue (Cardenas-Perez et al. 2017). Reduced turgor of tissue cells, cell wall destruction, weakened intercellular cohesive force, and the reduced amount of starch play key

roles in softening the fruit tissue and in the decline of firmness (Galani et al. 2017). Fruit softening showed significant differences between genotypes, revealing diversities in the shelf-life among siblings (Salazar et al. 2020). The highest firmness was related to longer postharvest and shelf-life capacity in melon genotypes (Faruh et al. 2020). We observed similar differences among potato cultivars.

One of the important indicators of crop quality is TSS. The increase in TSS during storage may be related to the rapid hydrolysis of starch to simple sugars (fructose, glucose, and sucrose). However, differences in the amount of TSS can also be ascribed to maturity, cultivar, and long storage periods (Adu-Kwarteng et al. 2014). Reasons for the increase in TSS include an increase or decrease in substances such as acids, soluble pectin, and phenolic compounds (Ghasemnezhad and Shiri 2010). The present results are consistent with the studies of Kvikliene et al. (2006) and Echeverria et al. (2002). The total carbohydrate content of all potato cultivars increased in cold storage, which may lead to starch hydrolysis into soluble carbohydrates at low temperatures and play an important role in sweetening potatoes (Karim et al., 2008). The results are consistent with the research of Karim et al. (2008) on potatoes.

Table 7 Pearson correlation among studied traits of potato cultivars at harvest time, 90 days, and 180 days after storage

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13
Tuber FW	1												
Tuber DW	-0.610**	1											
Volume weight	0.453**	-0.266*	1										
TSS	-0.637**	0.527**	-0.237*	1									
Firmness	0.421**	-0.384**	0.117	-0.580**	1								
Vitamin C	0.666**	-0.476**	0.303*	-0.585**	0.642**	1							
Carbohydrate	-0.629**	0.511**	-0.283**	0.630**	-0.407**	-0.741**	1						
Phenol	0.735**	-0.519**	0.240*	-0.702**	0.610**	0.739**	-0.671**	1					
Beta-carotene	-0.478**	0.221*	-0.285**	0.488**	-0.406**	-0.636**	0.442**	-0.452**	1				
Antioxidant activity	0.695**	-0.499**	0.182	-0.765**	0.416**	0.565**	-0.612**	0.707**	-0.379**	1			
Protein	0.693**	-0.627**	0.236*	-0.702**	0.568**	0.736**	-0.730**	0.731**	-0.516**	0.687**	1		
POX activity	-0.625**	0.444**	-0.189	0.576**	-0.588**	-0.637**	0.466**	-0.636**	0.632**	-0.484**	-0.641**	1	
Starch	0.260*	0.053	0.164	-0.163	0.165	0.420**	-0.403**	0.355**	-0.125	0.199	0.299**	-0.039	1

**, * Correlation is significant at the 0.01 and 0.05 level (2-tailed), respectively. Y1: tuber fresh weight, Y2: tuber dry weight, Y3: volume weight, Y4: TSS, Y5: firmness, Y6: vitamin C, Y7: carbohydrate, Y8: phenol, Y9: Beta-carotene, Y10: antioxidant activity, Y11: protein, Y12: POX activity, Y13: Starch

Table 8 Total Variance Explained

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	7.084	54.491	54.491
2	1.194	9.182	63.673
3	1.015	7.809	71.482
4	0.958	7.371	78.853
5	0.607	4.666	83.519
6	0.526	4.045	87.564
7	0.416	3.199	90.763
8	0.275	2.115	92.878
9	0.255	1.960	94.838
10	0.212	1.630	96.468
11	0.186	1.434	97.902
12	0.156	1.198	99.100
13	0.117	0.900	100.000

Extraction Method: Principal Component Analysis

Table 9 Rotated Component Matrix

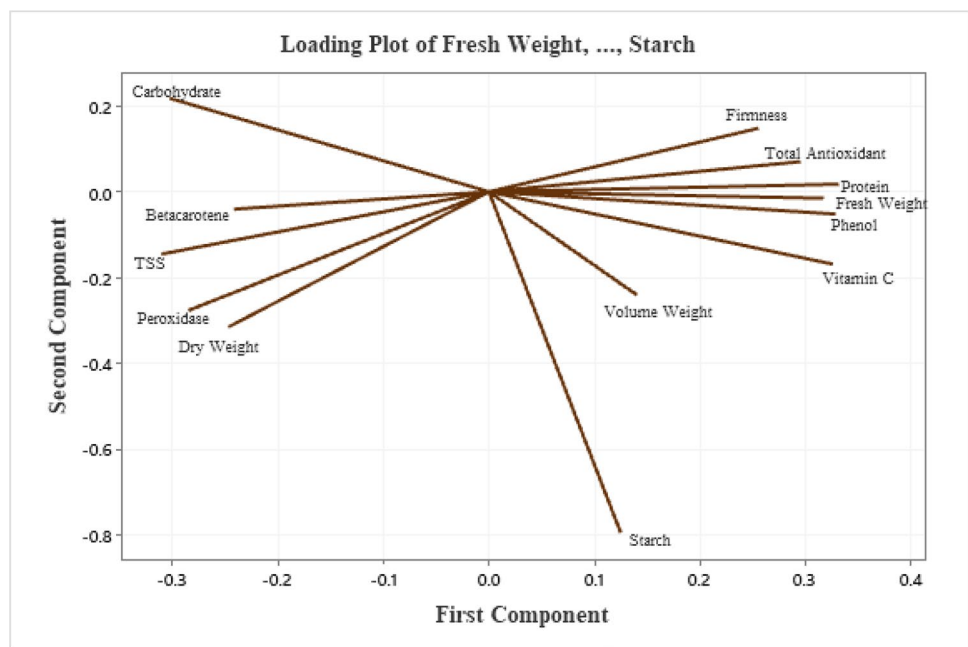
	Principal Components		
	1	2	3
Tuber FW	0.665	0.582	0.113
Tuber DW	-0.569	-0.526	0.286
Volume weight	0.028	0.846	0.146
TSS	-0.798	-0.263	-0.018
Firmness	0.784	-0.116	0.072
Vitamin C	0.785	0.215	0.384
Carbohydrate	-0.651	-0.374	-0.377
Phenol	0.807	0.249	0.251
Beta-carotene	-0.641	-0.104	-0.119
Antioxidant activity	0.717	0.326	0.072
Protein	0.817	0.293	0.166
POX activity	-0.825	-0.081	0.096
Starch	0.127	0.085	0.940

Extraction Method: Principal Component Analysis

Rotation Method: Varimax with Kaiser Normalization

ANOVA showed that cultivars affected total carbohydrate content, total phenol, vitamin C, and total antioxidant activity significantly at $p \leq 0.01$ (Table 5). The decrease in phenolic compounds during storage may be due to the presence of these compounds in the metabolism or as a result of enzymatic and non-enzymatic reactions during storage. The decrease in total phenols is probably due to the enzymatic oxidation of phenolic compounds during storage. Enzymatic reactions during storage reduce the amount of total phenol (Khademi and Ershadi 2013). The key enzyme involved in the biosynthesis of phenolic compounds is phenylalanine ammonia lyase whose activity depends on the concentration

Fig. 7 The loading plot of the evaluated variables included in the PC analysis



of phenolic compounds, and since phenolics are the substrate of polyphenol oxidase enzyme, the enzyme decreases during storage (Ibrahim et al. 2004). Our results are consistent with the studies of Cao et al. (2009) on loquat and Ismail et al. (2010) on melons.

Vitamin C is the most important water-soluble antioxidant that reduces the damage of free radicals, such as superoxide and hydrogen peroxide (Klimczak et al. 2007). There are numerous reports of significant reductions in vitamin C in potatoes stored for 6 months. Changes in the content of vitamin C in the potato tubers can be a reflection of the genes expression and the activity of enzymes in the vitamin C metabolism during storage. Vitamin C may be synthesized in response to storage temperature stress (Galani et al. 2017). This compound significantly declines under long-term storage, which seems quite natural because vitamin C and organic acids are consumed in the Krebs cycle and respiration with the prolonged storage time-course and the onset of aging (Klimczak et al. 2007). The present results are consistent with the research of Dale et al. (2003) on potatoes.

Antioxidants inhibit both oxidation reactions caused by free radicals in fruit and vegetable tissues and the oxidation of proteins and molecules, such as deoxyribonucleic acid (DNA), by inhibiting the oxidative reactions. The antioxidant activity probably changes due to the intensity of respiration and changes in metabolic activity during storage (Plaza et al. 2011). The reason for the decrease in the antioxidant capacity during storage may be a response to the reduction of phenolic compounds, as reported in red raspberries (Kruger et al. 2011), which is consistent with the results of Ferree and Warrington (2003) in strawberries and Kruger et al. (2011) in red raspberries.

Biochemical changes, such as the degradation of chlorophyll and pigment-binding proteins, were reported along with the accumulation of beta-carotene and chromoplast-specific proteins during storage and processing. In addition, beta-carotene levels were responsive to the cultivar, fruit size, and soil type in mangoes (Vásquez-Cañedo et al. 2006). The present study is consistent with the results of Lester and Eischen (1996) in melons.

Antioxidant enzymes play an important role in keeping plants at low temperatures against damage triggered by reactive oxygen species (ROS). They have also been implicated in enzymatic browning, possibly through the reduction of diphenols and the production of lignins. Although the lack of compounds, such as superoxidase radicals, hydrogen peroxidase, and lipid peroxidase, limits peroxidase activity (Cai et al. 2006), Shaham et al. (2003) reported that peroxidase activity increased during storage for 16 weeks in apple.

Total protein content decreased during storage. The storage period was reported to result in differences in protein content in potato cultivars. The degradation of proteins into their constituents (amino acids) is probably due to the consumption of proteins for growing buds during the storage (Casajús et al. 2019).

The starch content decreased in potato tubers during storage at low temperatures. The decrease was probably associated with the changes in starch decomposition due to the physiological reactions during storage. Potato starch granules are completely resistant to degrading enzymes. The starch granules are destroyed as the tubers germinate, indicating the presence of unstable destructive enzymes in the tubers (Sarian et al. 2012). Adu-Kwarteng et al. (2014) reported that starch decreased in potato cultivars during

storage. Knutsson (2012) reported that in all potato cultivars, starch content decreased during the storage, which is consistent with the present results.

The above results exhibit the great differences in biochemical parameters between potato genotypes with great variations in postharvest storage capability. In this study, the total carbohydrates content was positively correlated with firmness, which is consistent with the results of Markovic et al. (1996). According to the findings by Ben Sadok et al. (2015) in apples, this kind of methodology must be completed with the assessment of more seasons and genotypes in order to understand more consistent relationships between genotype differences and postharvest parameters to realize the features of the potatoes, which are related to fresh food and processing qualities.

Conclusion

Based on the results, it can be stated that there were considerable variations among common cultivars in relation to storage characteristics and for uses such as fresh food and processing. In the current potato breeding programs, postharvest parameters such as firmness, weight loss, and biochemical traits are important and worthy of huge attention. Based on our results, it was found that “Red Scarlet”, “Challenger”, and “Innovator” were found to be suitable for fresh consumption and some were found to be appropriate for processing and chips production, including “Picasso”, “Sante” and “Banba”. It was also found that some cultivars, such as “Challenger” and “Sante”, had longer shelf-life and better marketability after six months of storage. In conclusion and in accordance with previous studies (Salazar et al. 2020; Faruh et al. 2020), we may declare that this work provides valuable information on the correlation between genetic diversity and postharvest potato quality in the current and future breeding programs. Also, detailed studies on potatoes under cold storage conditions are necessary to find higher differences between genotypes and cultivars to classify them according to their postharvest characteristics.

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Declarations

Conflict of Interests The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Financial Interests The authors declare they have no financial interests.

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