EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 36: 1–13
doi: 10.3897/ejfa.2024.123760

RESEARCH PAPER

Effect of calcium on quality parameters in three varieties of tubers of *Solanum tuberosum* L. at harvest and after four and eight months of cold storage conservation

Ana Rita F. Coelho[1,2], Fernando Cebola Lidon[1,2], Diana Daccak[1,2], Inês Carmo Luís[1,2], Ana Coelho Marques[1,2], Cláudia Campos Pessoa[1,2], Maria Manuela Silva[1,2], Maria Manuela Simões[1,2], Paulo Legoinha[1,2], José Cochicho Ramalho[2,3], Isabel P. Pais[2,4], José Manuel N. Semedo[2,4], Paula Scotti-Campos[2,4], Elsa M. Gonçalves[2,4], Nuno Alvarenga[2,4], Sandra Fernandes Gomes[4], Fernando Henrique Reboredo[1,2]

1 *Departamento Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal*

2 *Unidade de Geobiociências, Geoengenharias e Geotecnologias (GeoBioTec), Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal*

3 *PlantStress and Biodiversity Lab, Centro de Estudos Florestais (CEF), Laboratório Associado TERRA, Instituto Superior Agronomia (ISA), Universidade de Lisboa (ULisboa), Quinta do Marquês, Av. República, 2784-505 Oeiras, and Tapada da Ajuda, 1349-017 Lisboa, Portugal*

4 *INIAV—Instituto Nacional de Investigação Agrária e Veterinária, Quinta do Marquês, 2784-505 Oeiras, Portugal*

Corresponding author: Ana Rita F. Coelho (arf.coelho@fct.unl.pt)

Academic editor: Abdul Jaleel ♦ **Received** 22 March 2024 ♦ **Accepted** 28 August 2024 ♦ **Published** 26 November 2024

Abstract

Potato (*Solanum tuberosum* L) is one of the most important food crops worldwide, being a carbohydrate-rich food and presenting a good source of vitamins and minerals. Moreover, the mineral enrichment of potatoes through foliar application has been implemented over the years, namely in calcium (Ca). As such, this study aimed to assess the Ca effect on some quality parameters in three varieties of tubers of *Solanum tuberosum* L. plants produced in Portugal (Agria, Picasso, and Rossi) and submitted to Ca biofortification process carried out with two types of Ca ($CaCl_2$ and Ca-EDTA) and two different concentrations (12 and 24 $kg.ha^{-1}$), at harvest and after four and eight months under cold storage conservation. The Ca content increased with the biofortification treatments in the three varieties relative to control tubers and different correlations were observed between the mineral elements analyzed (Ca, P, K, Fe, Zn, and Mg). Only Agria (the control and treatment with 24 $kg.ha^{-1}$ of Ca-EDTA) was found suitable for industrial processing in the three periods analyzed (harvest, 4M and 8M) and overall, both in raw and cooked tubers, there were differences between each variety considering the work strength, adhesiveness and CIELAB parameters (L, a*, and b*).

Keywords

Calcium biofortification, mineral content, *Solanum tuberosum* L., storage conservation

Introduction

Potatoes (*Solanum tuberosum* L.) are considered one of the of the most important food crop worldwide and can be a low-cost energy source for humans (Ali et al. 2021). The potato tuber originates from the Andes (South America) and is considered as a staple food (Camire et al. 2009) due to the diverse nutritional components and the fact that is a carbohydrate-rich food (Lal et al. 2020). Additionally, it is a good source of vitamins, minerals, and dietary fiber (Tian et al. 2016).

In 2021, the European Union produced 50 444 270 tonnes of potatoes, with a yield of 360 026 $kg.ha^{-1}$ and a production area of 1 401 130 ha. In Portugal, despite in 2021 the production area was smaller than the one in 2020, the yield and the potato production increased, obtaining 246 024 $kg.ha^{-1}$ and 413 320 tonnes, respectively (FAOSTAT 2023).

The enrichment of potatoes through foliar applications in *Solanum tuberosum* L. plants in certain mineral elements has been carried out throughout the years. In fact, the mineral enrichment in potato tubers were implemented not only in micro elements such as selenium (Se) (Poggi et al. 2000; Zhang et al. 2019) or zinc (Zn) and manganese (Mn) (Mousavi et al. 2007) as well as in macro elements such as potassium (K) (El-Zohiri and Asfour 2009) or calcium (Ca) (El-Zohiri and Asfour 2009; El-Hadidi et al. 2017; Seifu and Deneke 2017). In this context, biofortified food is considered as a functional food, being able to provide a potential positive effect on human health (Siró et al. 2008; Marques et al. 2021).

Texture and color are important parameters in the quality of potatoes (namely, cooked) (Chiavaro et al. 2006). In fact, the firmness is dependent on the stability of cellular membranes, being influenced by the adhesion of adjacent cells via pectins, which is dependent on the adequate amount of Ca. As such, Ca applications have been used to enhance post-harvest quality and improve the shelf life namely in fruits (Lobos et al. 2021). Besides, postharvest quality can be manipulated by preharvest application with specific compounds and Ca sprays (namely calcium chloride) are widely used, not only with the aim of increasing Ca content, but also for extending the storage period after harvest (Lara 2013). Calcium fertilization in tubers can reduce injuries by bruising (Palta 2010). Additionally, according to Gondwe et al. (2019) by increasing tuber Ca content, the incidence of bruises in potato tubers can also be mitigated. In different fruits, the effects of Ca application before harvest on different at-tributes considered important to assess the commercial quality, such as firmness or soluble solids content, were further reported (Lara 2013). Nevertheless, the degradation of lipids in food matrices, particularly in processed potato products, can lead to issues of off-flavor and rancidity (Galliard 1973). Additionally, research on potato tubers revealed significant variations in fatty acids over storage (Cotrufo and Lunsetter 1964; Dobson et al. 2004). Moreover, lipid content in raw tubers can serve as an indicator of flavor characteristics in processed potatoes (Dobson et al. 2004) and the aging of potato tubers during storage can influence DBI, impacting membrane permeability (Knowles and Knowles 1989).

Food storage is also essential to guarantee continuous supplies for fresh markets and post-harvest processing industries (Wang et al. 2020). Considering that at harvest the quality attains the highest and can deteriorate during storage due to physical, physiological, and even pathological processes (Lobos 2021), optimal storage conditions are essential to maintain potato quality (Olsen and Kleinkopf 2020). In this context, tubers of *Solanum tuberosum* L. are usually subjected to cold-stored temperatures (less than 9–10 °C) to minimize physiological weight loss (namely, fresh, and dry matter content) due to decreased respiration rates, to reduce losses in tubers due to bacterial and pathogens and to inhibit sprout growth (Blenkinsop et al. 2002).

Calcium foliar applications are extensively used to enhance food characteristics and Ca content. Several studies have explored the use of $CaCl_2$ and Ca-EDTA, revealing enhancements in different food matrices. In fact, recent investigations employing $CaCl_2$ foliar applications have been conducted across different crops, including apples (Kucukyumuk et al. 2022), grapes (Shi et al. 2022), sweet cherries (Matteo et al. 2022), Rocha pears (Pessoa et al. 2021), strawberries (Lateef et al. 2021), blueberries (Lobos et al. 2021), lettuce (Yuan et al. 2018), and pears (Wang et al. 2018). The predominant outcomes from $CaCl_2$ foliar applications are different and include for instance the enhancement of Ca content (Lobos et al. 2021; Yuan et al. 2018; Kucukyumuk et al. 2022; Shi et al. 2022), the reduction of respiration rate and ethylene production (Kucukyumuk et al. 2022) and the improvement of overall textural properties (Wang et al. 2018; Kucukyumuk et al. 2022; Matteo et al. 2022) and quality after storage (Lateef et al. 2021). Conversely, Ca-EDTA has been foliar applied to various crops such as sweet corn (El-Yazied et al. 2007) and pineapple (Loekito et al. 2022). For instance, Ca content increased in sweet corn in a study carried out with eight foliar sprays of Ca-EDTA (El-Yazied et al. 2007). In this framework, these investigations were not conducted in *Solanum tuberosum* L., or even in Portugal. As such, considering that Agria, Picasso and Rossi are widely produced in Portugal and have significant industrial importance, they were chosen as a test system. Moreover, these varieties are renowned for their high yields and exhibit culinary qualities appreciated by consumers.

Considering the importance of potatoes worldwide and the major rule of Ca for storage optimization, this study aimed to evaluate the Ca effect on the elemental composition and on quality parameters of three varieties of *Solanum tuberosum* L., submitted to an agronomic biofortification process, using two types of Ca (calcium chloride and Ca-EDTA) with two different concentrations (12 and 24 $kg.ha^{-1}$) at harvest and after four and eight months of cold storage conservation being the average time of conservation of potatoes in Portugal.

Materials and methods

Experimental design

Three varieties of *Solanum tuberosum* L. (Agria, Picasso and Rossi) were grown in three different experimental fields (A, B and C) in the Western region of (Fig. 1). Agria, Picasso and Rossi varieties were planted in fields B, A and C (GPS coordinates of Field A: 39°160390'N, 9°150080'W, Field B: 39°160310'N, 9°130470'W (182 m) and Field C: 39°2829873'N, 9°2376869'W), respectively. Seven foliar applications were carried out after the beginning of tuberization with 6 to 8 days interval with two concentrations (12 and 24 kg.ha^{-1}) of $CaCl_2$ or Ca-EDTA. Planting dates were 21 March, 15 March and 15 May of 2019 for Picasso, Agria, and Rossi varieties, respectively.

The first foliar application was carried out on 30 May for Picasso and Agria, and on 17 July for Rossi variety. Harvest was performed on 9 August, 29 July, and 17 September for Picasso, Agria and Rossi, respectively. As Ca-EDTA might become highly toxic to plants, only one foliar application of 24 kg.ha^{-1} with Ca-EDTA(24B) was carried out, whereas with 12 kg.ha^{-1} seven spraying applications were performed. Control plants were not sprayed at any time with $CaCl_2$ or Ca-EDTA. All treatments were performed in quadruplicate.

During the agricultural period (21 March to 17 September 2019), air temperatures varied between 13.8 and 21.9 °C with an average rainfall of 0.51 mm.

After being harvested, the three varieties were stored at low temperatures in cold chambers between 6 and 8 °C, for four and eight months.

Mineral content in tubers at harvest

In each variety, after being harvested, eight randomized tubers with similar size were prepared according to Coelho et al. (2021). Thereafter, an acid digestion procedure was performed in the samples with a mixture of HNO3 – HClO4 (4:1), according to Carrondo et al. (1984).

Dry weight content

The dry weight content was measured at harvest and after four and eight months of cold, considering four randomized tubers per treatment Coelho et al. (2021).

Total soluble solids content

Total soluble solids (an indication of sucrose, glucose, and fructose) were measured in the juice of four randomized tubers per treatment (n = 4), using a digital refractometer Atago (Atago, Tokyo, Japan).

Lipid content

The total fatty acids (TFA) and the DBI (double bond index) content in tubers were carried out in quadruplicate in randomized tubers at harvest, and after four and eight months of cold storage per treatment, as described in Pessoa et al. (2022). The degree of unsaturation was obtained through the unsaturation index (DBI), which reflects the

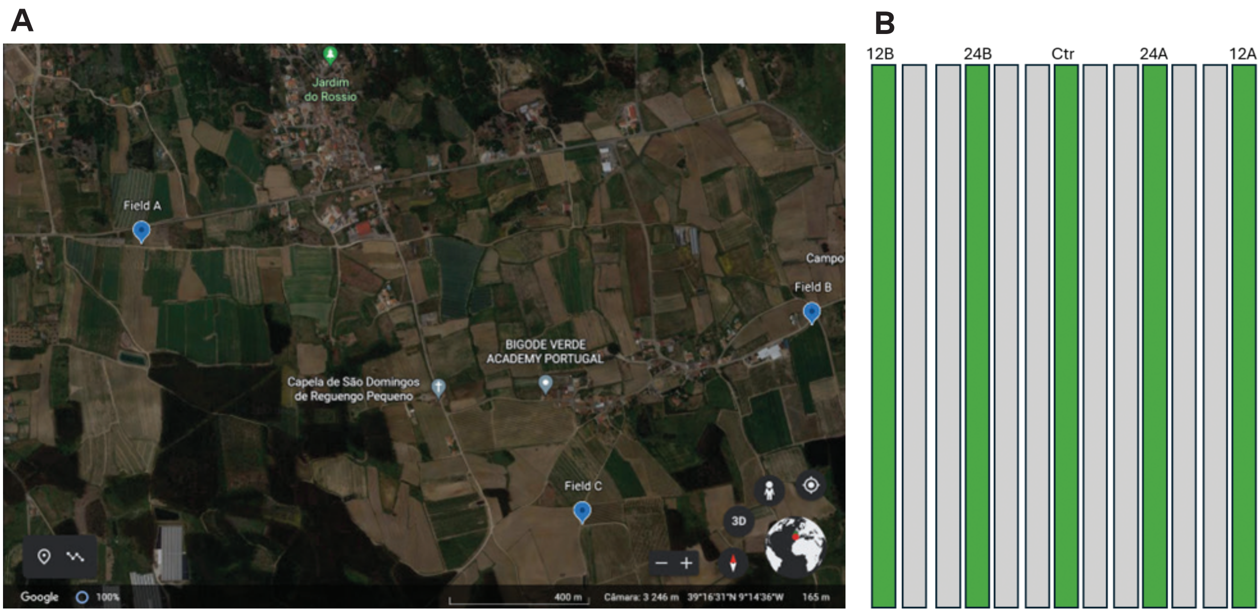

Figure 1. A. Geographic location of the three experimental fields (**A**, **B**, and **C**) (imagens obtained through Google Earth). Field A—GPS coordinates: 39°160390'N, 9°150080'W (142 m), Field B—GPS coordinates: 39°160310'N, 9°130470'W (182 m) and Field C – GPS coordinates: 39°2829873'N, 9°2376869'W (148 m).; **B.** Example of the experimental design in which "Ctr" stands for control, "12A" stands for 12 kg.ha^{-1} CaCl2, "24A" stands for 24 kg.ha^{-1} CaCl2, "12B" stands for 12 kg.ha^{-1} Ca-EDTA and "24B" stands for 24 kg.ha^{-1} Ca-EDTA; gray color represent the rows of *Solanum tuberosum* L. plants without any Ca foliar treatments.

relative abundance of mono- and polyunsaturated fatty acids in relation to saturated fatty acids, obtained by using the formula: DBI = [(X% monoenes + 2 X% dienes + 3 X% trienes)/% saturated fatty acids], following Mazliak (1983).

Heat treatment of tuber pulp

Each sample was washed, peeled, rinsed, cut into 3 × 3 cm cubes, and boiled (100 °C - 20 min) using a thermostatically-controlled water bath (with agitation; 10 L nominal capacity; Edelstahl Rost-Frei, Schwabach, Germany). The temperature at the geometric center of each cube was measured with a Fluke precision thermocouple (± 1 °C). The samples were then cooled in ice-cold potable water (0 °C) for 1 min, paper dried and held at 5 °C until evaluation.

Color and texture were analyzed in quadruplicate for each sample considering the binomial 20 min/ 100 °C, in tubers after harvest (control tubers and tubers submitted to the highest treatment of $CaCl_2$ or Ca-EDTA).

Colorimetric analysis was carried out with a colorimeter (Minolta CR-300, Japan) by measuring the CIE L*a*b* parameters, previously calibrated according to pre-established standards. Texture was measured by texturometer (Stable Micro System TAHDi, USA). For each sample, the texture was measured with a punch test in three repetitions, using a 3 mm probe up to a 15 mm of distance. The load cell force used was 5 kg, the test was carried out at a speed of 1 mm/s. The analysis was performed at 23 °C and each sample was analyzed. From the texture profiles (texturogram), the following parameters were determined: Fracturability (N), which represents the resistance exerted by the surface of the food to penetration and is registered by the force registered in the first peak; the work of the force (Nxs) that represents the energy exerted by the probe in the penetration and is determined by the positive area of the texturogram; the hardness (N), is determined by the maximum strength of the texture, being a measure of the firmness of the material; and the Adhesiveness (-N*s) which is the work required to overcome the forces of attraction between the material and the surface of the probe. It is given by the value of the area corresponding to the negative strength of the texturegram.

Statistical analysis

Statistical analysis was carried out with the IBM SPSS software using one way and two-way ANOVA to assess the differences between the treatments in each variety (Agria, Picasso, and Rossi) and between harvest, and after four and eight months of cold storage in each parameter analyzed, followed by Tukey's analysis for mean comparison. A 95% confidence level was adopted for all the tests. Additionally, correlation matrix and multivariate analysis (Principal Component Analysis) was carried out using R software "R Project for Statistical Computing".

Results

Mineral content in tubers at harvest

Calcium (Ca), phosphorus (P), potassium (K), iron (Fe), zinc (Zn), and magnesium (Mg) content in tubers at harvest was carried out for Agria, Picasso, and Rossi varieties (Table 1). There were no significant differences between treatments in P in the three varieties, in K on Agria and Picasso and in Mg on Picasso and Rossi varieties. Regarding Agria variety, 12A (12 $kg.ha^{-1}$ $CaCl_2$) treatment showed a significant increase in Ca, Fe and Mg content. In Picasso and Rossi varieties, 12B (12 $kg.ha^{-1}$ Ca-EDTA) treatment showed a significant increase in Ca content, as well in Fe. Zinc showed a significant increase in content in the three varieties with 12B treatment. Calcium increased by 3.3, 2.7 and 2.2 fold for Agria, Picasso, and Rossi, respectively.

In Fig. 2 presents the correlation matrix between the mineral elements in the three varieties, the larger the size of the circle, the greater the correlation. Considering Agria (Fig. 2A) it's possible to observe a higher correlation between P and Mg, P and Zn, P and K, K and Mg, Fe and Ca, and Ca and Mg. Regarding Picasso (Fig. 2B), K and Fe are the pair with the highest correlation, followed by Ca and Zn, and P and Mg. Moreover, Rossi (Fig. 2C) relative to the other two varieties, is the one that showed a highest correlation among all the mineral elements, showing a higher correlation between the pairs: P and Mg, Ca and Fe, Ca and K, Ca and Zn, and K and Zn.

In Fig. 3, the graphical results for the contribution of the variables of the principal components and the projection of the factorial plane creased with component 1 and component 2 are presented for the macro and micro elements in tubers of *Solanum tuberosum* L. for Agria, Picasso, and Rossi varieties. Regarding the contribution of the variables of the principal components (Fig. 3A, C, E), the mineral elements that have a higher contribution in the component 1 (PC1 or Dim. 1) are Ca, P, K, Fe and Mg in Agria, Ca, K, Fe and Zn in Picasso and Ca, P, K, Fe, Zn and Mg in Rossi. As such, Rossi has a higher variance in PC1 (73.4%), followed by Agria (50.9%) and Picasso (48%). Moreover, the variables are projected into the four semi-axes and the four quadrants, defined by the intersection of the factorial axes (Fig. 3B, D, F). The projection of the variables defined by PC1 and PC2 explain 78.9%, 78.5% and 89.4% of the initial data variability, for Agria, Picasso and Rossi, respectively.

In Agria (Fig. 3B), considering the PC1, the variables are projected on the positive semi-axis and regarding PC2, there is a separation between elements, located on the positive (Fe and Ca) or on the negative semi-axis (K, Mg, Zn and P). The proximity of the pairs Ca-Fe and K-Mg shows a great affinity due to their position in PC1 with a higher coordinate, also reflecting the correlation between these elements.

In Picasso (Fig. 3D), regarding PC1, the variables are projected on the positive (Fe, K, Zn and Ca) and on the negative (Mg and P) semi-axis and in PC2, Mg, P, Fe and K are projected on the positive semi-axis and, Zn and Ca on the nega-

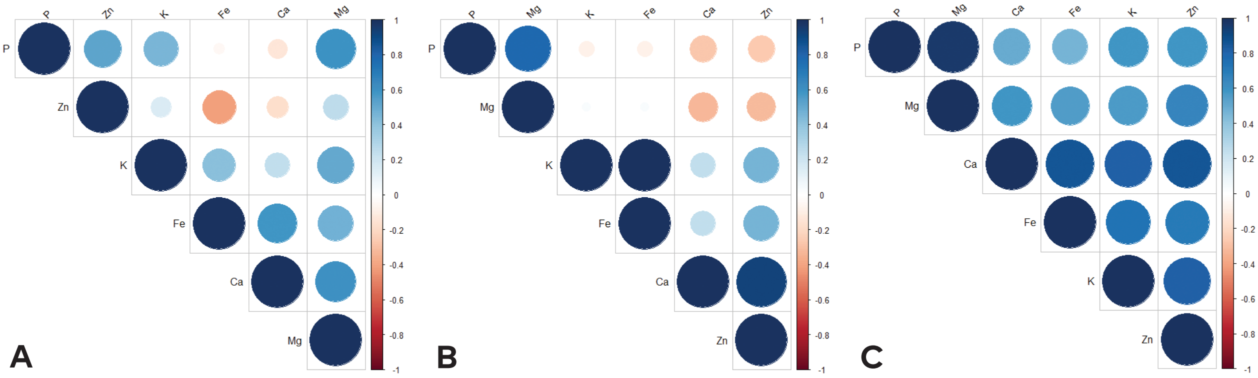

Figure 2. Correlation matrix of the macro and micro elements (Ca, P, K, Fe, Zn and Mg) in tubers of the three varieties of *Solanum tuberosum* L. Agria (**A**), Picasso (**B**) and Rossi (**C**), at harvest.

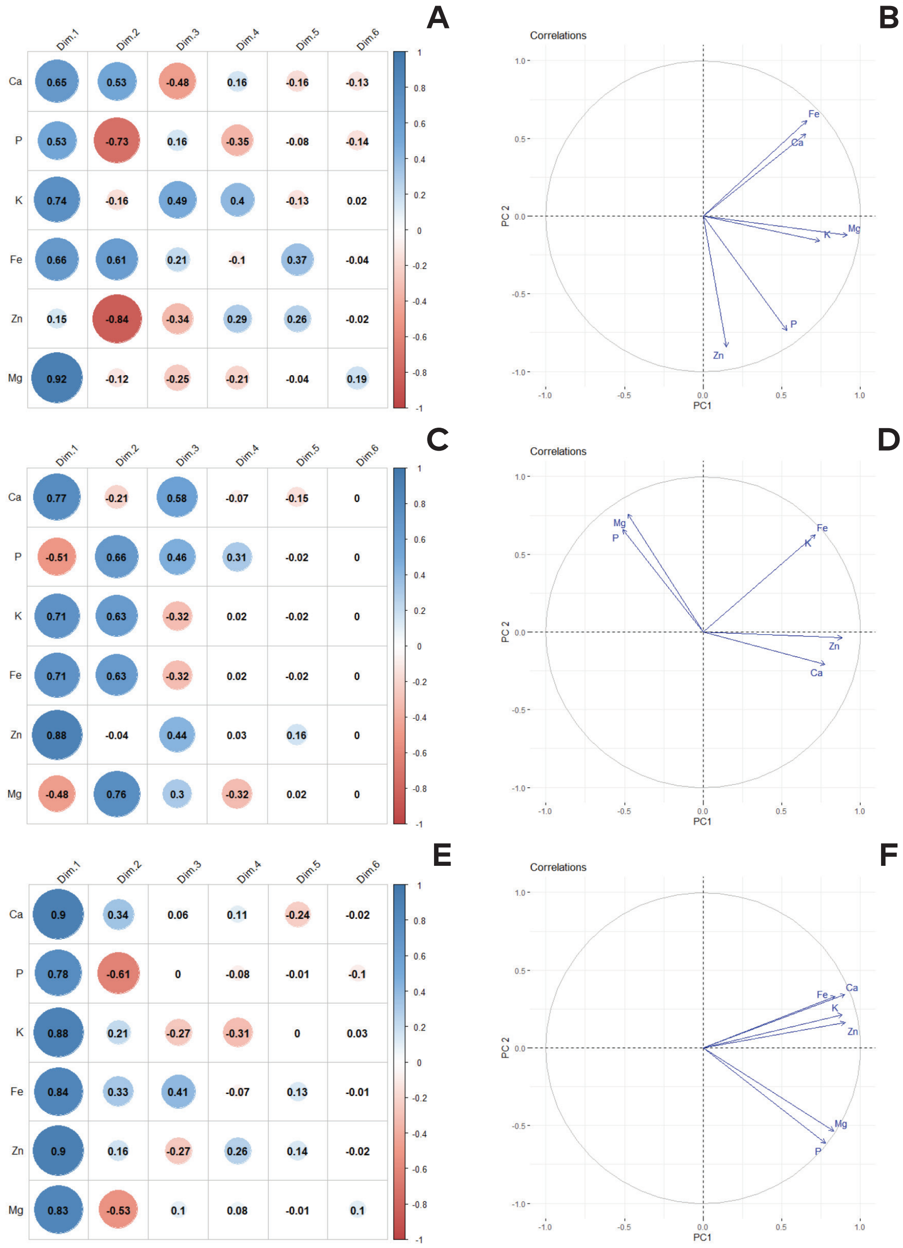

Figure 3. Variable contributions of the principal components of macro and micro elements (**A**, **C** and **E**) and projection onto the factorial plane created with Component 1 (or PC1 or Dim1) and Component 2 (or PC2 or Dim2) in tubers of *Solanum tuberosum* L., Agria (**A**, **B**), Picasso (**C**, **D**) and Rossi (**E**, **F**) varieties at harvest. The variance in PC1 was 50.9%, 48%, 73.4% and in PC2 was 28%, 30.5%, 16.01% for Agria, Picasso and Rossi varieties, respectively.

Table 1. Calcium, K, P, Fe, Zn and Mg content (considering the dry weight) in tubers of the three varieties of *Solanum tuberosum* L. (Agria, Picasso and Rossi) at harvest. Mean values (*n* = 4) ± S.E. (standard error). "T." stands for treatments, "Ctr" stands for control, "12A" stands for 12 kg.ha^{-1} $CaCl_2$, "24A" stands for 24 kg.ha^{-1} $CaCl_2$, "12B" stands for 12 kg.ha^{-1} Ca-EDTA and "24B" stands for 24 kg.ha^{-1} Ca-EDTA.

T.	Ca	P	K	Fe	Zn	Mg
	%			mg.kg^{-1}		
Agria						
Ctr	0.019 ± 0.001b	0.129 ± 0.004a	1.57 ± 0.19a	63.3 ± 4.08b	8.87 ± 0.12b	381 ± 3.4c
12A	0.063 ± 0.019a	0.149 ± 0.015a	1.98 ± 0.077a	94.1 ± 4.88a	9.98 ± 0.36b	452 ± 5.9a
24A	0.027 ± 0ab	0.14 ± 0.003a	1.79 ± 0.086a	75.7 ± 0.98ab	8.62 ± 0.18b	399 ± 10.6bc
12B	0.025 ± 0.001ab	0.148 ± 0.004a	1.94 ± 0.235a	58 ± 9.18b	15.9 ± 1.86a	408 ± 15.3bc
24B	0.024 ± 0.001ab	0.161 ± 0.003a	1.75 ± 0.046a	56.5 ± 2.95b	15.3 ± 1.84a	432 ± 4.5ab
Picasso						
Ctr	0.018 ± 0.001b	0.14 ± 0.013a	1.75 ± 0.159a	71.7 ± 7.18b	11.0 ± 1.13b	365 ± 20a
12A	0.022 ± 0.001b	0.159 ± 0.005a	2.75 ± 0.21a	100 ± 6.74ab	11.3 ± 0.5b	440 ± 16a
24A	0.026 ± 0.003b	0.152 ± 0.011a	2.16 ± 0.046a	123 ± 3.35a	14.3 ± 3.32ab	420 ± 30a
12B	0.049 ± 0.02a	0.12 ± 0.006a	2.46 ± 0.253a	138 ± 12.23a	27 ± 6.06a	356 ± 19a
24B	0.032 ± 0.001b	0.135 ± 0.02a	2.29 ± 0.458a	109 ± 16.64ab	15.4 ± 1.51ab	394 ± 28a
Rossi						
Ctr	0.022 ± 0.001c	0.145 ± 0.001a	1.91 ± 0.039b	40.5 ± 1.93c	10.6 ± 0.13b	377 ± 6.45a
12A	0.027 ± 0.001bc	0.153 ± 0.005a	1.96 ± 0.145ab	55.4 ± 10.81bc	15 ± 1.4ab	418 ± 14.9a
24A	0.029 ± 0.001bc	0.162 ± 0.013a	2.30 ± 0.089ab	75.1 ± 9.74bc	12.7 ± 0.38ab	439 ± 30.4a
12B	0.048 ± 0.004a	0.165 ± 0.011a	2.96 ± 0.283a	129 ± 9.23a	23.7 ± 5.86a	452 ± 30.2a
24B	0.032 ± 0.002b	0.165 ± 0.006a	2.72 ± 0.298ab	89 ± 7.01b	17.6 ± 0.66ab	440 ± 6.21a

For each mineral element, different letters indicate significant differences between treatments.

tive semi-axis. Moreover, as seen in Fig. 2, Fe and K have the highest correlation, followed by Ca and Zn, and Mg and P.

Considering Rossi variety (Fig. 3F), regarding PC1, the variables are projected on the positive semi-axis and in PC2 there is a separation between mineral elements, located on the positive (Fe, Ca, K and Zn) and on the negative (Mg and P) semi-axis. Thus, the pairs Ca-Fe, K-Zn and Mg-P showed higher correlations between each other.

Dry weight content

Considering the dry weight content of the three varieties (Table 2), only significant differences were found between treatments in Agria after 4 (4M) and eight (8M) of cold storage. At harvest, the dry weight content of Agria, Picasso, and Rossi, varied between 22.87–26.49%, 16.77–21.89% and 16.27–25.27%, respectively. Picasso and Rossi variety presented the lowest dry weight content in treatment 24A (24 kg.ha^{-1} $CaCl_2$). Moreover, there were significant differences in the three varieties, between the different times of analysis (harvest, 4M and 8M). After 4M, the dry weight content varied between 17.32–23.88%, 15.89–19.6% and 11.76–20.11%, respectively for Agria, Picasso and Rossi. After 8M, the dry weight content varied between 20.57–24.73%, 16.8–24.36% and 18.98–25.44%, respectively for Agria, Picasso, and Rossi varieties.

Table 2. Dry weight content (%) in tubers of the three varieties of *Solanum tuberosum* L. (Agria, Picasso and Rossi) at harvest (H), and after four months (4M) and eight months (8M) of cold storage. Mean values (*n* = 4) ± S.E. (standard error). "T." stands for treatments, "Ctr" stands for control, "12A" stands for 12 kg.ha^{-1} $CaCl_2$, "24A" stands for 24 kg.ha^{-1} $CaCl_2$, "12B" stands for 12 kg.ha^{-1} Ca-EDTA and "24B" stands for 24 kg.ha^{-1} Ca-EDTA.

T.	Dry weight (%)		
	H	4M	8M
Agria			
Ctr	25.94 ± 0.23aA	22.75 ± 0.78aC	23.54 ± 1.05abB
12A	22.87 ± 0.84aB	17.32 ± 1.87bC	24.73 ± 1.29abA
24A	24.24 ± 1.03aA	19.6 ± 0.91abB	23.97 ± 0.2abA
12B	26.49 ± 3.91aA	19.58 ± 0.85abB	20.57 ± 0.9bB
24B	25.87 ± 1.24aA	23.88 ± 0.51aB	23.98 ± 0.37aB
Picasso			
Ctr	17.12 ± 0.69aB	15.89 ± 1.61aC	24.36 ± 1.03aA
12A	21.89 ± 0.89aA	19.6 ± 1.09aB	18.77 ± 0.7bcB
24A	16.77 ± 2.52aA	16.49 ± 0.67aA	16.8 ± 0.9cA
12B	20.97 ± 1.87aA	16.72 ± 0.75aC	18.12 ± 0.54bcB
24B	18.99 ± 0.44aB	18.15 ± 0.65aB	21.6 ± 0.66abA
Rossi			
Ctr	25.27 ± 1.03aA	19.94 ± 2.62aB	22.88 ± 1.59aA
12A	23.38 ± 1.87abA	16.91 ± 2.36aB	21.97 ± 1.62aA
24A	16.27 ± 0.89cB	11.76 ± 5.03aC	22.4 ± 1.79aA
12B	17.43 ± 1.67cA	14.84 ± 1.46aB	18.98 ± 0.7aA
24B	18.48 ± 0.15bcC	20.11 ± 0.84aB	25.44 ± 1.45aA

Different letters indicate significant differences between treatments in each variety (a,b) or between different times (harvest, 4M and 8M) (A,B).

Total soluble solids content

Total soluble solids (TSS) content in Rossi and Picasso varieties did not show significant differences among treatments at harvest (Table 3). Moreover, each treatment during the three times of analysis (harvest, 4M and 8M) there were significant differences. At harvest the TSS content varied between 5.47–6.53 °Brix, 4.67–5.1 °Brix and 5.0–5.67 °Brix for Agria, Picasso and Rossi, respectively.

Table 3. Total soluble solids (°Brix) in tubers of the three varieties of *Solanum tuberosum* L. (Agria, Picasso and Rossi) at harvest (H), and after four months (4M) and eight months (8M) of cold storage. Mean values (n = 4) ± S.E. (standard error). "T." stands for treatments, "Ctr" stands for control, "12A" stands for 12 kg.ha^{-1} $CaCl_2$, "24A" stands for 24 kg.ha^{-1} $CaCl_2$, "12B" stands for 12 kg.ha^{-1} Ca-EDTA and "24B" stands for 24 kg.ha^{-1} Ca-EDTA.

T.	TSS (°Brix)		
	H	4M	8M
Agria			
Ctr	6.53 ± 0.12aA	5.13 ± 0.07abB	6.5 ± 0.22bA
12A	6.3 ± 0.21abA	4.97 ± 0.07bB	6.27 ± 0.12bA
24A	6.03 ± 0.03abA	5.1 ± 0.05abC	5.83 ± 0.07bB
12B	5.47 ± 0.27bB	5.23 ± 0.05abB	6.27 ± 0.07bA
24B	6.2 ± 0.09abB	5.4 ± 0.05aC	8.2 ± 0.05aA
Picasso			
Ctr	5 ± 0.09aB	5.13 ± 0.07abB	6.23 ± 0.05aA
12A	4.67 ± 0.1aB	5.03 ± 0.03abA	5.03 ± 0.07bA
24A	4.83 ± 0.27aB	4.9 ± 0.05bB	6.1 ± 0.12aA
12B	5.1 ± 0.05aB	5.23 ± 0.07aA	5.33 ± 0.05bA
24B	4.87 ± 0.05aB	4.97 ± 0.03abB	6.37 ± 0.07aA
Rossi			
Ctr	5.33 ± 0.27aB	5.13 ± 0.07abB	8.17 ± 0.12aA
12A	5.67 ± 0.27aB	4.97 ± 0.03bC	7.6 ± 0.12abA
24A	5.0 ± 0aB	5.1 ± 0.05abB	6.27 ± 0.07cA
12B	5.0 ± 0aB	5.07 ± 0.03abB	7.33 ± 0.23bA
24B	5.0 ± 0.47aB	5.37 ± 0.1aB	7.5 ± 0.12abA

Different letters indicate significant differences between treatments in each variety (a,b) or between different times (harvest, 4M and 8M) (A,B).

After 4M the TSS content oscillated in the three varieties between 4.9 and 5.4 °Brix and after 8M the values varied between 5.83–8.2 °Brix, 5.33–6.37 °Brix and 6.27–8.17 °Brix for Agria, Picasso, and Rossi, respectively.

Lipid content

Considering the total fatty acid content and the double bound index of lipids in tuber of *Solanum tuberosum* L. on Agria, Picasso and Rossi varieties (Table 4), significant differences were found between the different time periods of analysis (harvest, 4M and 8M) (except at most treatments in DBI on Rossi). Overall, the content of TFA followed the pattern 4M> 8M> harvest in the three varieties. Regarding the DBI content, the following trend was detected harvest >4M >8M in Agria, 4M> Harvest > 8M in Picasso, whereas Rossi revealed similar values between the different times of analysis. There were only significant differences between the different treatments in Agria (Table 4) in TFA, at harvest and at 4M. Regarding Picasso (Table 4), in < DBI at harvest, in TFA and DBI at 4M and in DBI at 8M.

Heat treatment of tuber pulp

The fracturability and hardness of the three varieties of potato were carried out at harvest and after four months of cold storage, both in raw (Fig. 4A) and cooked (Fig. 4B)

Table 4. Total fatty acid content (TFA) and double bound index (DBI) of lipids in tubers of *Solanum tuberosum* L. Agria, Picasso and Rossi varieties, at harvest (H), and after four months (4M) and eight months (8M) of cold storage. Mean values (n = 4) ± S.E. (standard error). "T." stands for treatments, "Ctr" stands for control, "12A" stands for 12 kg.ha^{-1} $CaCl_2$, "24A" stands for 24 kg.ha^{-1} $CaCl_2$, "12B" stands for 12 kg.ha^{-1} Ca-EDTA and "24B" stands for 24 kg.ha^{-1} Ca-EDTA.

T.	Agria		Picasso		Rossi	
	TFA g/100 g FW	DBI	TFA g/100 g FW	DBI	TFA g/100 g FW	DBI
Harvest						
Ctr	0.22 ± 0.03abB	30.69 ± 0.74aA	0.11 ± 0.01aC	13.41 ± 1.04bB	0.13 ± 0.02aB	13.61 ± 2.75aA
12A	0.24 ± 0.02abC	29.04 ± 5.01aA	0.16 ± 0.03aC	14.88 ± 1.28bA	0.16 ± 0.01aB	12.54 ± 1.96aA
24A	0.24 ± 0.01aC	22.95 ± 2.04aA	0.19 ± 0.02aC	17.15 ± 3.18abA	0.16 ± 0.04aB	12.97 ± 0.66aB
12B	0.16 ± 0.02abC	21.63 ± 2.96aA	0.16 ± 0.02aB	15.88 ± 1.81bA	0.12 ± 0.01aB	9.63 ± 1.62aB
24B	0.15 ± 0bC	26.67 ± 1.27aA	0.17 ± 0.03aB	26.06 ± 2.2aA	0.16 ± 0.01aB	13.29 ± 1.74aA
4M						
Ctr	0.9 ± 0.1bC	19.6 ± 3.22aB	1.27 ± 0.07aA	34.04 ± 3.04aA	0.97 ± 0.11aA	12.61 ± 2.39aA
12A	1.06 ± 0.13bA	23.27 ± 2.93aA	0.83 ± 0.09bA	15.97 ± 1.74bA	0.82 ± 0.11aA	11.21 ± 1.35aA
24A	1.33 ± 0.1abA	24.48 ± 3.72aA	0.95 ± 0.04abA	14.49 ± 1.83bB	1.24 ± 0.17aA	17.86 ± 1.48aA
12B	1.36 ± 0.11ab	26.78 ± 2.21aA	0.69 ± 0.07bA	10.9 ± 1.61bA	0.95 ± 0.15aA	13.72 ± 2.41aB
24B	1.57 ± 0.1aA	25.83 ± 1.39aA	0.85 ± 0.12bA	13.06 ± 1.84bC	1.1 ± 0.09aA	13.79 ± 1.9aA
8M						
Ctr	0.81 ± 0.06aA	16.12 ± 1.05aB	0.65 ± 0.14aB	11.68 ± 2.05bB	0.9 ± 0.08aA	12.06 ± 0.43aA
12A	0.72 ± 0.03aB	14.59 ± 0.6aB	0.58 ± 0.07aB	9.51 ± 0.77bB	0.93 ± 0.05a	16.38 ± 1.17aA
24A	0.81 ± 0.03aB	15.3 ± 0.3aB	0.7 ± 0.03aB	12.39 ± 1.05bB	1.08 ± 0.06aA	18.55 ± 0.77aA
12B	0.85 ± 0.04aB	16.62 ± 1.64aB	0.64 ± 0.11aA	12.32 ± 1.7bA	1.01 ± 0.04aA	17.49 ± 0.66aA
24B	0.92 ± 0.08aB	15.29 ± 1.77aB	0.83 ± 0.11aA	18.08 ± 2.18aB	1.01 ± 0.15aA	14.49 ± 1.73aA

For each parameter, different letters indicate significant differences between treatments in each variety (a,b) or between different times (harvest, 4M and 8M) (A,B).

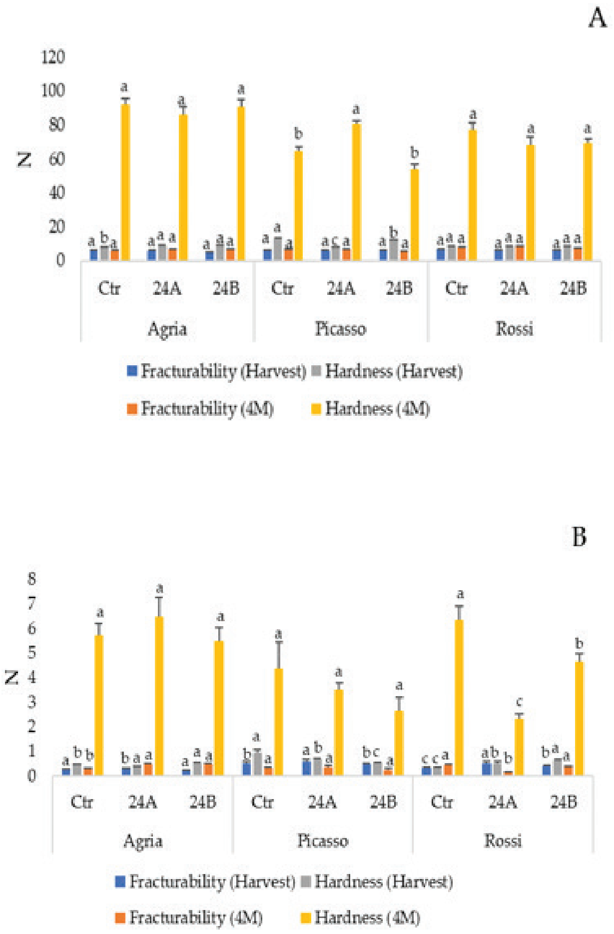

Figure 4. Fracturability (N) and Hardness (N) on raw (A) and cooked (B) tubers of *Solanum tuberosum* L. Agria, Picasso and Rossi varieties, at harvest (H), and after four months (4M) of cold storage. Mean values (*n* = 4) ± S.E. and for each parameter, different letters indicate significant differences between treatments in each variety (a,b). "T." stands for treatments, "Ctr" stands for control, "12A" stands for 12 kg.ha^{-1} $CaCl_2$, "24A" stands for 24 kg.ha^{-1} $CaCl_2$, "12B" stands for 12 kg.ha^{-1} Ca-EDTA and "24B" stands for 24 kg.ha^{-1} Ca-EDTA.

states. Considering the raw tubers (Fig. 4A), Agria exhibited a significant decrease in hardness in Ctr treatment, while Rossi displayed a similar trend in 24A treatment. After 4M, only Picasso variety showed significant differences between treatments, with the 24A treatment showing higher hardness levels. Regarding cooked tubers (Fig. 4B), significant differences were observed across most treatments for all three varieties at harvest and after 4M of cold storage. In fact, no significant differences were obtained in fracturability for Agria variety at harvest and in hardness after 4M, while for Picasso variety, no significant differences were observed in fracturability and hardness after 4M of cold storage.

The work strength, adhesiveness and colorimetric parameters were carried out in the three varieties at harvest and after four months of cold storage (Table 5). Considering the raw tubers of the three varieties compared to the cooked tubers at harvest and after 4M, there was a significant decrease in all the parameters (except in L parameter on Picasso and Rossi at harvest and after 4M and on Agria after 4M; and in b* parameter on Rossi after 4M).

Regarding the raw tubers at harvest, in work strength Ctr showed a significantly higher value in Picasso and Rossi and in Adhesiveness, Ctr showed a significantly lower value in Agria and Picasso. In L and a* parameters on Picasso at harvest, 24A treatments showed a significantly lower value compared to the remaining treatments. In raw tubers after 4M of cold storage, Ctr treatment on Agria presented a significantly higher values in work strength, L and b* parameter, despite in adhesiveness showed a significantly lower value. Regarding Picasso variety in the same analysis conditions, 24A treatment showed a significantly higher values in work strength and adhesiveness and a significant decrease in b* parameter. Also, Rossi variety showed a significant decrease in that treatment (24A) in b* parameter.

Considering the cooked tubers at harvest, in Ctr Agria variety obtained a significantly higher values in adhesiveness and L parameter and a significantly lower values in a* and b*parameters. Additionally, Picasso variety showed a significant decrease in work strength and adhesiveness in 24B and in L and b* parameter a significantly higher value in Ctr. Regarding Rossi, Ctr showed a significantly lower value in work strength, adhesiveness, and b* parameter and a significantly higher value in L parameter. Also, in cooked tubers but after 4M of cold storage, only work strength and a* parameter didn't' show significant differences between treatments on Agria. On Picasso variety, 24B treatment presented a significantly lower value in work strength, adhesiveness, and a* parameter and a significantly higher value in b* parameter. Additionally, Rossi variety showed in all the parameters (except L) significantly lower values in 24A treatment.

Discussion

Potato variety, tuber maturity, and climacteric conditions have a huge impact on the final quality of tubers (Alamar et al. 2017). Besides, it is important to have a good management practice during the post-harvest storage to maintain the quality of tubers, namely for nutrient availability (Hossain and Miah 2009). As such, mineral content and quality parameters were assessed in three varieties submitted to agronomic biofortification with Ca (Tables 1–4; Fig. 4).

Calcium is crucial for plant growth and development, providing integrity and stability to cell walls (Wei et al. 2017) or being involved as a cofactor of numerous enzymes implicated in the catabolism of ATP and phospholipids (Taiz and Zeiger 2002). On the other hand, Ca deficiency might occur among fruits and tubers (both are considered low-transpiring organs), as this nutrient moves with water through the xylem at a lower relative to the leaves (Palta 2010). In this content, Ca accumulation in tubers was assessed after harvest, considering, after tuberization, seven foliar applications with calcium chloride or Ca-EDTA. In this context, only in 24B treatment were visible toxicity

Table 5. Total Work strength (N.mm), Adhesiveness (-N.mm) and L, a* and b* parameters (CIELAB scale) of raw and cooked tubers of *Solanum tuberosum* L. Agria, Picasso and Rossi varieties, at harvest (H), and after four months (4M) cold storage. Mean values (n = 4) ± S.E. (standard error). "T." stands for treatments, "Ctr" stands for control, "12A" stands for 12 kg·ha^{-1} $CaCl_2$, "24A" stands for 24 kg·ha^{-1} $CaCl_2$, "12B" stands for 12 kg·ha^{-1} Ca-EDTA and "24B" stands for 24 kg·ha^{-1} Ca-EDTA.

	Variety	T.	Work strength	Adhesiveness	L	a*	b*
Raw tubers							
Harvest	Agria	Ctr	79.16 ± 3.22aA	2.38 ± 0.3bA	66.94 ± 0.83aA	-4.22 ± 0.11aA	21.95 ± 0.46aA
		24A	82.58 ± 1.14aA	3.24 ± 0.25aA	69.26 ± 0.68aA	-4.51 ± 0.04aA	22.65 ± 0.33aA
		24B	83.43 ± 3.35aA	3.09 ± 0.3aA	67.23 ± 1.04aA	-4.43 ± 0.13aA	24.67 ± 0.82aA
	Picasso	Ctr	128.4 ± 2.55aA	2.33 ± 0.61cA	70.38 ± 0.76aA	-2.78 ± 0.11aA	18.2 ± 0.58aA
		24A	84.03 ± 3.59cA	4.52 ± 0.38aA	65.62 ± 0.8bA	-3.45 ± 0.13bA	18.25 ± 0.57aA
		24B	116.15 ± 2.13bA	3.52 ± 0.34bA	71.88 ± 1.33aA	-2.89 ± 0.08aA	18.23 ± 0.15aA
	Rossi	Ctr	94.12 ± 3.21aA	4.42 ± 0.5aA	69.89 ± 1.16aA	-4.68 ± 0.1aA	30.75 ± 0.26aA
		24A	92.07 ± 2.57aA	4.67 ± 0.56aA	71.28 ± 0.82aA	-4.88 ± 0.15aA	29.59 ± 0.47aA
		24B	86.79 ± 1.65bA	5.06 ± 0.66aA	73.42 ± 0.84aA	-4.73 ± 0.04aA	30.42 ± 0.71aA
4M	Agria	Ctr	8.45 ± 0.24aA	2.48 ± 0.21cA	71.32 ± 0.76aA	-4.37 ± 0.16aA	32.08 ± 0.32aA
		24A	7.89 ± 0.26aA	4.85 ± 0.95aA	66.84 ± 0.71bB	-3.8 ± 0.15aA	25.57 ± 0.2cA
		24B	8.35 ± 0.44aA	3.91 ± 0.33bA	68.57 ± 0.51bB	-3.87 ± 0.09aA	29.71 ± 0.59bA
	Picasso	Ctr	7.01 ± 0.33bA	1.68 ± 0.39cA	64.09 ± 0.68aA	-3.87 ± 0.12aA	21.37 ± 0.3aA
		24A	8.8 ± 0.3aA	3.22 ± 0.52aA	65.23 ± 0.7aA	-3.86 ± 0.08aA	19.97 ± 0.27bA
		24B	5.85 ± 0.26cA	2.1 ± 0.31bA	64.18 ± 0.42aA	-3.61 ± 0.16aA	21.79 ± 0.8aA
	Rossi	Ctr	8.2 ± 0.31aA	1.33 ± 0.15aA	69.84 ± 0.65aA	-2.97 ± 0.07aA	19.13 ± 0.14aA
		24A	8.6 ± 0.34aA	1.42 ± 0.29aA	67.28 ± 0.96aA	-2.39 ± 0.13aA	18.16 ± 0.45bA
		24B	7.87 ± 0.43aA	1.86 ± 0.23aA	69.41 ± 0.76aA	-2.89 ± 0.08aA	19.86 ± 0.19aA
Cooked tubers							
Harvest	Agria	Ctr	3.86 ± 0.27aB	0.52 ± 0.05aB	54.6 ± 0.67aB	-7.56 ± 0.13bB	7.17 ± 0.25bB
		24A	3.23 ± 0.32aB	0.32 ± 0.03bB	51.22 ± 0.58bB	-6.96 ± 0.07aB	7.19 ± 0.22bB
		24B	4.2 ± 0.49aB	0.38 ± 0.04bB	54.77 ± 0.87aB	-7.27 ± 0.18bB	9.6 ± 0.47aB
	Picasso	Ctr	9.63 ± 1.23aB	1.48 ± 0.21aB	70.76 ± 0.61aA	-5.3 ± 0.13aB	9.29 ± 0.32aB
		24A	8.02 ± 0.6aB	1.2 ± 0.13aB	66.22 ± 0.68bA	-5.22 ± 0.08aB	5.83 ± 0.26cB
		24B	5.46 ± 0.58bB	0.69 ± 0.12bB	66.26 ± 0.67bB	-5.39 ± 0.12aB	7.42 ± 0.23bB
	Rossi	Ctr	3.45 ± 0.13bB	0.49 ± 0.06bB	64.47 ± 0.98aA	-9.22 ± 0.14aB	17.21 ± 0.61cB
		24A	6.26 ± 0.26aB	0.8 ± 0.04aB	65.1 ± 0.53aB	-8.77 ± 0.87aB	20.61 ± 0.5aB
		24B	6.36 ± 0.39aB	0.83 ± 0.04aB	65.66 ± 1.09aB	-9.52 ± 0.16aB	19.02 ± 0.67bB
4M	Agria	Ctr	0.5 ± 0.05aB	0.79 ± 0.08bB	68.29 ± 0.56bB	-8.35 ± 0.04aB	18.07 ± 0.33cB
		24A	0.53 ± 0.07aB	0.96 ± 0.16aB	70.46 ± 0.24aA	-8.16 ± 0.12aB	19.82 ± 0.97bB
		24B	0.52 ± 0.07aB	0.71 ± 0.08bB	70 ± 0.99aA	-8.62 ± 0.28aB	23.56 ± 1.25aB
	Picasso	Ctr	0.44 ± 0.13aB	0.49 ± 0.09aB	59.35 ± 0.43aB	-4.85 ± 0.13bB	3.17 ± 0.51aB
		24A	0.38 ± 0.07aB	0.47 ± 0.08aB	58.92 ± 0.67aB	-4.1 ± 0.1aB	0.33 ± 0.34bB
		24B	0.31 ± 0.11bB	0.28 ± 0.04bB	60.35 ± 0.36aB	-5.13 ± 0.12cB	3.53 ± 0.38aB
	Rossi	Ctr	0.55 ± 0.03aB	0.88 ± 0.09aB	69.63 ± 0.6aA	-5.74 ± 0.06bB	9.54 ± 0.44bB
		24A	0.26 ± 0.02cB	0.3 ± 0.04cB	68 ± 0.51aA	-5.64 ± 0.1bB	6.78 ± 0.36cB
		24B	0.44 ± 0.03bB	0.58 ± 0.06bB	67.67 ± 0.68aA	-3.15 ± 0.3aB	19.08 ± 1.12aA

For each parameter, different letters indicate significant differences between treatments in each variety (a,b) or between raw and cooked tubers at the same time of analysis (harvest and 4M) (A,B).

symptoms in the three genotypes and, as such, only the first foliar application was carried out with Ca-EDTA concentration. Nonetheless, independently of the Ca accumulation in the three varieties, our data (Table 1) suggested that Ca2+ mass flow through the xylem (Ziegler 1975; Barthakur et al. 2001; White and Broadley 2003; Drazeta et al. 2004; Subramanian et al. 2011) was complemented by phloem redistribution of Ca obtained by the foliar applications carried out, being in accordance with several authors (Davies and Millard 1985; Oparka and Davies 1988; Nelson et al. 1990). Also, regarding the other minerals analyzed (Table 1), it was possible to observe a few changes mediated by Ca since significantly higher content of Fe and Mg in Agria, Fe and Zn in Picasso and K, Fe and Zn in Rossi were found in the highest Ca treatment. In fact, according to Fageria (2001), Ca has a synergistic relationship with K, as verified in Rossi. Moreover, was also possible to verify different correlations between mineral elements depending on the variety (Fig. 2). In fact, a close interaction prevailed between the accumulation of minerals and the increase of Ca (Table 1), as well as with the correlation between them (Fig. 2). Additionally, those correlations were also observed in Fig. 3. Nevertheless, in this case study, the results showed different interactions of elements per variety, suggesting significant differences in the distribution and content of macro and micro elements (Table 1). As such, correlation between mineral elements is an indicative of the synergetic and antagonistic interactions between mineral elements (namely, between Ca and P, K, Fe, Zn and Mg).

According to some studies carried out with different food matrixes (namely, apples, potatoes, and peaches), the supply of Ca has some beneficial effects on quality (Dayod et al. 2010). For instance, according to Braun et al. (2010), dry matter content is a putative criterion that can determine potato texture, yet, according to our data (Table 2), a link between the highest Ca in tubers of the three varieties and the dry matter content could not be found. Moreover, the control and 24B treatment of Agria might be highly suitable for industrial processing (DW > 20%) (Braun et al. 2010), at harvest and after four and eight months under cold storage (Table 2). Additionally, was verified a tendency of dry matter content: harvest > 8M > 4M. In fact, tuber's weight loss is dependent on tuber variety and storage conditions. Although lower storage temperatures have been shown less impacts in tuber's weight loss, there are still losses (Haider et al. 2023) as verified in our study (Table 2). Besides, the increase in dry weight content after 8M of storage compared to 4M data is probably due to evaporation and decay of tubers, considering that after 4M of storage the lower dry weight content observed is probably due to sprout development, respiration, and transpiration of tubers (Burton 1989).

Regarding the TSS (Table 3), the values obtained align with a previous study carried out with the same varieties (Coelho et al. 2021).

Considering that lipid degradation in food matrixes (namely, in processed potato products) can cause off-flavor and rancidity problems (Galliard 1973), the total fatty acid content (TFA) and the double bound index (DBI) were analyzed (Table 4). Nevertheless, foliar application with Ca using both chemical forms (calcium chloride and Ca-EDTA), at 12 and 24 $kg.ha^{-1}$ concentrations, did not reveal impacts in lipid contents in the three varieties and at the different times of analysis (harvest, 4M and 8M). The values obtained in our study revealed higher values of TFA relative to other *Solanum tuberosum* L. varieties (Galliard 1973). Moreover, according to Cotrufo and Lunsetter (1964) research in potato tubers, there were also significant differences in fatty acids during storage (2 months), being in that time that the break in the rest period of the tubers occurred. Moreover, another study carried out by Dobson et al. (2004) also showed that the TFA content increased in the initial storage time and then showed a decrease (after more than 5 months), as seen in our study (Table 4). Additionally, following Knowles and Knowles (1989), the content of specific fatty acids or lipids in raw tubers can be used as markers for flavor characteristics of cooked potatoes. Besides, with ageing of potato tubers during storage, DBI (Table 4) affects membrane permeability, as it changes membrane bilayer (Knowles and Knowles 1989). In fact, a higher DBI determines more resistance to leakage of metabolites (Knowles and Knowles 1989). As such, overall, there is only a significant decrease in the DBI content in the tubers of Agria and Picasso varieties after 8M of storage conditions and not in Rossi variety, suggesting that the decrease is variety dependent, and that Ca sprays did not affect the permeability of the lipid's membrane in *Solanum tuberosum* L. tubers regarding the storage time.

Following Lobos et al. (2021) working with blueberries, with the assumption that through Ca sprays, the improvement of cell walls can lead to firmer tissues, early Ca applications showed the highest firmness and the lowest mass loss during the storage period. Additionally, according to Lara (2013), Ca fertilization leads to a reduction of the occurrence of physiological disorders (namely, internal brown spot, hollow heart, and bruising) and the reduction of storage rot due to the increase of tuber Ca content. Other studies have also presented evidence linking Ca to tuber quality (Karlsson et al. 2006). In fact, the physiological disorders that can occur in tubers diminish quality of tubers and consequentially decreases their market value (Clough, 1994). In this context, the increase of Ca content though foliar application seems a sustainable approach to limit economic loss.

Cocked potatoes and related products are highly consumed and represent a significant sector in the fast-food industry (Chiavaro et al. 2006). In this context, raw and cooked tubers (i.e. tubers pulp submitted to heat treatment) (Fig. 4; Table 5), through Ca foliar application, showed minor changes in tubers quality. Regarding raw tubers, fracturability wasn't affected by Ca treatments in the three varieties at harvest and after 4M. However, regarding cooked tubers Ca treatments interfered with fracturability in the three varieties booth at harvest and after 4M. In fact, according to Taguchi et al. (1991) study, varieties, despite showing differences in fracturability, can be correlated with the tuber Ca content. The higher Ca content in tubers can improve resistance of tubers to mechanical impacts as it is probably linked to the role of Ca in the cell wall (Koch et al. 2019). Following this item, hardness parameter on raw and cooked tubers (Fig. 4), was higher at harvest in 24A and 24B treatments on Agria and in Ctr on Picasso. Yet, also at harvest, hardness values in Rossi pointed to a change after the tubers being cooked, showing a significantly higher value in 24B treatment. Additionally, after 4M, both in raw and cooked tubers there was an enormous increase in all the treatments in hardness. In fact, in a study carried out in tubers of D. dumetorum (Afoakwa and Sefa-Dedeh 2001), it was found that with the increase of storage time the hardness parameter augmented, being associated with the cell wall polysaccharide components, being related to the hardening phenomenon's that occurs after harvesting. Moreover, the hardness phenomenon is complex and has been associated with pectin and action of enzymes that modify its structure (Kaaber et al. 2007). Probably those polysaccharides are involved when changes in potato tubers texture prevails, considering that is a crucial component in the cell wall and for the middle lamella in potatoes (Kaaber et al. 2007). Nevertheless, the texture of cooked tubers is dependent on the variety (Jayanty et al. 2019), as verified in our study.

Considering Table 5, Picasso variety in 24B treatment seems to influence work strength parameter in raw and cooked tubers at harvest and after 4M under cold storage.

Overall, work strength parameter didn't seem to be influenced by Ca biofortification treatments in Agria and Rossi varieties. Additionally, the reduction of the work strength observed in cooked tubers compared to the raw ones, is due to the water uptake by the polysaccharides of the cell wall that occurs during cooking (Warren and Woodamn 1974). In the raw tubers of the three varieties, with the Ca biofortification treatments the adhesiveness parameter (Table 4) increased at harvest and after 4M, indicating that Ca has a positive effect in adhesiveness. Overall, our data with cooked tubers, showed a higher value with compared with the ones obtained by Bordoloi et al. (2012) in Agria, Moonlight, Nadine, and Red Rascal varieties. However, at harvest Agria, in the Ca biofortification treatments showed similar values (0.38) to the ones obtained by Bordoloi et al. (2012), and much higher values relatively to those obtained after 4M, in cooked tubers. Nevertheless, changes that occur in the mechanical properties of cooked tubers of *Solanum tuberosum* L. are mostly due to changes that affect structural components, namely the cell wall and middle lamella (Bordoloi et al. 2012).

As color is considered a very important parameter in potato tubers because affects consumers' acceptability (Xiao et al. 2020), the L parameter of cooked tubers showed a darker color compared to raw tubers and b* parameter where higher in raw tubers relative to the cooked ones, showing a more yellow color. Additionally, in raw tubers Agria showed lower values of L and b* parameters but similar values of a*, as previously found by Cabezas-Serrano et al. (2009).

Generally, there were differences between each variety considering the work strength, adhesiveness and CIELAB parameters (L, a* and b*) both in raw and cooked tubers submitted to Ca biofortification treatments. Regardless of some parameters being variety dependent, Ca biofortification process showed beneficial influence in texture and their interference in the remaining parameters was negligible, pointing to the absence of negative effects in quality.

Conclusion

Through the Ca biofortification process of tubers of *Solanum tuberosum* L (Agria, Picasso, and Rossi varieties), the calcium content was successfully increased through foliar sprays with $CaCl_2$ or Ca-EDTA - 12 or 24 $kg.ha^{-1}$. Furthermore, the impact of both products on the enhancement of Ca varied across the three varieties studied: Ca-EDTA 12 $kg.ha^{-1}$ was found to be more effective for Picasso and Rossi varieties, while $CaCl_2$ 12 $kg.ha^{-1}$ was more suitable for Agria variety. Additionally, different correlations were observed among Ca, P, K, Fe, Zn and Mg, with variations specific to each variety.

In terms of dry weight content and TSS, there appears to be no relationship between this quality parameter and the Ca content in tubers. Moreover, Ca sprays did not seem to affect the permeability of the lipids, regardless of the storage time. It can further be concluded that Ca biofortification can be implemented to achieve tubers with higher quality in terms of texture, at harvest or under cold storage conservation.

Acknowledgements

This work received funding from PDR2020-101-030719 and from Fundação para a Ciência e a Tecnologia, I.P. (FCT), Portugal, through the research units UIDB/04035/2020 (GeoBioTec) and UIDB/00239/2020 (CEF). This work was further supported by the grant of the Fundação para a Ciência e Tecnologia (FCT) UI/BD/150806/2020.

References

Afoakwa EO, Sefa-Dedeh S (2001) Chemical composition and quality changes occurring in *Dioscorea dumetorum* pax tubers after harvest. Food Chemistry 75: 85–91. https://doi.org/10.1016/S0308-8146(01)00191-1

Alamar MC, Tosetti R, Landahl S, Bermejo A, Terry LA (2017) Assuring potato tuber quality during storage: a future perspective. Frontiers in Plant Science 8: 2034. https://doi.org/10.3389/fpls.2017.02034

Ali MME, Petropoulos SA, Selim DAFH, Elbagory M, Othman MM, Omara AE-D, Mohamed MH (2021) Plant Growth, yield and quality of potato crop in relation to potassium fertilization. Agronomy 11(4): 675. https://doi.org/10.3390/agronomy11040675

Barthakur NN, Donnelly DJ, Habib A (2001) Transfer of Strontium-90 and Ca-45 from medium to plant and their translocation in micropropagated potato. In: Proceedings of the International Congress on the Radioecology and Ecotoxicology of Continental and Estuarine Environments (ECO-RAD, 2001), Aix en Provence, France, 3–7 September 2001.

Blenkinsop RW, Copp LJ, Yada RY, Marangoni, AC (2002) Changes in compositional parameters of tubers of potato (*Solanum tuberosum*) during low-temperature storage and their relationship to chip processing quality. Journal of Agricultural and Food Chemistry 50: 4545–4553. https://doi.org/10.1021/jf0255984

Bordoloi A, Kaur L, Singh J (2012) Parenchyma cell microstructure and textural characteristics of raw and cooked potatoes. Food Chemistry 133: 1092–1100. https://doi.org/10.1016/j.foodchem.2011.11.044

Braun H, Fontes P, Finger F, Busato C, Cecon P (2010) Carboidratos e matéria seca de tubérculos de varieties de batata influenciados por doses de nitrogênio. Ciência e Agrotectecnologia 34: 285–293. https://doi.org/10.1590/S1413-70542010000200003

Burton WG (1989) The Potato, 3rd ed.; Longaman Scientific & Technical.

Cabezas-Serrano AB, Amodio ML, Cornacchia R, Rinaldi R, Colelli G (2009) Suitability of five different potato varieties (*Solanum tuberosum* L.) to be processed as fresh-cut products. Postharvest Biology and Technology 53: 138–144. https://doi.org/10.1016/j.postharvbio.2009.03.009

Camire ME, Kubow S, Donnelly DJ (2009) Potatoes and human health. Critical Reviews in Food Science and Nutrition 49: 823–840. https://doi.org/10.1080/10408390903041996

Carrondo M, Reboredo F, Ganho R, Santos OJF (1984) Heavy metal analysis of sediments in Tejo estuary, Portugal, using a rapid flameless atomic absorption procedure. Talanta 31: 561–564. https://doi.org/10.1016/0039-9140(84)80141-1

Chiavaro E, Barbanti D, Vittadini E, Massini R (2006) The effect of different cooking methods on the instrumental quality of potatoes (cv. Agata). Journal of Food Engineering 77: 169–178. https://doi.org/10.1016/j.jfoodeng.2005.06.060

Clough GH (1994) Potato tuber yield, mineral concentration, and quality after calcium fertilization. Journal of the American Society for Horticultural Science 119: 175–179. https://doi.org/10.21273/JASHS.119.2.175

Coelho ARF, Lidon FC, Pessoa CC, Marques AC, Luís IC, Caleiro J, Simões M, Kullberg J, Legoinha P, Brito M, Guerra M, Leitão RG, Galhano C, Scotti-Campos P, Semedo JN, Silva MM, Pais IP, Silva MJ, Rodrigues AP, Pessoa MF, Ramalho JC, Reboredo FH (2021) Can foliar pulverization with $CaCl_2$ and $Ca(NO_3)_2$ trigger calcium enrichment in *Solanum tuberosum* L. tubers? Plants 10: 245. https://doi.org/10.3390/plants10020245

Cotrufo C, Lunsetter P (1964) The fatty acids of potato tubers (*Solanum tuberosum*). American Potato Journal 41: 18–22. https://doi.org/10.1007/BF02862811

Davies HV, Millard P (1985) Fractionation and distribution of calcium in sprouting and non-sprouting potato tubers. Annals of Botany 56: 745–754. https://doi.org/10.1093/oxfordjournals.aob.a087066

Dayod M, Tyerman S, Leigh R, Gilliham M (2010) Calcium storage in plants and the implications for calcium biofortification. Protoplasma 247: 215–231. https://doi.org/10.1007/s00709-010-0182-0

Dobson G, Griffiths DW, Davies HV, NcNicol JW (2004) Comparison of fatty acid and polar lipid contents of tubers from two potato species, *Solanum tuberosum* and *Solanum phureja*. Journal of Agricultural and Food Chemistry 52: 6306–6314. https://doi.org/10.1021/jf049692r

Drazeta L, Lang A, Hall AJ, Volz RK, Jamson PE (2004) Causes and effects of changes in xylem functionality in apple fruit. Annals of Botany 93: 275–282. https://doi.org/10.1093/aob/mch040

El-Hadidi EM, El-Dissoky RA, Abdelhafez AAH (2017) Foliar calcium and magnesium application effect on potato crop grown in clay loam soils. Journal of Soil Science and Agricultural Engineering 8: 1–8. https://doi.org/10.21608/jssae.2017.37074

El-Yazied A, Ragab ME, Ibrahim RE, El-Wafa A (2007) Effect of nitrogen fertigation levels and chelated calcium foliar application on the productivity of sweet corn. Arab University Journal of Agricultural Sciences 15(1): 131–139. https://doi.org/10.21608/ajs.2007.14681

El-Zohiri SSM, Asfour HE (2009) Effects of foliar sprays of potassium, magnesium, and calcium on yield, quality, and storageability of potato. Proceedings of the Fifth International Congress of Sustainable Agriculture Development, 57–71, Faculty of Agriculture, Fayoum University, Egypt, 21–23 December 2009.

Fageria VD (2001) Nutrient interactions in crop plants. Journal of Plant Nutrition 24: 1269–1290. https://doi.org/10.1081/PLN-100106981

FAOSTAT (2023) Production and Trade Statistics. https://www.fao.org/faostat/en/#data/QCL [Accessed on 7 March, 2023]

Galliard T (1973) Lipids of potato tubers. 1. Lipid and fatty acid composition of tubers from different varieties of potato. Journal of Science of Food and Agriculture 24: 617–622. https://doi.org/10.1002/jsfa.2740240515

Gondwe RL, Kinoshita R, Suminoe T, Aiuchi D, Palta J, Tani M (2019) Soil and tuber calcium affecting tuber quality of processing potato (*Solanum tuberosum* L.) varieties grown in Hokkaido, Japan. Soil Science and Plant Nutrition 65: 159–165. https://doi.org/10.1080/00380768.2019.1579044

Haider MW, Nafees M, Iqbal R, Asad HU, Azeem F, Shaheen G, Iqbal J, Vyas S, Arslan M, Rahman MHU (2023) Postharvest starch and sugars adjustment in potato tubers of wide-ranging dormancy genotypes subjected to various sprout forcing techniques. https://doi.org/10.21203/rs.3.rs-2394606/v1

Hossain MA, Miah MAM (2009) Post-harvest losses and technical efficiency of potato storage systems in Bangladesh. Research report. FAO Bangladesh, Food Planning and Monitoring Unit (FPMU), Ministry of Food and Disaster Management, Dhaka, Bangladesh.

Jayanty SS, Diganta K, Raven B (2019) Effects of cooking methods on nutritional content in potato tubers. American Journal of Potato Research 96: 183–194. https://doi.org/10.1007/s12230-018-09704-5

Kaaber L, Kaack K, Kriznik T, Brathen E, Knutsen SH (2007) Structure of pectin in relation to abnormal hardness after cooking in pre-peeled, cool-stored potatoes. LWT-Food Science and Technology 40(5): 921–929. https://doi.org/10.1016/j.lwt.2006.03.026

Karlsson BH, Palta JP, Crump PM (2006) Enhancing tuber calcium concentration may reduce incidence of blackspot bruise injury in potatoes. Journal of Horticultural Science 41: 1213–1221. https://doi.org/10.21273/HORTSCI.41.5.1213

Knowles NR, Knowles LO (1989) Correlations between electrolyte leakage and degree of saturation of polar lipids from aged potato (*Solanum tuberosum* L) tuber tissue. Annals of Botany 63: 331–338. https://doi.org/10.1093/oxfordjournals.aob.a087749

Koch M, Naumann M, Pawelzik E (2019) Cracking and fracture properties of potato (*Solanum tuberosum* L.) tubers and their relation to dry matter, starch, and mineral distribution. Journal of the Science of Food and Agriculture 99: 3149–3156. https://doi.org/10.1002/jsfa.9530

Kucukyumuk Z, Erdal İ (2022) Effect of calcium on mineral nutrient concentrations and fruit quality in different apple tree varieties. Journal of Elementology 27(1): 1. https://doi.org/10.5601/jelem.2022.27.1.2168

Lal MK, Kumar A, Kumar A, Raigond P, Oko AO, Thakur N, Parmar V, Thakur A, Singh B (2020) Dietary Fibres in Potato. In: Raigond P, Singh B, Dutt S, Chakrabarti SK (Eds) Potato: Nutrition and Food Security. Springer, Singapore, 37–50. https://doi.org/10.1007/978-981-15-7662-1_3

Lara I (2013) Preharvest sprays and their effects on the postharvest quality of fruit. Stewart Postharvest Review 9: 1–12. https://doi.org/10.2212/spr.2013.3.5

Lateef MA, Noori AM, Saleh YM, Al-Taey DK (2021) The effect of foliar spraying with salicylic acid and calcium chloride on the growth, yield, and storage traits of two strawberry cultivars, *Fragaria* x *ananassa* Duch. International Journal of Agricultural and Statistical Sciences 17(2): 611–615.

Lobos TE, Retamales JB, Hanson EJ (2021) Early preharvest calcium sprays improve postharvest fruit quality in 'Liberty' highbush blueberries. Scientia Horticulturae 277: 109790. https://doi.org/10.1016/j.scienta.2020.109790

Loekito S, Afandi A, Nishimura N, Koyama H, Senge M (2022) The effects of calcium fertilizer sprays during fruit development stage on pineapple fruit quality under humid tropical climate. International Journal of Agronomy 2022(1): 3207161. https://doi.org/10.1155/2022/3207161

Marques E, Darby HM, Kraft J (2021) Benefits and limitations of non-transgenic micronutrient biofortification approaches. Agronomy 11: 464. https://doi.org/10.3390/agronomy11030464

Matteo M, Zoffoli JP, Ayala M (2022) Calcium sprays and crop load reduction increase fruit quality and postharvest storage in sweet cherry (*Prunus avium* L.). Agronomy 12: 829. https://doi.org/10.3390/agronomy12040829

Mazliak P (1983) Plant membrane lipids: Changes and alterations during aging and senescence. In: Lieberman M (Ed.) Post-Harvest Physiology and Crop Preservation. Springer, Boston, MA, USA, Volume 46, 123–140. https://doi.org/10.1007/978-1-4757-0094-7_5

Mousavi S, Galavi M, Ahmadvand G (2007) Effect of zinc and manganese foliar application on yield, quality, and enrichment on potato (*Solanum tuberosum* L.). Asian Journal of Plant Sciences 6: 1256–1260. https://doi.org/10.3923/ajps.2007.1256.1260

Nelson DP, Pan WL, Franceschi VR (1990) Xylem and phloem transport of mineral nutrients from *Solanum tuberosum* roots. Journal of Experimental Botany 41: 1143–1148. https://doi.org/10.1093/jxb/41.9.1143

Olsen N, Kleinkopf G (2020) Storage Management. In: Stark J, Thornton M, Nolte P (Eds) Potato Production Systems. Springer, Cham, 523–546. https://doi.org/10.1007/978-3-030-39157-7_17

Oparka KJ, Davies HV (1988) Subcellular localization of calcium in potato tubers. Potato Research 31: 297–304. https://doi.org/10.1007/BF02365538

Palta JP (2010) Improving potato tuber quality and production by targeted calcium nutrition: the discovery of tuber roots leading to a new concept in potato nutrition. Potato Research 53: 267–275. https://doi.org/10.1007/s11540-010-9163-0

Pessoa CC, Lidon FC, Coelho ARF, Caleiro JC, Marques AC, Luís IC, Kullberg JC, Legoinha P, Brito MG, Ramalho JC, Guerra MAM, Leitão RG, Simões M, Scotti PC, Semedo JMN, Silva MM, Pais IP, Leal N, Alvarenga N, Gonçalves EM, Silva MJ, Rodrigues AP, Abreu M, Pessoa MF, Reboredo FH (2021) Calcium biofortification of rocha pears, tissues accumulation and physicochemical implications in fresh and heat-treated fruits. Science Horticulturae 277: 109834. https://doi.org/10.1016/j.scienta.2020.109834

Pessoa CC, Lidon FC, Daccak D, Luís IC, Marques AC, Coelho ARF, Legoinha P, Ramalho JC, Leitão AE, Guerra M, Leitão RG, Campos PS, Pais IP, Silva MM, Reboredo FH, Pessoa MF, Simões M (2022) Calcium biofortification of rocha pear fruits: implications on mineral elements, sugars and fatty acids accumulation in tissues. Sci 4: 35. https://doi.org/10.3390/sci4040035

Poggi V, Arcioni A, Filippini P, Pifferi P (2000) Foliar application of selenite and selenate to potato (*Solanum tuberosum*): Effect of a ligand agent on selenium content of tubers. Journal of Agricultural and Food Chemistry 48: 4749–4751. https://doi.org/10.1021/jf000368f

Seifu YW, Deneke S (2017) Effect of calcium chloride and calcium nitrate on potato (*Solanum tuberosum* L.). growth and yield. Journal of Horticulture 4: 1–4.

Shi H, Zhou X, Qin M, Wang W, He X, Zhou W (2022) Effect of $CaCl_2$ sprays in different fruit development stages on grape berry cracking. Frontiers in Plant Science 13: 870959. https://doi.org/10.3389/fpls.2022.870959

Siró I, Kápolna E, Kápolna B, Lugasi A (2008) Functional food: Product development, marketing and consumer acceptance—A review. Appetite 51: 456–467. https://doi.org/10.1016/j.appet.2008.05.060

Subramanian NK, White P, Broadley M, Ramsay G (2011) The three-dimensional distribution of minerals in potato tubers. Annals of Botany 107: 681–691. https://doi.org/10.1093/aob/mcr009

Taguchi M, Schafer HW, Breene WM (1991) Influence of variety and prewarming on texture retention of thermally processed potatoes. Potato Research 34: 29–39. https://doi.org/10.1007/BF02358092

Taiz L, Zeiger E (2002) Plant Physiology, 3rd ed. Sinauer Associates, Inc.,Sunderland, UK, 665 pp.

Tian J, Chen J, Ye X, Chen S (2016) Health benefits of the potato affected by domestic cooking: A review. Food Chemistry 202: 165–175. https://doi.org/10.1016/j.foodchem.2016.01.120

Wang Y, Naber MR, Crosby TW (2020) Effects of wound-healing management on potato post-harvest storability. Agronomy 10: 512. https://doi.org/10.3390/agronomy10040512

Wang Y, Zhang X, Wang Y, Yang S, Qu H (2018) The changes of intracellular calcium concentration and distribution in the hard end pear (*Pyrus pyrifolia* cv. 'Whangkeumbae') fruit. Cell Calcium 71: 15–23. https://doi.org/10.1016/j.ceca.2017.11.002

Warren DS, Woodman JS (1974) The texture of cooked potatoes: A review. Journal of the Science of Food and Agriculture 25: 129–138. https://doi.org/10.1002/jsfa.2740250204

Wei S, Qin G, Zhang H, Tao S, Wu J, Wang S, Zhang S (2017) Calcium treatments promote the aroma volatiles emission of pear (*Pyrus ussuriensis* "Nanguoli") fruit during post-harvest ripening process. Scientia Horticulturae 215: 102–111. https://doi.org/10.1016/j.scienta.2016.12.008

White PJ, Broadley MR (2003) Calcium in plants. Annals of Botany 92: 487–511. https://doi.org/10.1093/aob/mcg164

Xiao Q, Bai X, He Y (2020) Rapid screen of the color and water content of fresh-cut potato tuber slices using hyperspectral imaging coupled with multivariate analysis. Foods 9: 94. https://doi.org/10.3390/foods9010094

Yuan W, Yuan S, Liu Z, Chen L, Qiu Z (2018) Effect of foliar application of $CaCl_2$ on lettuce growth and calcium concentrations with organic and conventional fertilization. HortScience 53: 891–894. https://doi.org/10.21273/HORTSCI13056-18

Zhang H, Zhao Z, Zhang X, Zhang W, Huang L, Zhan Z, Yuan L, Lui X (2019) Effects of foliar application of selenate and selenite at different growth stages on selenium accumulation and speciation in potato (*Solanum tuberosum* L.). Food Chemistry 286: 550–556. https://doi.org/10.1016/j.foodchem.2019.01.185

Ziegler H (1975) Nature of transported substances. In: Zimmermann MH, Milburn JA (Eds) Transport in Plants I: Phloem Transport. Encyclopedia of Plant Physiology. Springer, New York, NY, USA, Volume 1, 59–100. https://doi.org/10.1007/978-3-642-66161-7_3