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Effect of potassium fertilizers associated with cold storage on peach (*Prunus persica* L.) quality

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Abstract

Potassium (K) fertilization may affect peach quality and preservation. This study aimed at evaluating the effect of doses of K on physico-chemical and functional characteristics of 'Sensação' peaches in the postharvest period. Mass loss, pulp color, total soluble solids, titratable acidity, pH, pulp and skin firmness, total concentrations of phenolic compounds and carotenoids and antioxidant activity were evaluated in fruits. The experiment was a randomized block design in a 5x3 factorial scheme, five doses of fertilizers (0, 40, 80, 120 and 160 Kg ha^{-1} K_2O) and three storage periods (harvest day, 10 days and 20 days in cold storage at 1±1ºC, followed by a day of simulated commercialization at 20±1ºC). Mass loss, pulp firmness, phenolic compounds, antioxidant activity and carotenoids decreased when fruit underwent cold storage, independent of the dosage of K fertilization. Doses of 40 and 160 kg ha^{-1} K_2O applied to the soil lead to a larger number of phenolic compounds and higher antioxidant activity in fruits at harvest time. After cold storage, fertilization with 160 kg ha^{-1} K_2O exhibited the highest antioxidant activity and the lowest mass loss in fruits. Increase in doses of K strengthened the color of peach pulp.

Keywords: bioactive compounds, plant nutrition, postharvest period, *Prunus persica*.
Abbreviations: K_ Potassium; K_2O_ potassium chloride; RS_ Rio Grande do Sul; CV_ Coefficient of variation.

Introduction

Peach trees (*Prunus persica*) represent an economically and socially important culture in Brazil, a country that yields about 216 thousand ton of peaches per year, mainly in the south and in the southeast. Rio Grande do Sul (RS), the southernmost state, is the country's major producer, since it yields 117 thousand ton of fruit per year (IBGE, 2018) and dominates peach cultivation both for consumption and industry.
'Sensação" is the peach tree cultivar that has been recommended for the industry and for fresh fruit consumption. It results from free pollination of the selection 'Conserva 471', which originates from hybridization between the cultivar 'Alpes' and the selection 'Conserva 102' (Raseira et al., 2014).
In order to commercialize peaches, they must be produced with high quality and factors, such as size, color, taste and lack of defects, are important. These characteristics are directly related to cultivar genetics, edaphoclimatic conditions, use of culture techniques (Farias et al.2019; Mayer et al., 2019) and orchard fertilization (Ferreira et al., 2018).
However, since post-harvest of these peaches is limited by their high perishability, they need commercialization and/or consumption right after harvest or the use of storage methods that aim at extending the preservation period (Pegoraro et al., 2015). Refrigeration has been the most common storage method used for preserving peaches (Pinto et al., 2012).
An alternative to extend shelf life is to align refrigeration with potassium (K) fertilization. K is not only the most exported essential macronutrient from fruits (Rombolá et al., 2012), but it also performs specific and essential functions in plants, such as cell expansion, photosynthesis, protein synthesis and carbohydrate transport and accumulation (Taiz et al., 2017).
K fertilization may also extend preservation periods of fruits yielded by stone fruit trees (Rombolá et al., 2012), besides influencing fruit resistance (Ganeshamurthy et al., 2011), pulp color, firmness (Trevisan et al., 2006), acidity (Jawandha et al., 2017; Castricini et al., 2017) and soluble solids (Solhjoo et al., 2017; Jawandha et al., 2017). K fertilization may influence fruit quality since this nutrient is related to reactions of enzyme synthesis and activation which contribute to ripening, sugar synthesis and maintenance of cell turgor (Lester et al., 2010; Taiz et al., 2017).
Since there are very few data on the effect of K on physico-chemical characteristics of fruits, mainly on their bioactive compounds during storage, this study aimed at evaluating the effect of the combination of doses of K fertilization and different periods of cold storage on physico-chemical and phytochemical characteristics of peaches in post-harvest.

Results and discussion

Loss of peach mass after cold storage

Fruit mass loss, on day 10+1, was significantly lower when 120 kg ha^{-1} K_2O (Table 1) was used. When peaches were stored for 20+1 days, the lowest mass losses were found with the use of 160 kg ha^{-1} K_2O, by comparison with plants which got 40 kg ha^{-1} K_2O. Results show dose dependent variation but do not establish any direct relationship. K fertilization favors increase in fruit size (Souza et al., 2013).

Thus, high doses of K applied to plants may increase fruit size and influence mass loss during cold storage. According to Tutida (2006), high doses of K decrease plum mass loss after cold storage. Peach mass loss increased in the storage periods (Table 1), regardless of the dose of K, as the result of water loss, mainly due to transpiration, which is related to the vapor-pressure deficit between fruits and the environment (Pinto et al., 2012).

Titratable acidity and pH in peaches

K fertilization just influenced titratable acidity at harvest time; the dose of 120 kg ha^{-1} K_2O exhibited the lowest value of acidity (Table 2). Concerning consumption of fresh peaches, low acidity is desirable. Since doses of K fertilization decreased fruit acidity at harvest time, it is an important factor to make the cultivar 'Sensação' have dual finality and enable its fruits to be consumed fresh. Variation in acid contents in fruits may be associated with their ripening process, since K fertilization is related to reactions of enzyme synthesis and activation which directly contribute to this process. Increase in doses of K may have brought forward the fruit ripening process and increased organic acid degradation and, thus, decreased peach acidity in the harvest period.

Fruit pH did not show any difference between doses of K on harvest day and after 10+1 storage days (Table 2). However, after 20+1 days, pH of fruit juice was higher when 160 kg ha^{-1} K_2O was applied; it only differed from the dose of 80 kg ha^{-1} K_2O. According to Çolvan et al. (2013), increase in fruit pH may result from increase in K, a fact that was observed in the experiment described by this paper after 20+1 storage days. The fact that the highest dose of K fertilization increased fruit pH after 20+1 storage days may be undesirable because, in conditions of high K concentration, there may be stoichiometric exchange of protons, causing decrease in malic acid transport to the cytoplasm and leading to decrease in its degradation rate. Thus, malic acid may decrease and result in increase in pH and microbiological damage.

Fruit pH decreased between storage periods when doses of 80 and 120 kg ha^{-1} K_2O were applied, while the other doses did not show any differences among storage periods under study (Table 2). The lowest values of fruit pH may have occurred due to water loss during storage, a fact that led to H+ ion concentration.

Phenolic compounds in peach pulp

Both phenolic compound content and antioxidant activity varied as the result of doses of K fertilization and storage periods (Table 3). Peaches that had the highest concentrations of phenolic compounds at harvest time were yielded by plants to which 40 and 160 kg ha^{-1} K_2O had been applied.

When peaches were submitted to 10+1 and 20+1 days storage days, the highest concentration of phenolic compounds was found in fruits of plants that got 40 and 160 kg ha^{-1} K_2O. In general, doses of 40 and 160 kg ha^{-1} K_2O influenced fruits to produce more phenolic compounds in the three periods under evaluation. The fact that K fertilization applied to the soil influences phenolic compound contents in peaches draws much commercial interest, since phenolic compounds are beneficial to health (Silva et al., 2010). Although doses of 40 and 160 kg ha^{-1} K_2O led to increase in phenolic compounds in peaches, it should be highlighted that, if the objective is to increase their contents in these fruits, a lower dose (40 kg ha^{-1} K_2O) can be used, considering fertilizer costs and a sustainable ecosystem.

Phenolic compounds were found to decrease in fruits throughout storage days; they were more accentuated in peaches yielded by plants that had not gotten any K fertilization (Table 3). In the case of no K fertilization at all, phenolic compounds decreased 39% between harvest day and after 20+1 storage days. This decrease may result from the fact that peaches were stored at 1±1ºC in this study. It may have caused high oxidation of phenolic compounds at low temperature. According to Junmatong et al. (2015) at low temperatures, there may be production of species that react to oxygen, thus, resulting in higher consumption of phenolic compounds. Besides, the decrease may also be attributed to several chemical and enzyme changes that take place in phenols throughout the fruit ripening process (Vieites et al., 2012).

Antioxidant activity in peach pulp

Regarding antioxidant activity, fruits yielded by plants which got 40 and 160 kg ha^{-1} K_2O exhibited the highest concentrations on harvest day (Table 3). After 10+1 storage days, the highest means of antioxidant activity were found when 160 kg ha^{-1} K_2O was applied to the plants, by comparison with 80 and 120 kg ha^{-1} K_2O. Peaches stored for 20+1 days exhibited high antioxidant activity when 160 kg ha^{-1} K_2O was applied to the plants, by comparison with fruits yielded by plants that were not submitted to any K fertilization and 80 kg ha^{-1} K_2O. Therefore, if the objective is the consumption of peaches with high content of antioxidant compounds, doses of 40 and 160 kg ha^{-1} K_2O may be used at harvest time. However, if peaches undergo cold storage, plant must be fertilized with 160 kg ha^{-1} K_2O to keep high concentrations of this compound throughout fruit storage and commercialization.

Concerning fruit storage, antioxidant activity of peaches, regardless of doses of K, decreased in the periods under evaluation, mainly after 20+1 days (Table 3). Antioxidant activity of peaches decreased throughout cold storage; it may have happened because this compound degrades at low temperatures. According to Rotili et al. (2013), it results from the activity of compounds that are either degraded or synthesized during storage as a response to biotic and abiotic stress. In addition, decrease in antioxidant activity may be related to decrease in phenolic compounds, since a strong relation was found between both variables ($r = 0.946$). This correlation between the compounds has also been observed in the fruit by Pereira et al. (2017).

Pulp color in peaches

Pulp color, expressed as °Hue, exhibited linear increase as a response to doses of K applied to the soil (Figure 1). Color is one of the important attributes in fruit commercialization; thus, the dose of 160 kg ha^{-1} K_2O, applied to the soil, led to high color intensity in peach pulp. K is directly related to fruit color due to its mobility in plant phloem and xylem,

Table 1. Mass loss in fruits yielded by 'Sensação' peach trees submitted to different doses of K and storage periods.

	Storage periods			
Dose of K_2O (kg ha^{-1})	Day 10+1		Day 20+1	
	Mass loss (%)			
0	7.33	aB	12.91	bA
40	7.33	aB	18.93	aA
80	6.99	aB	12.30	bA
120	4.04	bB	13.16	abA
160	7.69	aA	9.52	bA
CV (%)	18.29			

Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability. CV (%) = Coefficient of variation.

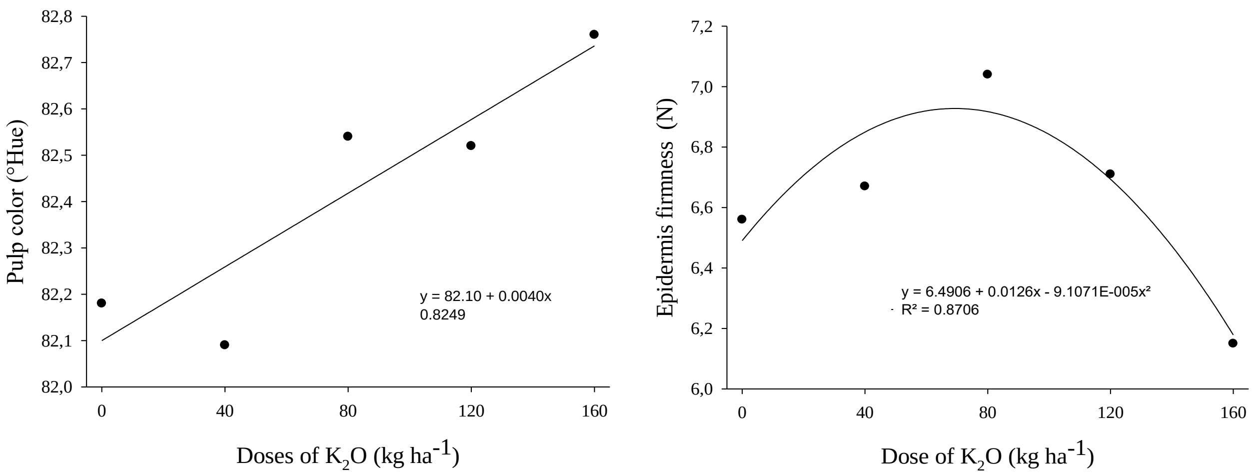

Figure 1. Pulp color and epidermis firmness in fruits yielded by 'Sensação' peach trees submitted to different doses of K and storage periods.

Table 2. Titratable acidity and pH in fruits yielded by 'Sensação' peach trees submitted to different doses of K and storage periods.

	Storage periods					
Dose of K_2O (kg ha^{-1})	Day 0		Day 10+1		Day 20+1	
	Titratable acidity (citric acid 100 g^{-1})					
0	1.14	aA	1.07	aA	1.01	aA
40	1.12	aA	1.01	aA	1.12	aA
80	1.06	abA	1.05	aA	1.07	aA
120	0.93	bB	1.13	aA	1.11	aA
160	1.00	abA	1.12	aA	0.98	aA
CV (%)	8.46					
	pH in fruits					
0	3.58	aA	3.60	aA	3.60	abA
40	3.57	aA	3.54	aA	3.57	abA
80	3.62	aA	3.57	aAB	3.54	bB
120	3.67	aA	3.61	aAB	3.57	abB
160	3.67	aA	3.64	aA	3.64	aA
CV (%)	1.30					

Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability. CV (%) = Coefficient of variation.

Table 3. Phenolic compounds and antioxidant activity in pulp of fruits yielded by 'Sensação' peach trees submitted to different doses of K and storage periods.

	Storage periods					
Dose of K_2O (kg ha^{-1})	Day 0		Day 10+1		Day 20+1	
	Phenolic compounds[1]					
0	177.68	bA	143.79	bB	108.33	cC
40	190.57	aA	161.01	abB	148.71	aB
80	162.81	cA	152.95	bA	122.29	cB
120	165.60	cA	149.53	bA	135.58	bB
160	197.83	aA	168.11	aB	147.23	aB
CV (%)	1.08					
	Antioxidant activity[2]					
0	2434.00	bA	2055.71	bA	1336.74	bB
40	2994.79	aA	2227.15	abB	1774.96	abC
80	2328.94	bA	2266.50	abA	1542.72	abB
120	2339.23	bA	1986.77	bB	1724.83	abB
160	2675.97	abA	2319.23	aB	1989.38	aB
CV (%)	13.94					

[1]mg galic acid equivalent 100 g^{-1} fresh weight. [2]mg trolox equivalent 100 g^{-1} fresh weight. Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability. CV (%) = Coefficient of variation.

Table 4. Pulp firmness, soluble solids and total carotenoids in fruits yielded by 'Sensação' peach trees submitted to different doses of K and storage periods.

Dose of K_2O (kg ha^{-1})	Pulp firmness		Soluble solids		Carotenoids ¹	
0	2.31	ns	9.33	ns	5.19	ns
40	2.56		9.13		5.29	
80	2.43		9.21		4.86	
120	2.54		9.40		5.16	
160	2.25		9.34		5.01	
Storage periods						
0	3.32	a	8.66	c	5.66	a
10+1	2.48	b	9.25	b	4.82	b
20+1	1.45	c	9.94	a	4.78	b
CV(%)	15.70		3.98		13.94	
Interaction (Dose x Storage periods)	ns		ns		ns	

¹ mg de β-caroteno.$100g^{-1}$. Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability. CV (%) = Coefficient of variation. ns = not significant.

solute transport, assimilate partitioning and synthesis of polyphenols, which are responsible for fruit color and aroma (Brunetto et al., 2015). These results corroborate the ones found by Bertolini et al. (2018), who found intense color in 'Marli' peaches when K fertilization was used. Pulp color did not show any difference during fruit storage and the °Hue mean was 82.4.

Epidermis and pulp firmness in peaches

Regarding epidermis firmness, quadratic behavior was found; the highest value was observed when about 80 kg ha^{-1} K_2O was applied to the soil (Figure 1). Epidermis firmness is an important attribute to maintain fruit integrity throughout transport and commercialization. Ganeshamurthy et al. (2011) stated that one of the beneficial effects of K is fruit resistance to handling and/or physical damage during transportation and storage.

Even though K is considered an element that influences fruit quality (Castricini et al., 2017), increase in doses of K did not change pulp firmness in the conditions of this study (Table 4). It contradicts data found in the literature which reports that increase in doses of K decreases citrus firmness (Castricini et al., 2017) and apple firmness (Souza et al., 2013). The absence of any effect may result from pectin activity, since it is a polymer that determines firmness and contributes to mechanical resistance of cell walls but its activity is not affected by fertilizers applied to plants.

Pulp firmness and epidermis firmness decreased in the storage periods (Table 4). After cold storage, peaches were in an advanced stage of ripening due to pectin solubilization and decrease in cohesion among cells. Pulp firmness decreased as a consequence of solubilization of cell wall components (Pegoraro et al., 2015). Decrease in pulp firmness in peaches during cold storage was also observed by Barreto et al. (2016).

Soluble solids in peaches

Contents of soluble solids found in peaches were not affected by different doses of K applied to the peach trees (Table 4). These data agree with the ones reported by Tutida (2006), who found that contents of soluble solids did not change after K application. However, other authors reported that K fertilization increases concentrations of soluble solids in fruits (Solhjoo et al., 2017; Jawandha et al., 2017), since this nutrient helps carbohydrate transport. In this study, the initial level of K in the soil (high content) may have been enough to reach this objective and better response was not obtained. In the storage periods, these contents increased, a fact that shows the advanced stage of fruit ripening, since this process leads to increase in both sugar concentration (Jie et al., 2013) and mass loss.

Carotenoids in peach pulp

A content of carotenoids in peaches was not affected by different doses of K fertilization (Table 4). This result may be due to the fact that the initial level of K in the soil may have been enough to reach this objective. Thus, no response was given to this variable. According to Fanasca et al. (2006), this nutrient may be involved in the activation of several enzymes that regulate carbohydrate metabolism, such as isopentenyl pyrophosphate, precursor of carotenoid biosynthesis.

Fruits evaluated at harvest time exhibited higher contents of carotenoids than the ones that were evaluated after cold storage. It may have happened due to carotenoid degradation caused by oxidation resulting from the high temperature throughout the period of simulated commercialization (Pestana et al., 2008).

Materials and methods

Plant material and study area

In this experiment, peaches borne by the cultivar 'Sensação' were harvested in the 2016 crop in a commercial orchard which had been implanted in 2012 in Morro Redondo, RS, Brazil (31°31'49.3"S and 52°35'39.8"W). Physico-chemical analyses of the soil, that were carried out before the assay was conducted, reached the following results: pH in water was 5.8; 11.3 mg dm^{-3} P; 101 mg dm^{-3} K; 3.7 $cmolcdm^{-3}$ Ca; 0.9 cmolc dm^{-3} Mg; 22 g kg^{-1} organic matter; and 26 g kg^{-1} clay.

Treatments and experimental design

The following doses of K were applied to the plants: 0, 40, 80, 120 and 160 Kg ha^{-1} K_2O. The source of K was potassium chloride (60% K_2O); it was applied annually, close to full bloom of peach trees (July), on the layer of crown projection, on the soil surface, with no incorporation. All plants got equal doses of nitrogen (N) and phosphorus (P), in agreement with recommendations issues by CQFS-RS/SC (2016).

Cold storage periods lasted 10 and 20 days at 1±1ºC and air relative humidity ranged from 85 to 90%, followed by a day of simulated commercialization at 20±1ºC (day 10+1 and day 20+1). Harvest day (day 0) was the control.

The experimental was a randomized block design consisting of four plants per replicate, the two central plants being used for the evaluations. The 5x3 factorial scheme (five doses of K and three storage periods) with four replicates and ten fruits per plot.

Traits under evaluation

Mass loss: determined by the difference between fruit mass at harvest time and at the evaluation of storage and results expressed as percentage; Colorimetry of pulp: determined by readings carried out in the equatorial region of whole fruits with their skin, by a Minolta 400/410 colorimeter and measurements conducted in the CIELAB color space, a three-dimensional model (L* a* b*), and results expressed as values of color shades (HUE angle) and luminosity (L*); Firmness of the pulp: evaluated by a texture analyzer (TA.XT plus®, Stable Micro Technologies Texture Systems) with a 2-mm P2 tip, force of 5 g, speed of 5 mms-1 and results expressed as Newton (N);

Soluble solids: determined by an ATAGO digital refractometer, model PAL^{-1}, Atago® brand digital refractometer, with results expressed in ºBrix (AOAC, 2005); Potential of Hydrogen (pH): A ground sample of 10 g was diluted in 100 mL of distilled water and homogenized. The pH was measured by potentiometry and duly calibrated with solutions of 4.0 and 7.0 pH, according to the Analytical Standards of the Adolfo Lutz Institute (2008); Titratable Acidity: We diluted 10 g of ground sample in 90 mL of distilled water and titrated with a standard 0.1N NaOH solution using phenolphthalein as an indicator. The result was expressed in g of citric acid.100g^{-1} of pulp according to the Analytical Standards of the Adolfo Lutz Institute (2008); Total phenolic compounds: were determined according to the adapted method adapted from Swain and Hillis (1959) using the reaction with the Folin-Ciocalteau reagent, the results were expressed in mg Gallic acid per 100 g of sample; Antioxidant activity: determined by the DPPH method, in agreement with the method proposed by Brand-Williams et al. (1995); results were expressed as µg equivalent trolox.100 g^{-1} fresh mass; Carotenoids: determined by the methodology developed by Talcott and Howard (1999); results were calculated by a standard curve, which was constructed with β-carotene, and expressed as mg β-carotene.100g^{-1}.

Statistical analysis

Data were submitted to the analysis of variance by the F-test. When the effect was significant, the Tukey's test and the analysis of polynomial regression were carried out by the ASSISTAT statistical program (Silva & Azevedo, 2016). The analysis of Pearson's correlation was conducted to show whether there was any positive or negative relation between two variables.

Conclusion

K fertilization at the dose of 120 kg ha^{-1} led to the lowest values of acidity in fruits at harvest time. Doses of 40 and 160 kg ha^{-1} K_2O led to high contents of phenolic compounds and antioxidant activity, but the dose of 160 kg ha^{-1} K_2O decreased mass loss after 20+1 storage days. Pulp firmness, phenolic compounds, antioxidant activity and carotenoids of peaches decreased throughout cold storage. K fertilization in the cultivar 'Sensação' did not influence pulp firmness, soluble solids and total carotenoids.

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