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Physicochemical and functional characteristics of peach cv. Esmeralda fertilized with different doses of nitrogen

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Abstract

The aim of this study was to evaluate the physicochemical and functional characteristics of fruits yielded by peach trees which were fertilized with different doses of nitrogen. The experiment, which was installed in 2014. It had a randomized complete block design with four replicates. The nitrogen rates applied were 0, 40, 80, 120, and 160 kg N per hectare. Fruits were harvested in four crops in a row (2014, 2015, 2016, and 2017). The parameters were evaluated: soluble solids, pH, titratable acidity, epidermis and pulp firmness, attributes of pulp color, carotenoids, phenolic compounds, and antioxidant activity. Responses were only related to luminosity in the first crop. However, N fertilization influenced not only the soluble solid content, pH and chroma in the second crop but also all attributes of color in the third crop. SS, pH, °Hue and chroma differed among treatments in the fourth crop. The more N in the first three crops, the more carotenoids. Phenolic compounds decreased significantly in the 2016 crop whereas antioxidant activity diminished in both the 2015 and 2016 crops. Even though an ideal dose of N cannot be recommended due to high variation in attributes in the years under evaluation, it is needed because of other factors, such as weather.

Keywords: antioxidant activity, mineral nutrition, post-harvest, Prunus persica

Introduction

Nitrogen is often regarded as the most important mineral nutrient, limiting crop production in many agricultural crops worldwide (Carranca et al., 2018). It plays specific roles in plants, such as the constitution of amino acids and proteins, regulation of metabolic reactions and composition of chloroplasts (Kerbauy, 2012). According to Rombolà et al. (2012), N is the most important nutrient for stone fruit trees and the second most exported mineral element through fruits yielded by peach trees and the most exported one through leaves and branches.

Adequate management of N fertilization in peach tree orchards has direct impact on their productivity and quality, as well as on the ones of other temperate fruit trees. Therefore, care must be taken to avoid either excessive or insufficient fertilization. Excess of N may stimulate vegetative growth (Ferreira et al., 2018) and delay the lignification of plant tissues, a fact that may make the plant sensitive to fungal diseases (Rombolà et al., 2012). Deficiency of N may increase plant susceptibility to canker, due to the higher carbon and lower nitrogen, and therefore higher [carbon/nitrogen] ratios. (Cao et al., 2011). Besides, Serrat et al. (2004) pointed out that N may enable plants to keep their leaves for a longer period of time; consequently, it broadens the time of photosynthetic activity and leads to higher reserve accumulation.

In addition to these characteristics, N fertilization may influence productivity (Della-Bruna & Back, 2014; Ferreira et al., 2018), ripening (Ames et al., 2020; Rufat et al., 2011) and fruit qualitative characteristics, such as size (Della-Bruna & Back, 2014), solid soluble content (Dolinski et al., 2018) epidermis color (Ames et al., 2020), phenolic compounds, antioxidant activity (Barreto et al., 2020; Ferreira, et al., 2016; Vashisth, et al., 2017), carotenoids

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(Ferreira, et al., 2016) and quality after cold storage (Barreto et al., 2017; Barreto et al., 2020).

Therefore, this study aimed at evaluating physicochemical characteristics and bioactive compounds of fruits yielded by peach trees cv. Esmeralda which was fertilized with different doses of N for four crops.

Materials and Methods

This study was carried out in a commercial orchard which comprises peach trees of the cultivar Esmeralda. The 9-year-old orchard is located in Morro Redondo, Rio Grande do Sul (RS) state, Brazil (latitude 31°31'49.3"S; longitude 52°35'39.8"W). Spacing between rows is 5.0 m whereas between plants, which are conducted in a vessel system, it is 1.5 m.

The experiment had a randomized complete block design, with four replicates. Every experimental unit consisted of four plants. Both located in the center were considered useful for evaluation. Increasing doses of N, in the form of urea (45% N), i. e., 0, 40, 80, 120 and 160 kg ha^{-1} N, were administered to every block. It totaled five parcels at different doses which were applied to the surface of the soil twice (half at the beginning of bloom and half in the phase of fruit thinning), with no incorporation. Equal doses of phosphorus (P) and potassium (K), in agreement with the CQFS-RS/SC (2004), were administered to all parcels, based on soil analyses.

The closest weather station (latitude 31° 24' 11.9'' S and longitude 52° 42' 2.5'' W), which is located 17.36 km from the experimental area and belongs to the Instituto Nacional de Meteorologia (INMET, 2017), provided data on rainfall (**Figure 1**).

In order to carry out the physicochemical evaluation at the time of commercial ripening, a 30-fruit sample was collected from two plants that composed each replicate. It was taken to the Laboratory of Postharvest Physiology at the Embrapa Clima Temperado, located in Pelotas, RS, Brazil.

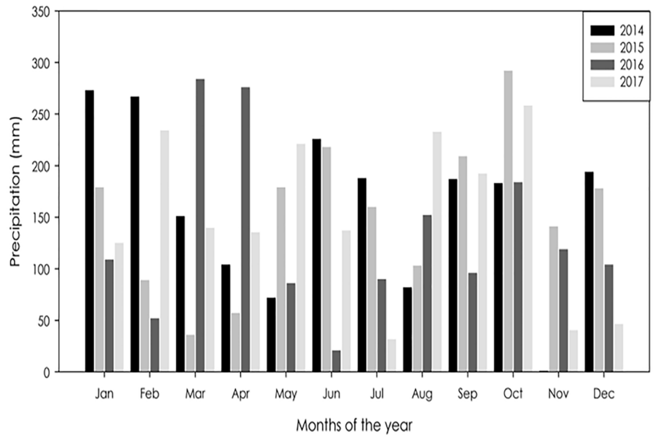

Figure 1. Rainfall (mm) in the period of the experiment.

The following evaluations were conducted: pulp color was examined by a Minolta colorimeter model CR-400, in which L* expresses luminosity (L* = 0 is black and L* = 100 is white); chroma is chromaticity, which was calculated by the relation between a* and b* (+a* = red and –a* = green; +b* = yellow and –b* = blue) and matrix (Hue angle), calculated by arctg b*/a*. Determination of epidermis color was carried out in the equatorial area of the fruits. Epidermis and pulp firmness was measured by a Stable Micro Systems texture analyzer model TA-XT Plus with a P-2 pointer. Its pre-test, test and post-test velocities were 1.00 $mm.s^{-1}$, 2.00 $mm.s^{-1}$ and 10.00 $mm.s^{-1}$, respectively, at a distance of 6.00 mm. This parameter was read in the median part of the fruit and the results were expressed as Newton. Soluble solids were measured in the fruit juice by a manual ATAGO digital refractometer model PAL-1. Results were expressed as °Brix. An electrometric method was used for determining the hydrogen-ion potential (pH) by a Quimis pHmeter model Q400A. To determine titratable acidity (TA), 10 mL of fruit pulp was added to 90 mL of distilled water. Afterward, sample titration was carried out by a Brand® digital burette with sodium hydroxide (NaOH) solution at 0.1N up to the turning point, which is pH 8.1. Results were expressed as g citric acid.$100g^{-1}$ pulp.

Total carotenoid quantification was conducted by a method adapted from Talcott & Howard (1999). Protected from exposure to direct light, a 2.5 g-sample was weighed and homogenized by an Ultra-Turrax homogenizer with an ethanol/acetone/BHT solution up to uniform consistence. The sample was centrifuged at 4000 RPM at 0°C for 20 minutes. The supernatant was then poured into plastic containers. These processes were repeated whenever necessary, up to total sample discoloration. Afterward, 25 mL hexane was added and the sample rested for 30 minutes. Then, 25 mL distilled water was added and the sample rested for 30 minutes again. Finally, reading was conducted by a quartz cuvette at 470 nm absorbance.

Total phenolic compound quantification was determined by a method adapted from Swain & Hillis (1959). A 5-gram sample was weighed and homogenized with 20 mL methanol (solvent) by an Ultra-Turrax homogenizer up to uniform consistence. Samples were centrifuged at 4000 RPM at 0°C for 20 minutes. Then, 100 µL supernatant was pipetted into a flask and 150 µL methanol (solvent), 4 mL distilled water and 250 µL Folin-Ciocalteau (0.25 N) were added to it. After agitation, samples rested for three minutes so that reactions could occur. Afterward, 0.5 mL 1N Na_2CO_3 was added, and flasks were agitated and left to rest for two hours. Absorbance was measured by a quartz cuvette at 725 nm.

Total antioxidant activity was determined by a method adapted from Brand-Williams et al. (1995) with the use of the stable radical DPPH (2,2-diphenyl-1-picrylhydrazyl). It was diluted (from a concentrated solution) in methanol up to 1.1±0.02UA absorbance at 515 nm. Five-gram samples were homogenized with 20 mL methanol (solvent) by an Ultra-Turrax homogenizer. Samples were centrifuged at 4000 RPM at 0°C for 20 minutes. Solvent (methanol) was added to the samples so as to reach 200 µL, as well as 3.8 ml diluted DPPH. After agitation, samples were left to react for 24 hours in the dark in sealed flasks at room temperature. Absorbance was measured by a quartz cuvette at 515 nm.

Results were submitted to the analysis of variance. When effects were significant, regression equations were adjusted and both linear and quadratic models were examined by the F-test. In order to interpret the results of correlation among bioactive compounds, the classification proposed by Dancey & Reidy (2005) was used. Positive or negative values below 0.3 show either weak or non-significant correlation, values between 0.3 and 0.7 show moderate correlation and values above 0.7 show strong correlation.

Results and Discussion

In the first crop under evaluation (2014), no significant differences in soluble solids (SS), pH, titratable acidity (TA) and SS/TA were found (**Table 1**). These results corroborate data introduced by Brunetto et al. (2007) and Ferreira et al. (2016), who did not observe any effect of doses of N on the quality of fruits yielded by peach trees in the first year under evaluation. The fact that there is no response to N fertilization in the first year under evaluation is common in fruit trees, since they may have N reserves that are capable of ensuring the quality of their fruits in this period.

Table 1. Soluble solids (SS), pH, titratable acidity (TA) and SS/TA in fruits of peach trees cv. Esmeralda submitted to different doses of N for four crops under evaluation (means of 4 replicates)

Dose kg ha^{-1} N	SS (°Brix)	pH	TA (g ac. cit.100g^{-1})	SS/TA
Harvest 2014				
0	12.73	3.45	0.93	13.78
40	12.30	3.50	0.93	13.29
80	12.38	3.48	0.98	12.74
120	12.58	3.52	0.94	13.40
160	12.83	3.48	0.97	13.35
CV	3.03	1.04	6.36	8.83
Linear	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns
Harvest 2015				
0	10.45	3.26	1.08	9.71
40	9.90	3.29	1.05	9.52
80	8.75	3.34	1.02	8.55
120	9.85	3.27	1.09	9.08
160	9.75	3.35	1.03	9.60
CV	5.16	1.47	8.38	10.51
Linear	ns	ns	ns	ns
Quadratic	**(1)	ns	ns	ns
Harvest 2016				
0	11.28	3.43	1.09	10.42
40	11.68	3.32	1.25	9.40
80	11.80	3.39	1.22	9.82
120	11.88	3.38	1.16	10.31
160	11.93	3.38	1.16	10.42
CV	5.57	1.4	10.91	14.87
Linear	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns
Harvest 2017				
0	13.25	3.28	1.02	13.05
40	12.80	3.33	1.13	11.32
80	12.40	3.30	1.11	11.13
120	13.23	3.38	1.06	12.53
160	11.78	3.33	1.08	10.95
CV	5.07	1.27	6.90	7.87
Linear	*(2)	*(3)	ns	ns
Quadratic	ns	ns	ns	ns

ns = not significant; *, **, significant 5 e 1% at probability of error, respectively. (1) $y = 10.48-0.0261x+0.000141x^2$; $R^2 = 0.604$; (2) $y = 13.195- 0.006312x$, $R^2 = 0.416$; (3) $y = 3.2915+0.000381x$; $R^2 = 0.361$.

In the second crop under evaluation (2015), response was only given to SS and pH. Regarding SS, N fertilization led to decrease in its contents. Brunetto et al. (2007) also found different responses among crops concerning the effect of N fertilization on SS contents. The authors state that variation in SS contents may be associated with water absorption by plants in response to either high or low rainfall, a fact that may cause sugar dilution in fruits. It may be corroborated by Alcobendas et al. (2013), who found higher SS values in fruits yielded by plants that had been submitted to water deficit, with no difference in fruit size. The authors' statements may be related to data on rainfall shown in (Table 1). In the 2015 crop, since there was more rainfall in months in which fruit grew and developed, it may have caused low SS values, by comparison with the other crops. Results found by Alcobendas (2013) attribute differences in SS contents to the location of fruits in the plant, i. e., the ones in the base of the plant have higher SS contents than the ones located in its distal end. Regarding pH, the more doses of N, the higher the pH of fruits, i. e., there was linear behavior. Ferreira et al. (2016) did not find significant differences in pH of peaches submitted to different doses of N fertilization. Results introduced by Alcobendas et al. (2013) show the influence of fruit orientation towards sunlight on pH values.

In the third crop (2016), SS, TA, pH and SS/TA values did not show any significant difference among treatments, a fact that indicates the influence of the environment on these characteristics. SS and pH had linear behavior whereas TA and SS/TA did not show any significant difference in the 2017 crop.

Epidermis and pulp firmness were evaluated in 2014 to 2017 and 2015 to 2017, respectively. These parameters are not affected by the treatments in any crop under evaluation (**Table 2**), a fact that agrees with the results of several studies (Brunetto et al. (2007); Falguera et al. (2012) and Ferreira et al. (2016)). According to Sams (1999), the balance between fruit diameter and its mass keeps similar cell volume, so that resistance to penetration is almost not affected. Lewallen and Marini (2003) found a correlation between pulp firmness and the location of fruits in the plant, i. e., fruits located inside the plant were firmer. Alcobendas et al. (2013) observed that irrigation led to fruits with less pulp firmness, by comparison with the ones harvested after treatment with no irrigation.

Fruit firmness is closely related to the ripening degree. In this study, strong influence of N fertilization on ripening degree of fruits was observed. When there was no N, fruits reached harvest point earlier; evidence of this fact is the high proportion of fruits harvested in the first crop (data not shown). It agrees with data introduced by Ames et al. (2020), who state that excess of N delays fruit ripening, due to a sink competition between shoot development and ripening fruit, since vigorous trees direct more carbohydrates resources to the late vegetative growth delaying ripening. However, since harvest was carried out in three periods, there was standardization of the ripening degree, considering that only ripe fruits were harvested. It may explain the low influence of N fertilization on fruit firmness found by this study.

(Table 2) shows data on colors of fruit pulp. Luminosity (L*) just exhibited significant differences among treatments in 2014 and 2016 crops. It gave a quadratic response in which the dose with the highest value of L* was about 145 kg ha^{-1} N in the 2014 crop, while the dose of 34 kg ha^{-1} N yielded fruits with higher luminosity in the 2016 crop. Falgueira et al. (2012) and Ferreira et al. (2016) observed no response to this characteristic when they evaluated the influence of N fertilization on colors of fruits yielded by three peach tree cultivars.

The Hue angle had curvilinear behavior in its response to N fertilization in the 2016 crop when it reached its highest value at about 51 kg ha^{-1} N. In the 2017 crop, its behavior was linear, in descending order, as N increased in the soil. Lower values of the Hue angle show that fruit epidermis is reddish whereas higher values mean that it is yellowish, a characteristic of fruits yielded

Table 2. Epidermis and pulp firmness, luminosity (L*), Hue and chromaticity (chroma) in fruits of peach trees cv. Esmeralda submitted to different doses of N for four crops under evaluation (means of 4 replicates)

Dose kg ha^{-1} N	Epiderm firmness	Pulp firmness	L*pulp	Hue pulp	Chroma of pulp
Harvest 2014					
0	9.24	-	70.68	73.44	50.91
40	10.45	-	71.29	77.88	54.53
80	9.98	-	70.30	77.01	53.38
120	10.52	-	70.76	76.56	56.65
160	10.55	-	70.61	77.64	55.41
CV	8.06	-	3.44	4.41	6.69
Linear	ns	-	ns	ns	ns
Quadratic	ns	-	ns	ns	ns
Harvest 2015					
0	9.29	2.80	70.94	83.45	47.30
40	9.71	2.94	70.84	84.34	47.35
80	8.99	2.64	70.65	83.99	48.74
120	9.24	2.73	70.74	85.01	47.90
160	9.41	2.79	71.05	84.41	49.66
CV	7.05	7.59	1.07	1.79	1.61
Linear	ns	ns	ns	ns	**(1)
Quadratic	ns	ns	ns	ns	ns
Harvest 2016					
0	7.27	1.68	68.85	80.99	55.39
40	7.88	1.88	69.71	81.28	54.50
80	7.76	1.92	70.75	81.39	53.84
120	8.34	2.13	68.29	80.53	54.02
160	7.80	2.00	68.87	79.92	56.45
CV	10.03	15.84	1.11	0.83	2.90
Linear	ns	ns	ns	ns	ns
Quadratic	ns	ns	**(2)	ns	ns
Harvest 2017					
0	10.86	3.19	69.88	84.93	55.72
40	10.02	2.94	67.13	84.68	56.26
80	10.73	3.10	70.00	84.31	51.89
120	10.71	3.14	69.20	82.70	49.76
160	10.91	3.29	67.35	83.66	57.43
CV	7.04	12.36	1.43	1.07	2.18
Linear	ns	ns	ns	*(3)	ns
Quadratic	ns	ns	ns	ns	**(4)

ns = not significant; *, **, significant 5 e 1% at probability of error, respectively. (1) $y = 47.138+0.01344x$; $R^2 = 0.686$; (2) $y = 68.991+0.0255x+0.000181x^2$; $R^2 = 0.371$; (3) $y = 84.9625–0.011325x$; $R^2 = 0.637$; (4) $y = 57.1839+0.1255x–0.000736x^2$; $R^2 = 0.485$.

by the cv. Esmeralda. Lewallen & Marini (2003) found a correlation between the Hue angle and the location of fruits in the plant, i. e., fruits that were little exposed to light (inside the plant) had high Hue values and were yellowish. Chromaticity had curvilinear behavior; the maximum chroma value was found when the dose of N was about 73 kg ha^{-1}.

Chromaticity had linear behavior in the 2015 crop. It showed that there was linear increase in chromaticity as doses of N increased, with increment in color intensity. In other words, increase in N led to fruits with brighter colors in this crop. Lewallen & Marini (2003) identified the relation between peach chromaticity and the location of fruits in the plant. Fruits that were exposed to more light tended to have higher chroma values. Alcobendas et al. (2013) found a high correlation between chroma and fruit orientation toward sunlight. In both 2016 and 2017 crops, chromaticity had negative quadratic behavior, i. e., there was decrease in chromaticity with N increment in the soil, followed by increase in the attribute when doses of N were higher.

(**Table 3**) shows results of quantification of total carotenoids found in the fruits. Increase in N in the soil led to increase in total carotenoid contents in fruits in 2014, 2015 and 2016 crops. Similar results were found by Ferreira et al. (2016) who worked with three peach tree cultivars.

Carotenoids can be found in green leaves and fruits along with chlorophylls (Saini et al., 2015). According Boskovic-Rakocevic et al. (2012) fertilization with N, especially at high rates increases the concentration of carotenes. Thus, when more N is available, contents of pigments connected to photosynthesis increase. It results in increase in total carotenoid contents.

In conventional production systems high doses of nitrogen are applied rapidly, leading to rapid vegetative growth, and consequently to an increase in the production of chloroplasts. Carotenoid synthesis happens within the chloroplast, consequently, plants with vigorous vegetative growth have many sites for accumulation of carotenoids (Mditshwa et al., 2017).

Variation in total carotenoid concentrations was observed in the crops under evaluation. Santos et al. (2013) state that the weather affects concentrations of this compound directly. It is shown in Figure 1, since the 2015 crop had the highest rainfall in the period of fruit development (from September to December) and fruits had the lowest carotenoid concentrations, by comparison with the other crops under evaluation (Table 3).

Total phenolic compounds of fruits only exhibited significant differences among treatments in both 2016 and 2017 crops (Table 3). There was decrease in these compounds when more N was applied to the soil in the 2016 crop. Decrease in total phenolic compounds after N application had already been observed in fruits of two peach tree cultivars (Vashisth et al., 2017), as well as in apples (Strissel et al., 2005). In the 2017 crop, negative quadratic behavior was observed. It was characterized by decrease in phenolic compound content, followed by its increase after a dose of about 60 kg ha^{-1} N was applied.

Strissel et al. (2005) state that decrease in phenolic compound contents as the result of N increment is mainly connected to reduction in flavonoid synthesis as a response to decrease in the contents of the enzyme phenylalanine ammonia-lyase (PAL), which may limit phenolic compound synthesis. The authors mention that environmental stress, such as nutrient deficiency, triggers translation of messenger RNA which codifies PAL and increases its amount, a fact that results in higher phenolic compound synthesis.

As mentioned before, total phenolic compounds only responded to N fertilization in the second to last crop (2016). Thus, it may be inferred that plants had adequate supply of N in previous crops. However, consumption of these reserves along with low supply of N in some treatments (and considering that N is the second most

Table 3. Total carotenoids in mg β carotene equivalent/100g tissue, total phenolic compounds in mg Chlorogenic acid equivalent/100g tissue and total antioxidant activity in µg trolox equivalent/g tissue in fruits yielded by peach trees cv. Esmeralda submitted to different doses of N for four crops under evaluation (means of 4 replicates)

Doses kg ha^{-1} N	Total carotenoids	Total phenolic compounds	Total antioxidant activity
Harvest 2014			
0	4.641	260.265	3499.405
40	5.201	276.159	3931.161
80	5.368	253.243	3396.084
120	5.941	269.320	3702.253
160	5.407	288.504	4230.565
Linear	ns	ns	ns
Quadratic	ns	ns	ns
CV	10.92	11.72	15.21
Harvest 2015			
0	4.255	312.586	4436.709
40	4.034	278.882	3830.236
80	4.580	238.816	3185.416
120	4.215	237.838	3052.769
160	4.945	255.493	3335.487
Linear	ns	ns	*(1)
Quadratic	ns	ns	ns
CV	9.54	17.44	17.57
Harvest 2016			
0	5.527	291.402	3600.133
40	6.390	257.367	2809.623
80	7.213	227.043	2519.142
120	6.824	191.870	2157.424
160	7.303	249.306	2702.873
Linear	*(2)	ns	ns
Quadratic	ns	*(3)	**(4)
CV	11.69	14.32	15.93
Harvest 2017			
0	3.664	315.674	1130.198
40	3.458	262.403	902.772
80	3.432	266.309	969.901
120	4.109	336.158	1211.259
160	3.958	365.797	1203.469
Linear	ns	ns	ns
Quadratic	ns	ns	ns
CV	16.33	17.40	17.86

ns = not significant; *, **, significant 5 e 1% at probability of error, respectively. (1) $y = 4164.1055-7.4498x$; $R^2 = 0.689$; (2) $y = 5.856+0.009956x$; $R^2 = 0.755$; (3) $y = 298.7775-1.6463x+0.007595x^2$; $R^2 = 0.826$; (4) $y = 3618.7104-24.6931x+0.1161x^2$; $R^2 = 0.955$.

exported mineral element through fruits yielded by peach trees (Rombolà et al., 2012), made plants react to the low availability of N in the 2016 crop. This reaction was characterized by high concentrations of total phenolic compounds in treatments with low doses of N.

Total antioxidant activity (Table 3) did not show any significant difference in treatments in both 2014 and 2017 crops. However, there was decrease in total antioxidant activity when more N was applied to the soil in both 2015 and 2016 crops. This behavior indicates that phenolic compounds make a significant contribution to the total antioxidant activity. Besides, both had similar behavior, a fact that can be confirmed by correlations between them. However, antioxidant activity involves a large number of compounds, such as vitamins, carotenoids and other phenols (Silva et al., 2010). Thus, the antioxidant activity of a sample cannot be explained only by its phenolic compound content; it requires the characterization of other compounds (Häkkinen et al., 1998). Barreto et al. (2020) observed a decrease in antioxidant activity with an increase in the dose of nitrogen in 'Cascata-1067' peach.

The Pearson linear correlation between total phenolic compounds and total antioxidant activity enables to quantify the contribution of the former to the latter.

(**Table 4**) shows correlations among the three bioactive compounds under evaluation in the four crops.The results showed a strong correlation between antioxidant activity and phenolic compounds in the four crops under evaluation. These data corroborate the ones found by Zhao et al. (2015) and Manzoor et al. (2012), who observed strong correlation between both attributes. Carotenoids only had significant correlation with the antioxidant activity and phenolic compounds in the 2017 crop.

Table 4. The Pearson linear correlation among, total phenolic compounds and total carotenoids in fruits yielded by peach trees cv. Esmeralda submitted to different doses of N for four crops under evaluation (means of 4 replicates)

	Total antioxidant activity	Total phenolic compounds
Harvest 2014		
Total phenolic compounds	0.890**	1
Total carotenoids	0.157^{ns}	0.114^{ns}
Harvest 2015		
Total phenolic compounds	0.918**	1
Total carotenoids	-0.056^{ns}	0.022^{ns}
Harvest 2016		
Total phenolic compounds	0.940**	1
Total carotenoids	-0.380*	-0.299^{ns}
Harvest 2017		
Total phenolic compounds	0.953**	1
Total carotenoids	0.923**	0.895**

** = strong significant correlation, * = moderate correlation ns = non-significant correlation.

Conclusions

The levels of soluble solids, phenolic compounds and antioxidant activity of fruits are reduced by N rates. However, this effect is not evident in all harvests, which indicates that there is interaction between environmental factors and nitrogen fertilization. Carotenoid content and fruit pH increased linearly in response to N rates applied to the soil, but only in some of the crops, again showing the interaction between more than one factor. The concentration of phenolic compounds and the antioxidant activity of peaches decrease when low doses of nitrogen are applied to the soil. The effects of nitrogen fertilization on the physicochemical characteristics of 'Esmeralda' peach varied in different harvests, making it difficult to recommend a specific nitrogen dose.

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