http://dx.doi.org/10.1590/1678-4499.0330

Effect of phosphorus nutrition on quality of fresh tuber of potato cultivars

Adalton Mazetti Fernandes ([1*]); Rogério Peres Soratto ([2]); Letícia de Aguila Moreno ([2]); Regina Marta Evangelista ([3])

([1]) Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Faculdade de Ciências Agronômicas (FCA), Centro de Raízes e Amidos Tropicais, Rua José Barbosa de Barros, 1.780, 18610-307 Botucatu, (SP), Brasil.

([2]) UNESP/FCA, Departamento de Produção e Melhoramento Vegetal, 18610-307 Botucatu (SP), Brasil.

([3]) UNESP/FCA, Departamento de Horticultura, 18610-307 Botucatu (SP), Brasil.

(*) Corresponding author: adalton@cerat.unesp.br

Received: *Sept. 22, 2014;* ***Accepted:*** *Oct. 23, 2014*

Soil and Plant Nutrition / Article

Abstract

Phosphorus (P) is essential to increase tuber yield and nutritional quality of potato tubers. However, it is unclear whether the influence of P fertilization on quality of tubers produced can vary depending on the cultivar and P availability in soil. This study evaluated the effect of P fertilization on the quality and nutritional composition of marketable tubers of potato cultivars. Experiments in soils with low, medium and high P availability were conducted in a randomized block design, with four replications. Treatments consisted of a 2×5 factorial arrangement of two potato cultivars (Agata and Mondial) and five P_2O_5 rates (0, 125, 250, 500, and 1,000 kg ha^{-1}). Phosphorus fertilization increased the contents of P and starch, the size and yield of marketable tubers, with more expressive response to higher P rates in the soils with low and medium P availability. The Mondial cultivar had the highest yield, due to a greater tuber weight and greater increases in this characteristic in response to P fertilization. The Mondial cultivar produced tubers with firmer pulp, with higher dry matter percentage and higher contents of Ca, Cu, and Zn than Agata. In the soil with low P availability, P fertilization reduced Zn content, but, in general, had little influence on the nutritional composition of potato tubers.

Key words: *Solanum tuberosum*, phosphorus, tuber size, starch, protein, mineral concentration.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) tubers are an excellent food source for providing energy from carbohydrates, but are also rich in minerals and vitamins and present high-quality protein (Pereira et al., 2005).

In Brazil, the quality of potato tubers for the fresh market is still associated with their visual characteristics (Feltran et al., 2004; Silva et al., 2007). In this context, Agata and Mondial are among the main cultivars planted in the country, producing tubers with suitable characteristics for marketing in this segment (Evangelista et al., 2011; Fernandes et al., 2010). However, knowledge of the composition of food consumed is essential for food security and nutrition (UNICAMP, 2011) and recently consumers have also valued tubers of higher nutritional and culinary quality (Evangelista et al., 2011; Feltran et al., 2004; Silva et al., 2007).

As potato is a short-cycle crop and present high production capacity, it is highly influenced by application of nutrients to the soil (Fernandes & Soratto, 2012; Freeman et al., 1998 ;Luz et al., 2013). Furthermore, due to the low availability and high phosphorus (P) fixation capacity in most Brazilian soils and because potato is considered to be inefficient in absorbing P from the soil (Dechassa et al., 2003) it has been usually applied high rates of phosphate fertilizers in the cultivation, aimed at achieving high levels of tuber yield (Fernandes & Soratto, 2012; Luz et al., 2013) and larger tubers.

Phosphorus has various effects on tuber quality, since it functions in cell division and synthesis and storage of starch in the tubers (Houghland, 1960). Thus, P can increase the size and percentage of dry matter (DM) (indicated by specific gravity) of the tubers (Freeman et al., 1998; Rosen et al., 2014). Nevertheless, under high availability of soil P, its supply can decrease the production of larger tubers without changing the tuber specific gravity thereof

(Rosen & Bierman, 2008). In some cases, where the phosphate fertilizer promoted a great increase in size and yield of tuber, it was also observed reduction in their specific gravity as a function of P rates (Freeman et al., 1998). The management and the availability of nutrients in the soil can also influence the chemical composition of the harvested product (Quadros et al., 2009).

Physico-chemical characteristics and the nutritional composition of potato tubers may vary depending on various factors, such as cultivar, availability of nutrients in the soil, fertilization process, plant maturity, climate, etc. (Evangelista et al., 2011; Feltran et al., 2004; Fernandes et al., 2010; Klein et al., 1980; Lachman et al., 2005; Quadros et al., 2009; Rosen et al., 2014). According to Klein et al. (1980), P fertilization increases the concentrations of ascorbic acid, nitrogen (N), and protein in tubers. In addition to increasing the specific gravity of tubers, P fertilization can also change the texture, color, and flavor of cooked tubers (Sheard & Johnston, 1958). However, there is little research evaluating the effect of P on the nutritional composition of potato tubers (Rosen et al., 2014). In addition, it is unknown the influence of P fertilization on the quality of different tuber cultivars and according to the availability of P in soil.

This study evaluated the effect of P fertilization on the physico-chemical quality and nutritional composition of marketable potato tuber cultivars in soils with different availability of P.

2. MATERIAL AND METHOD

Three experiments were conducted in 2011, in potato production areas, in soil with different levels of available P: low (Avaré-SP), medium (Itaí-SP) and high (Cerqueira César-SP) (Table 1). The soils of the three sites were classified as a clayey-textured Oxisol. In each area, prior to installation of the experiments, soil samples were taken at 0-20 cm depth for determining the chemical characteristics, whose results are shown in table 1.

In all experiments, soil was prepared with disk plow and harrow. Each experiment was conducted in a randomized block design with a 2×5 factorial arrangement, with four replications. The treatments consisted of two potato cultivars (Agata and Mondial) and five rates of P_2O_5 (0, 125, 250, 500, and 1,000 kg ha^{-1}), using triple superphosphate as source. Each plot consisted of five rows of plants of 5 m in length. In the planting furrow, we applied 62 kg ha^{-1} N (ammonium sulfate) and 124 kg ha^{-1} K_2O (potassium chloride) in all experiments.

Seed tubers were planted between late April and early May (winter crop), spaced 0.80 m between rows and 0.30 m between seed tubers. Nitrogen topdressing fertilization was performed at 22, 24, and 28 days after planting (DAP), in areas with low, medium, and high availability of P, respectively. The amounts of N applied in areas with low, medium, and high P concentration in the soil were 43, 64, and 41 kg ha^{-1} N, respectively. After nitrogen fertilization, hilling was performed. All experiments were irrigated by sprinkling.

Table 1. Chemical characteristics of experimental soils at the 0-0.20m depth. Mean of four replications

Characteristic	Avaré	Itaí	Cerqueira César
pH($CaCl_2$)	5.7	4.8	4.8
OM (g dm^{-3})	48	27	28
P(resin) (mg dm^{-3})	14	36	70
K (mmol$_c$ dm^{-3})	2.3	2.3	3.3
Ca (mmol$_c$ dm^{-3})	60	31	31
Mg (mmol$_c$ dm^{-3})	19	11	9
H+Al (mmol$_c$ dm^{-3})	27	46	51
CEC (mmol$_c$ dm^{-3})	108	90	94
Base saturation (%)	75	49	46
B (mg dm^{-3})	0.33	0.64	0.77
Cu (mg dm^{-3})	8.3	1.2	6.2
Fe (mg dm^{-3})	60.7	44.0	32.7
Mn (mg dm^{-3})	24.6	8.2	9.3
Zn (mg dm^{-3})	1.0	1.6	2.9

In areas with low, medium, and high availability of P in soil, desiccation of shoots of the crop was carried out at 112, 94, and 97 DAP, respectively. Tubers were harvested at approximately 21 days after drying plants. The harvested tubers were washed and classified as for transversal diameter, considered marketable those with a diameter greater than 23 mm. Then, the tubers were counted and weighed to determine the marketable tuber yield and the mean weight of marketable tubers.

Firmness was determined in three tubers (with peel) of each plot harvested in the field, using a texturometer with 20 mm penetration depth and 2.0 mm s^{-1} speed and a TA 9/1000 probe tip. For the quantification of soluble solids (SS), some pulp slices were ground and two drops of the juice were placed on the prism of the electronic refractometer, and after a minute they were directly read in °Brix. To determine the titratable acidity, 10 g of the ground pulp were diluted in 100 mL of distilled water and the mixture was filtered and titrated with 0.1 N sodium hydroxide, with phenolphthalein as indicator (ANVISA, 2005). The percentage of DM was determined by drying the pulp of the tubers in a forced air circulation oven at a 105 °C to constant weight (ANVISA, 2005). The starch content was determined in DM according to the Somogyi methodology, adapted by Nelson (1944), and the readings were made in a spectrophotometer at 535 nm. Data were converted into percentage in the fresh matter. The protein content in the tubers was determined in the DM, with the Kjeldahl method (method 920.87 from Association of

Analytical Chemists – AOAC) (Horwitz & Latimer, 2005) and the conversion factor of 6.25 for crude protein. Then, the data were converted to protein percentage in the fresh matter. Mineral contents (P, K, Ca, Mg, Cu, Fe, Mn, and Zn) were determined on dry samples (Malavolta et al., 1997), and the obtained values converted to mg per 100 g fresh matter.

The results of each experiment were subjected to analysis of variance separately, considering the 2×5 factorial arrangement (2 cultivars × 5 rates of P_2O_5). Mean values of the cultivars were compared by t-test (LSD) ($p<0.05$), while the effects of P were evaluated by regression analysis.

3. RESULTS AND DISCUSSION

In the three experiments, the cultivar Mondial showed higher yield of marketable tubers (Table 2). Phosphorus fertilization increased the yield of marketable tubers in the three soils. However, the increases in the tuber yield were more expressive and occurred until higher rates of P under conditions of reduced availability of this nutrient in the soil. This demonstrates that, in soils with medium and high availability of P, the application of high rates of P does not increase potato crop yield, as also observed by Rosen & Bierman (2008). However, even in soils with medium and high concentration of available P, potato responded to application of up to 250 and 150 kg ha^{-1} P_2O_5.

The tuber mean weight was affected by the interaction cultivar x rate in the soil with low P, by factors separately in soil with medium concentration of P, and only by the cultivar in the soil with high concentration of P (Table 2). These results indicate that under high availability of P, P fertilization does not increase the size of potato tubers and can decrease the number of larger tubers (Rosen & Bierman, 2008). In the absence of P fertilization, the tuber mean weight was similar between cultivars in the soil with low availability of P. However, with the application of increasing rates of P, the tuber mean weight of both cultivars increased to the rate of 500 kg ha^{-1} P_2O_5, but always with more significant increases in the cultivar Mondial (Table 3). Zewide et al. (2012) also observed that P fertilization provided an increase in tuber mean weight of up to 24.5% in low-fertility soil, supporting our results, and indicate that under low availability of P in soil, P supply is essential for the production of larger tubers. In soil with medium availability of P, the P fertilization also increased the tuber mean weight, but with significant increases only up to the rate of 125 kg ha^{-1} P_2O_5, i.e. the P available in the soil was enough for the successful development of the tubers (Table 2).

In soils with low and high availability of P, pulp firmness of the tubers was affected only by cultivars, with tubers of the cultivar Mondial showing higher value (Table 2). Feltran et al. (2004) and Fernandes et al. (2010) also found that the tubers of the cultivar Mondial have firmer pulp than Agata. In the condition of medium availability of P in the soil, there was effect of the interaction, and only the cultivar Agata showed increased pulp firmness according to fertilization until the rate of 250 kg ha^{-1} P_2O_5 (Table 3). In the cultivar Mondial, although fertilization had no effect on the firmness of the tubers, we observed that in all rates of P studied, this cultivar presented tubers with firmer pulp than the cultivar Agata. Anzaldúa-Morales et al. (1992) reported that the firmness of the potato tuber pulp was related to the percentage of DM. The greater firmness of the Mondial cultivar tubers probably results from a combination of high percentages of DM and starch content (Tables 2, 3). Evangelista et al. (2011) also registered that cultivars with firmer pulp also had higher percentages of DM and starch contents.

Only in soils with medium and high availability of P, soluble solids were affected by cultivars, whose higher values were found in tubers of the cultivar Agata (Table 2). As the soluble solids are mainly sugars (sucrose) (Fernandes et al., 2010), these results indicate that Agata has tubers with a higher proportion of these substances. Feltran et al. (2004) and Fernandes et al. (2010) also verified relatively higher soluble solids in tubers of the cultivar Agata.

The titratable acidity of tuber pulp was only affected by the cultivar, under condition of low availability of P in the soil, and by both factors in the soil with medium availability of P (Table 2). In both conditions, higher values of titratable acidity were recorded for Agata tubers. Nevertheless, the changes were small, probably due to the little variation between cultivars in relation to the amount of organic acids in the pulp of the tubers (Evangelista et al., 2011; Feltran et al., 2004; Fernandes et al., 2010). Under medium availability of P, phosphate fertilization promoted a slight decrease in titratable acidity of the tubers. Moreover, values of this variable were lower in the soil with high availability of P, which indicates that the greater availability of this nutrient can reduce the amount of organic acids in the tubers.

Difference between cultivars for starch content in the tubers was only detected in the soil with medium availability of P, with the highest values observed in the cultivar Mondial (Table 2). Rates of P increased the starch content in soils with low and medium availability of this nutrient. The highest starch content in the tubers were registered with rates estimated at 600 and 433 kg ha^{-1} P_2O_5, in soils with low and medium concentration of P available, respectively. Besides being essential for the establishment of a greater number of tubers per plant (Rosen & Bierman, 2008), P participates in a number of key enzymes involved in the regulation of starch synthesis (sucrose phosphate synthase, fructose-1,6-bisphosphatase and ADP-glucose pyrophosphorylase) (Taiz & Zeiger, 2013) and is also part of its composition, being connected to the amylopectin fraction of starch, in the form of phosphate ester (Nielsen et al., 1994). Thus,

Table 2. Yield, mean weight and physico-chemical composition of marketable tubers of potato cultivars according to phosphorus fertilization in soils with low (14 mg dm^{-3}), medium (36 mg dm^{-3}) and high (70 mg dm^{-3}) availability of phosphorus[(1)]

Soil P availability	Cultivar (C)		Rates of P_2O_5 (kg ha^{-1}) (R)					CV (%)	Interaction C × R	Regression equation	R^2
	Agata	Mondial	0	125	250	500	1000				
Marketable tuber yield (kg ha^{-1})											
Low	18,474b	24,255a	7,376	20,724	24,156	27,270	27,296	13.4	ns	y = (1 + 0.051x)/0.0001 + 0.000002x)	0.99**
Medium	27,841b	46,679a	28,979	37,775	40,649	38,881	40,015	11.9	ns	y = 39845.5/(1 + exp(–(x + 58.8)/60.2))	0.98**
High	37,452b	41,599a	32,826	40,913	41,415	40,190	42,284	10.4	ns	y = 41297.7/(1 + exp(–(x + 50.7)/37.5))	0.96**
Mean weight of marketable tubers (g)											
Low	67a	99a	51	79	88	100	98	6.9	**	y = 55.4460 + 0.1503x –0.000108x^2	0.95**
Medium	109b	161a	113	140	134	139	148	12.6	ns	y = (1 + 0.024x)/0.0089 + 0.0002x)	0.88**
High	100b	126a	106	108	112	117	121	11.0	ns	ns	-
Firmness (N)											
Low	5.9b	9.2a	7.5	7.7	7.6	7.5	7.5	3.4	ns	ns	-
Medium	7.3a	8.9a	7.8	8.2	8.3	8.1	8.0	4.9	**	ns	-
High	6.3b	9.0a	7.9	7.5	7.6	7.9	7.3	4.1	ns	ns	-
Soluble solids (°Brix)											
Low	4.5a	4.5a	4.6	4.6	4.5	4.4	4.4	4.6	ns	ns	-
Medium	4.6a	4.5b	4.5	4.8	4.5	4.6	4.5	3.4	ns	ns	-
High	4.5a	4.0b	4.3	4.3	4.3	4.2	4.3	3.7	ns	ns	-
Titratable acidity (% citric acid per 100 g fresh matter)											
Low	0.17a	0.15b	0.17	0.16	0.16	0.16	0.16	9.6	ns	ns	-
Medium	0.19a	0.18b	0.19	0.18	0.18	0.18	0.18	10.0	ns	y = 0.188 –0.000031x + 0.00000003x^2	0.66*
High	0.16a	0.16a	0.16	0.16	0.16	0.16	0.16	7.7	ns	ns	
Dry matter (% fresh matter)											
Low	14.5b	16.7a	16.4	15.0	16.2	15.3	14.9	4.5	ns	y = 15.99 –0.012x	0.40*
Medium	14.6b	16.6a	15.8	15.5	15.7	15.8	15.3	4.7	ns	ns	-
High	14.1b	15.5a	14.9	14.8	14.8	15.0	14.6	5.3	ns	ns	-
Starch (% fresh matter)											
Low	9.3a	9.3a	6.3	9.1	10.4	10.9	9.9	9.4	ns	y = 6.79 + 0.0156x –0.000013x^2	0.92**
Medium	10.6b	12.0a	10.5	12.1	12.0	11.6	10.2	11.6	ns	y = 10.93 + 0.0052x –0.000006x^2	0.76**
High	10.6a	11.1a	10.7	10.7	11.4	10.9	10.7	9.2	ns	ns	-
Protein (% fresh matter)											
Low	1.8a	1.8a	1.9	1.8	1.8	1.8	1.8	10.0	ns	ns	-
Medium	1.7b	1.8a	1.7	1.7	1.8	1.8	1.7	9.0	ns	ns	-
High	1.6a	1.6a	1.6	1.6	1.6	1.6	1.6	9.0	ns	ns	-

(1) Means followed by different letters in the rows, for the factor cultivar, are significantly different by t-test (LSD) ($p<0.05$); ns = non-significant. * $p<0.05$; ** $p<0.01$.

the P plays great importance in starch metabolism and is required in relatively large amounts in the potato plant for the phosphorylation of starch during the filling of the tuber (Houghland, 1960). In this way, as evidenced herein, the availability of P has great influence on starch content in potato tubers.

The content of DM in the tubers was affected by factors separately in the soil with low concentration of available P and only by the cultivar in the other soils (Table 2). Under all conditions of P availability in the soil, the percentage of DM was higher in tubers of the cultivar Mondial. In soil with low P availability, P fertilization promoted a slight reduction in the tuber DM, possibly caused by the dilution effect, since in this condition was obtained the most significant increases in yield and in size of the tubers (Table 2). Freeman et al. (1998) also observed a reduction

Table 3. Cultivar x phosphorus fertilization interaction for mean weight of marketable tubers of potato crop in soil with low P availability, and firmness of tubers in soil with medium P availability[(1)]

Cultivar	Rate of P_2O_5 (kg ha^{-1})					Regression equation	R^2
	0	125	250	500	1000		
Mean weight of marketable tubers (g) – soil with low P availability							
Agata	46a	64b	72b	77b	77b	y = 77.3/(1+exp(–(x+44.9)/112.1))	0.99**
Mondial	55a	94a	104a	123a	119a	y = 120.3/(1+exp(–(x+11.4)/105.9))	0.98**
Firmness (N) - soil with medium P availability							
Agata	6.6b	7.1b	7.7b	7.4b	7.5b	y = 7.52/(1+exp(–(x+191.61)/98.11))	0.85*
Mondial	8.9a	9.3a	8.8a	8.8a	8.6a	ns	-

[(1)] Means followed by different letters in the columns are significantly different by t-test (LSD) ($p<0.05$); ns = non-significant; * $p<0.05$; ** $p<0.01$.

in the percentage of DM in the potato tubers (indicated by the specific gravity) according to P fertilization, under the conditions where it provided a great increase in tuber yield.

The protein content in the tubers was influenced only by the cultivar in the experiment on soil with medium concentration of available P (Table 2). In this condition, the cultivar Mondial produced tubers with higher protein content. Although Lachman et al. (2005) have stated that the protein content in potato tubers is affected by cultivars, fertilization systems, and crop management systems, similar to that observed in the present study, Fernandes et al. (2011) found no differences in the protein content of the tubers of Agata and Mondial grown in soil with high P availability. Phosphorus fertilization did not change the tuber protein content, but increased the yield of marketable tubers, which, consequently, results in a higher protein yield per area. This is a commercially interesting characteristic because, although the potato tubers have low protein content (Lachman et al., 2005; UNICAMP, 2011), this protein is of high nutritional value, which places the tubers as an important source of food (Pereira et al., 2005).

There were no differences between cultivars regarding the P content in the tubers (Table 4). On the other hand, P fertilization increased the content of this nutrient in the tubers in all experiments. In soil with medium concentration of available P, the levels of this nutrient in the tubers increased linearly with the increase in P fertilization. In soils with low and high availability of P, the contents of this nutrient in the tubers increased up to the estimated rates of 870 and 778 kg ha^{-1} P_2O_5, respectively. It is noteworthy that in addition to increasing the yield of tubers, the P fertilization is also important for the production of tubers rich in this nutrient (Tables 2 and 4), essential in human nutrition (Pereira et al., 2005; UNICAMP, 2011).

Phosphorus rates did not affect the K content in tubers, regardless of the availability of P in soil (Table 4). In soil with high concentration of available P, the cultivar Mondial showed higher K content in tubers, regardless of phosphorus fertilization. However, in all areas, K content in tubers of both cultivars were close to the values observed by Evangelista et al. (2011) with 11 potato cultivars, within the range reported by Quadros et al. (2009), 353-550 mg 100 g^{-1} fresh weight of tubers and above the average level of 302 mg 100 g^{-1} fresh weight, described in the Brazilian Table of Food Composition (UNICAMP, 2011).

Calcium content in potato tubers was not affected by treatments in soil with low P availability, but in soils with medium and high availability the cultivar Mondial showed higher, with no influence from P fertilization (Table 4). Regardless of the treatment, Ca content observed in tubers of the cultivars were higher than the mean content of 4 mg 100 g^{-1} fresh matter, described by UNICAMP (2011), but lower than those reported by Evangelista et al. (2011). Also noteworthy is that the higher content of Ca in tubers grown in soil with low concentration of P available is due to the greater availability of Ca in the soil (Table 1) and lower yields obtained in this experiment (Table 2), which probably concentrated Ca in tubers (Table 4).

Magnesium content in the tubers was not affected by the treatments. In all treatments, the values remained above the mean level described by UNICAMP (2011), which is 15 mg 100 g^{-1} fresh matter.

The rates of P fertilization did not interfere with Cu, Fe, and Mn contents in the tubers of the potato cultivars (Table 4). In soils with low and medium concentration of available P, the cultivar Mondial had higher Cu content in tubers, but in all treatments the contents of this nutrient were very close to those reported by Evangelista et al. (2011) and UNICAMP (2011). The cultivar Mondial also produced tubers with higher content of Fe and Mn than Agata, in soil with medium availability of P. In soil with high P availability, Agata exhibited a higher Mn content than Mondial. Zinc content of the tubers was affected by cultivar, with higher values observed in Mondial in soils with medium and high concentration of P available. These results demonstrate that

Table 4. Nutritional composition of marketable tubers of potato cultivars according to phosphorus fertilization in soils with low (14 mg dm^{-3}), medium (36 mg dm^{-3}) and high (70 mg dm^{-3}) availability of phosphorus[1]

Soil P availability	Cultivar (C)		Rate of P_2O_5 (kg ha^{-1}) (R)					CV (%)	Interaction C × R	Regression equation	R^2
	Agata	Mondial	0	125	250	500	1000				
						P (mg 100 g^{-1} fresh matter)					
Low	32a	30a	21	26	34	34	40	14.2	ns	y = 22.30 + 0.040x −0.000023x^2	0.92**
Medium	28a	30a	24	26	29	31	34	13.5	ns	y = 25.21 + 0.0099x	0.93**
High	25a	25a	22	24	24	27	27	9.7	ns	y = 21.96 + 0.014x −0.000009x^2	0.96*
						K (mg 100 g^{-1} fresh matter)					
Low	398a	419a	407	409	434	410	382	9.2	ns	ns	-
Medium	435a	450a	458	443	440	440	432	6.4	ns	ns	-
High	404b	440a	424	421	421	431	413	5.9	ns	ns	-
						Ca (mg 100 g^{-1} fresh matter)					
Low	11a	10a	8	11	11	11	11	22.6	ns	ns	-
Medium	6b	8a	6	8	7	8	6	18.1	ns	y = 6.45 + 0.0064x −0.000007x^2	0.66*
High	5b	7a	5	6	6	6	6	19.5	ns	ns	-
						Mg (mg 100 g^{-1} fresh matter)					
Low	19a	19a	19	19	21	19	18	13.2	ns	ns	-
Medium	24a	24a	24	24	23	24	24	8.3	ns	ns	-
High	20a	21a	21	20	21	21	20	8.4	ns	ns	-
						Cu (mg 100 g^{-1} fresh matter)					
Low	0.09b	0.12a	0.12	0.09	0.11	0.10	0.10	20.8	ns	ns	-
Medium	0.10b	0.11a	0.12	0.11	0.10	0.10	0.10	16.3	ns	ns	-
High	0.11a	0.10a	0.10	0.10	0.11	0.11	0.10	20.8	ns	ns	-
						Fe (mg 100 g^{-1} fresh matter)					
Low	2.52a	2.41a	2.59	2.26	2.55	2.46	2.47	14.9	ns	ns	-
Medium	1.41b	1.90a	1.67	1.68	1.61	1.67	1.63	19.6	ns	ns	-
High	1.33a	1.24a	1.16	1.25	1.38	1.34	1.30	18.0	ns	ns	-
						Mn (mg 100 g^{-1} fresh matter)					
Low	0.11a	0.11a	0.13	0.11	0.12	0.10	0.09	24.8	ns	ns	-
Medium	0.13b	0.19a	0.16	0.16	0.16	0.18	0.15	16.0	ns	ns	-
High	0.16a	0.12b	0.15	0.14	0.14	0.15	0.13	19.0	ns	ns	-
						Zn (mg 100 g^{-1} fresh matter)					
Low	0.28a	0.29a	0.36	0.28	0.27	0.26	0.25	15.1	ns	y = 0.28 + 0.081exp(−0.024x) −0.00003x	0.99**
Medium	0.29b	0.37a	0.39	0.30	0.31	0.32	0.32	19.0	ns	ns	-
High	0.20b	0.26a	0.25	0.23	0.23	0.23	0.21	14.4	ns	ns	-

[1] Means followed by different letters in the rows, for the factor cultivar, are significantly different by t-test (LSD) ($p<0.05$); ns = non-significant; * $p<0.05$; ** $p<0.01$.

there may be differences between cultivars in relation to the levels of these nutrients in the tubers.

In soil with low P availability, the contents of Zn in the tubers were reduced by P fertilization until the highest rate tested (Table 4). This indicates that depending on the condition, the application of higher rates of P may decrease the nutritional value of the tubers, particularly with regard to Zn, as Zn^{2+} and $H_2PO_4^-$ ions can form chemical bonds in the tissues of plants and soil, and in condition of excess P in soil or plant there may be a Zn deficiency induced by P (Barben et al., 2010), especially when the availability of Zn in soil is not high (Table 1). But, in general, the contents of Fe, Mn, and Zn were high, which is related to the medium-high availability of such nutrients in soils and the little influence of P on the nutritional composition of tubers of the both potato cultivars.

4. CONCLUSION

Phosphorus fertilization increases the content of P and starch, the size and yield of marketable tubers, however, more expressively and with the use of higher rates applied to soils with low and medium concentration of available P.

The cultivar Mondial produced more than the cultivar Agata, due to a higher tuber mean weight and greater increases in this characteristic in response to P fertilization.

The cultivar Mondial produced tubers with firmer pulp, with higher percentage of DM and higher contents of Ca, Cu, and Zn than the cultivar Agata.

In soil with low P availability, P fertilization reduced the Zn content, but, in general, had little influence on nutritional composition of potato tubers.

ACKNOWLEDGEMENTS

To the São Paulo Research Foundation (FAPESP) for the scholarship to the first and third authors (2010/04987-6 and 2012/12128-9); the National Council for Scientific and Technological Development (CNPq) for supporting research and providing Research Productivity fellowship to the second author; and to Ioshida Group, for providing the cultivation areas.

REFERENCES

Agência Nacional de Vigilância Sanitária – ANVISA. (2005). Métodos físico-químicos para análise de alimentos (4th ed.). Brasília: Ministério da Saúde.

Anzaldúa-Morales, A., Bourne, M. C., & Shomer, I. (1992). Cultivar, specific gravity and location in tuber affect puncture force of raw potatoes. Journal of Food Science, 57, 1353-1356. http://dx.doi.org/10.1111/j.1365-2621.1992.tb06855.x.

Barben, S. A., Hopkins, B. G., Jolley, V. D., Webb, B. L., & Nichols, B. A. (2010). Phosphorus and zinc interactions in chelator-buffered solution grown Russet Burbank potato. Journal of Plant Nutrition, 33, 587-601. http://dx.doi.org/10.1080/01904160903506308.

Dechassa, N., Schenk, M. K., Claassen, N., & Steingrobe, B. (2003). Phosphorus efficiency of cabbage (*Brassica oleraceae* L. var. *capitata*), carrot (*Daucus carota* L.), and potato (*Solanum tuberosum* L.). Plant and Soil, 250, 215-224. http://dx.doi.org/10.1023/A:1022804112388.

Evangelista, R. M., Nardin, I., Fernandes, A. M., & Soratto, R. P. (2011). Qualidade nutricional e esverdeamento pós-colheita de tubérculos de cultivares de batata. Pesquisa Agropecuária Brasileira, 46, 953-960. http://dx.doi.org/10.1590/S0100-204X2011000800023.

Feltran, J. C., Lemos, L. B., & Vieites, R. L. (2004). Technological quality and utilization of potato tubers. Scientia Agricola, 61, 593-603. http://dx.doi.org/10.1590/S0103-90162004000600006.

Fernandes, A. M., & Soratto, R. P. (2012). Nutrição mineral, calagem e adubação da batateira. Botucatu: FEPAF.

Fernandes, A. M., Soratto, R. P., Evangelista, R. M., & Nardin, I. (2010). Qualidade físico-química e de fritura de tubérculos de cultivares de batata na safra de inverno. Horticultura Brasileira, 28, 299-304. http://dx.doi.org/10.1590/S0102-05362010000300010.

Fernandes, A. M., Soratto, R. P., Evangelista, R. M., Silva, B. L., & Souza-Schlick, G. D. (2011). Produtividade e esverdeamento pós-colheita de tubérculos de cultivares de batata produzidos na safra de inverno. Revista Ciência Agronômica, 42, 502-508. http://dx.doi.org/10.1590/S1806-66902011000200033.

Freeman, K. L., Franz, P. R., & Jong, R. W. (1998). Effect of phosphorus on the yield, quality and petiolar phosphorus concentrations of potatoes (cv. Russet Burbank and Kennebec) grown in the krasnozem and duplex soils of Victoria. Australian Journal of Experimental Agriculture, 38, 83-93. http://dx.doi.org/10.1071/EA96045.

Horwitz, W., & Latimer, G. W., Jr. (2005). Official methods of analysis of the Association of Analytical Chemists International (18th ed.). Gaythersburg: AOAC International.

Houghland, G. V. C. (1960). The influence of phosphorus on the growth and physiology of the potato plant. American Potato Journal, 37, 127-138. http://dx.doi.org/10.1007/BF02855950.

Klein, L. B., Chandra, S., & Mondy, N. I. (1980). The effect of phosphorus fertilization on the chemical quality of Katahdin potatoes. American Potato Journal, 57, 259-266. http://dx.doi.org/10.1007/BF02855303.

Lachman, J., Hamouz, K., Dvorák, P., & Orsák, M. (2005). The effect of selected factors on the content of protein and nitrates in potato tubers. Plant, Soil and Environment, 51, 431-438.

Luz, J. M. Q., Queiroz, A. A., Borges, M., Oliveira, R. C., Leite, S. S., & Cardoso, R. R. (2013). Influence of phosphate fertilization on phosphorus levels in foliage and tuber yield of the potato cv. Ágata. Semina: Ciências Agrárias, 34, 649-656.

Malavolta, E., Vitti, G. C., & Oliveira, S. A. (1997). Avaliação do estado nutricional das plantas: princípios e aplicações (2nd ed.). Piracicaba: Potafós.

Nelson, N. (1944). A photometric adaptation of the Somogyi method for the determination of glucose. The Journal of Biological Chemistry, 153, 375-390.

Nielsen, T. H., Wischmann, B., Enevoldsen, K., & Moller, B. L. (1994). Starch phosphorylation in potato tubers proceeds concurrently with de novo biosynthesis of starch. Plant Physiology, 105, 111-117. PMid:12232190.

Pereira, E. M. S., Luz, J. M. Q., & Moura, C. C. (2005). A batata e seus benefícios nutricionais. Uberlândia: EDUFU.

Quadros, D. A., Iung, M. C., Ferreira, S. M. R., & Freitas, R. J. S. (2009). Composição química de tubérculos de batata para processamento, cultivados sob diferentes doses e fontes de potássio. Ciência e Tecnologia de Alimentos, 29, 316-323. http://dx.doi.org/10.1590/S0101-20612009000200013.

Rosen, C. J., & Bierman, P. M. (2008). Potato yield and tuber set as affected by phosphorus fertilization. American Journal of Potato Research, 85, 110-120. http://dx.doi.org/10.1007/s12230-008-9001-y.

Rosen, C. J., Kelling, K. A., Stark, J. C., & Porter, G. A. (2014). Optimizing Phosphorus Fertilizer Management in Potato Production. American Journal of Potato Research, 91, 145-160. http://dx.doi.org/10.1007/s12230-014-9371-2.

Sheard, R. W., & Johnston, G. R. (1958). Influence of nitrogen, phosphorus and potassium on the cooking quality of potatoes. Canadian Journal of Plant Science, 38, 394-400. http://dx.doi.org/10.4141/cjps58-063.

Silva, G. O., Pereira, A. S., Souza, V. Q., Carvalho, F. I. F., & Fritsche, R., No. (2007). Correlações entre caracteres de aparência e rendimento e análise de trilha para aparência de batata. Bragantia, 66, 381-388. http://dx.doi.org/10.1590/S0006-87052007000300003.

Taiz, L., & Zeiger, E. (2013). Fisiologia vegetal. Porto Alegre: Artmed.

Universidade Estadual de Campinas – UNICAMP. (2011). Tabela brasileira de composição de alimentos. Retrieved from august 8, 2014, http://www.unicamp.br/nepa/taco/tabela.php?ativo=tabela.

Zewide, I., Mohammed, A., & Tulu, S. (2012). Effect of different rates of nitrogen and phosphorus on yield and yield components of potato (*Solanum tuberosum* L.) at Masha District, Southwestern Ethiopia. International Journal of Soil Science, 7, 146-156. http://dx.doi.org/10.3923/ijss.2012.146.156.