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Productivity, mineral composition, and phenolic compound content in bush snap beans grown during different seasons

Produtividade, composição mineral e teor de compostos fenólicos em feijão-vagem de crescimento determinado em diferentes estações do ano

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Highlights:
Interaction between genotype and planting season favors seed yield.
Interaction between genotype and planting season favors seed crude protein content.
Interaction between genotype and planting season favors concentrations of zinc and manganese in the seed.
Genotype and season affect phosphorus, iron, potassium, and phenolic compound-accumulation in the seed.
Genotype affects calcium and magnesium concentration in seeds.

Abstract

The sowing of seeds during different seasons, characterized by distinct environmental conditions, can result in different agronomic characteristics and production rates of agricultural crops. Considering the lack of information on the effect of climatic variations on the agronomic performance of snap bean (*Phaseolus vulgaris*), it is important to evaluate the productivity and nutrient content when sown at different times of the year. Thus, the study aimed to evaluated plant productivity, and seed mineral and phenolic compound composition in different genotypes and cultivars of bush snap bean UEL 1, UEL 2, Isla Macarrão Baixo, Isla Manteiga Baixo, and Feltrin Macarrão Napoli sowed in the spring and autumn. The number of pods per plant, seeds per pod, seeds per plant, and seed yield were evaluated. Chemical composition of the seeds was determined by measuring the amounts of crude protein, calcium, magnesium, potassium, phosphorus, sulfur, iron, zinc, manganese, and total phenolic compounds present. The joint analysis of variance of the experiments was performed, with means compared by the Tukey test, at 5%. The interaction between genotype and sowing season affects the number of seeds per plant, seed productivity, and the seed concentrations of crude protein, zinc, and manganese. Spring sowing favored seed yield in the Isla Manteiga Baixo cultivar, the number of pods per plant, and the accumulation of phosphorus and iron in the seeds. Autumn sowing resulted in an increase in the seed-concentrations of potassium and total phenolic compounds. Seed-concentrations of calcium and manganese varied by genotype.
Key words: Environmental conditions. Agronomic performance. *Phaseolus vulgaris* L.

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Resumo

A semeadura de sementes em diferentes épocas do ano encontra condições ambientais distintas, que podem resultar em diferentes respostas agronômicas e na produtividade de culturas agrícolas. Considerando a falta de informações sobre o efeito das variações climáticas no desempenho agronômico do feijão-vagem (*Phaseolus vulgaris*) é importante avaliar a produtividade e o teor de nutrientes quando semeados em diferentes épocas do ano. Assim, o estudo objetivou avaliar a produtividade e a composição de compostos minerais e fenólicos em sementes de diferentes genótipos e cultivares de feijão-vagem – UEL 1, UEL 2, Isla Macarrão baixo, Isla Manteiga Baixo e Feltrin Macarrão Napoli – semeados na primavera e outono. Foram avaliados o número de vagens por planta, sementes por vagem, sementes por planta e produção de sementes. A composição química das sementes foi determinada medição das quantidades de proteína bruta, cálcio, magnésio, potássio, fósforo, enxofre, ferro, zinco, manganês e compostos fenólicos totais. Foi realizada análise de variância conjunta dos experimentos, com médias comparadas pelo teste de Tukey, a 5%. A interação entre genótipo e época de semeadura afeta o número de sementes por planta, a produtividade e as concentrações de proteína bruta, zinco e manganês. A semeadura na primavera favoreceu a produção de sementes na cultivar Isla Manteiga Baixo, o número de vagens produzidas por planta, e o acúmulo de fósforo e ferro nas sementes. A semeadura no outono resultou em um aumento nas concentrações de potássio e dos compostos fenólicos totais. As concentrações de cálcio e magnésio nas sementes variam de acordo com o genótipo.

Palavras-chave: Condições ambientais. Desempenho agronômico. *Phaseolus vulgaris* L.

Introduction

Approximately 1.9 million tons of snap beans (*Phaseolus vulgaris*) are produced globally per year, with 54% from the American continent, and 10% from South America. The world's largest producer of snap beans is the United States, with about 800,000 tons annually (Food and Agriculture Organization of the United Nations [FAO], 2018). Though data on produce production are incipient in Brazil, the most recent survey indicated that the production and commercialization of snap beans moved around 60 million dollars (Companhia Nacional de Abastecimento [CONAB], 2015).

As they are more productive, producers' growers prefer to use snap beans with indeterminate growth, also known as pole beans. However, cultivars with determinate growth—referred to as bush beans—do not require planting, have a shorter life cycle, concentrate flowering, and are faster to harvest, ultimately reducing the amount of cultural treatments used and production costs (Moreira et al., 2009). Snap and common bean (of the same species) can be grown throughout the year (Araújo & Ferreira, 2006). According to Barros, Pelúzio, Santos, Brito, and Almeida (2003), the sowing date is characterized by distinct environmental conditions that can alter the agronomic characteristics and production of crops. For beans, the association between temperature and relative humidity, as well as the amount and distribution of rainfall, decisively influence flowering and fruiting, ultimately affecting yield (Tsukaguchi et al., 2005).

During its life cycle, *Phaseolus vulgaris* L. consumes 300-600 mm of water (growing at an ideal temperature of 17-25ºC) (Barbosa & Gonzaga, 2012). However, the irregular distribution of rainfall can affect yield, especially if it occurs during the reproductive stages. Additionally, temperatures above 35ºC cause abscission of the reproductive structures, while low temperatures can reduce plant growth and development, both of which decrease yield (Carvalho, Castro, Dias, & Ferraz, 2014). The relative air humidity can interfere with the atmospheric evaporative demand, which, if higher (lower relative air humidity due to higher temperature), increases the transpiration rate and amount of water needed. Thus, the lack of water in the soil can affect the vegetative and reproductive stages as well (Gomide & Albuquerque, 2008).

Sowing at different times can also interfere with the mineral composition of the seeds (Farinelli & Lemos, 2010), and consequently, the absorption of water and nutrients. The production of phenolic compounds by secondary plant metabolism can also be altered depending when sowing takes place. These are aromatic compounds produced in response to biotic and abiotic stresses (Angelo & Jorge, 2007), and their quantification contributes to an understanding of the relationship between environmental stress and the levels of production and quality of the harvested product.

Considering that the environment can affect the quantity and quality of crop production, in addition to the lack of information on the effect of climatic variations on the performance of snap beans, it is important to evaluate the crop sowed during different seasons. We evaluated the productivity, mineral composition, and total phenolic compound content in bush snap beans sowed in two different seasons.

Materials and Methods

The experiments were carried out in Londrina, Paraná, Brazil, in eutropheric red latosol soil at 23º23'S, 51º11'W, at an altitude of 570 m. The region's climate is of the Cfa type (subtropical mesothermal with hot summers), with annual air temperatures of 21-22ºC, and rainfall of 1,400-1,600 mm (Nitsche, Caramori, Ricce, & Pinto, 2019). Rainfall, average temperature, and relative humidity, for the duration of the experiment are presented in Figure 1.

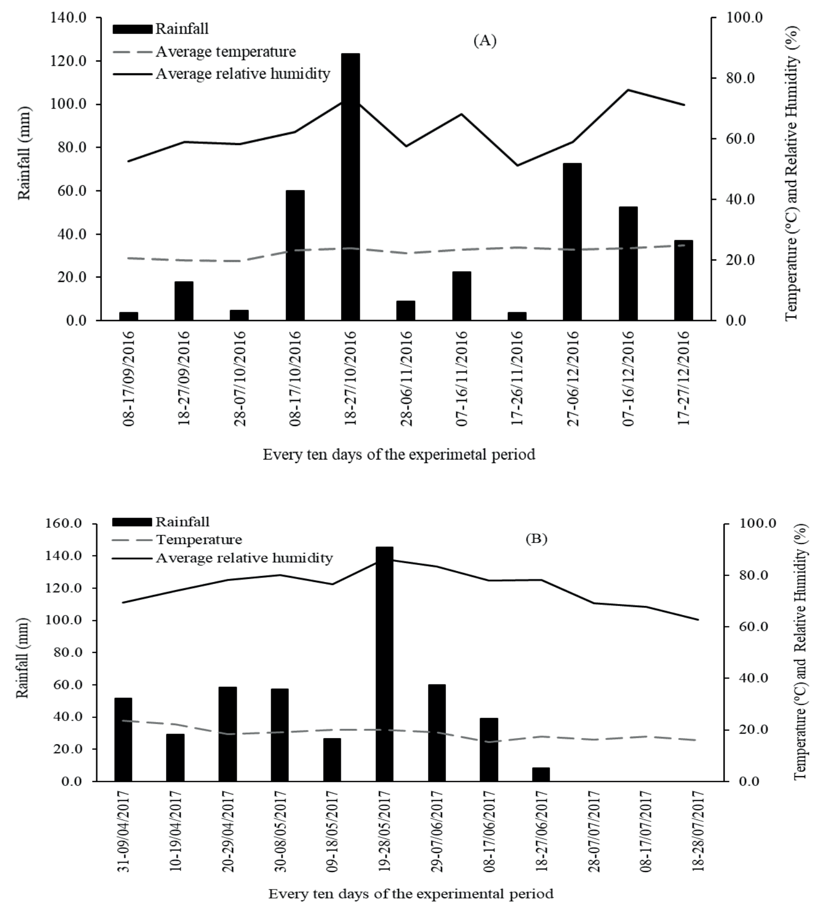

Figure 1. Precipitation, average temperature, and relative humidity over the durations of the experiments. Data were taken every ten days during the spring-summer (A) and autumn-winter (B) seasons.

The genotypes evaluated, all of which have determined (bush) growth, included UEL 1 and UEL 2, selected from a breeding program at the State University of Londrina (UEL), in addition to commercial cultivars Isla Macarrão Baixo, Isla Manteiga Baixo, and Feltrin Macarrão Napoli. With the exception of Isla Manteiga Baixo, which has black seeds, the other genotypes have white seeds. The experiment was organized into random blocks, with four replicates. An independent experiment was conducted at for each sowing.

Experiment I was sowed on 09/08/16 during the spring, and completed in the summer. Experiment II was sowed on 03/31/17 in the autumn, and completed in the winter. To prepare the land, fields were kept fallow and planted with the cover crop *Urochloa decumbens* (Stapf) R. D. Webster. Prior to each sowing, the soil was plowed and harrowed mechanically.

Prior to sowing, chemical analysis of the soil was performed at a depth of 0-20 cm. The soil used in the spring had a pH ($CaCl_2$) of 5.0, 19.26 g kg^{-1} of organic matter, 5.76 cmol$_c$ dm^{-3} of H^+ and Al^{3+}, 4.19 cmol$_c$ dm^{-3} of Ca^{2+}, 2.05 cmol$_c$ dm^{-3} of Mg^{2+}, 0.53 cmol$_c$ dm^{-3} of K^+, 1.31 mg dm^{-3} of P, and a base saturation of 54.03%. In the autumn, the soil had a pH of 5.6, 27.0 g kg^{-1} of organic matter, 3.97 cmol$_c$ dm^{-3} of H^+ and Al^{3+}, 3.05 cmol$_c$ dm^{-3} of Ca^{2+}, 1.6 cmol$_c$ dm^{-3} of Mg^{2+}, 0.3 cmol$_c$ dm^{-3} of K^+, 4.6 mg dm^{-3} of P, a base saturation of 55.49%.

Based on the chemical analyzes of the soils, the basic mineral fertilization in the sowing furrow, as well as the mineral cover fertilization, performed at 25 days after emergence, occurred according to Parra (2003). In both harvests, the formulated fertilizer used was 10-30-10, while urea (45% N) served as a source for covering fertilization.

In both experiments, plots were made of two rows (45 cm apart), each 2 m in length, with 10 cm between plants. Sowing was done manually, at a density of 10 seeds per meter. Common beans were planted in a border around the plots.

In the spring-summer experiment, 0.47 g ha^{-1} of thiamethoxam (Actara 250 WG) was applied to treat for whiteflies 41 days post-sowing. To treat for anthracnose, 0.19 g ha^{-1} of azoxystrobin (Amstar WG) was applied 77 days post-sowing. Weeding was done manually, as needed. In autumn-winter, the same strategies were used to control anthracnose and weeds, but there was no need for whitefly treatment.

Pods were harvested at the R_9 stage for the evaluation of the following characteristics. The number of pods per plant (NPP) was determined by the ratio between the number of pods and plants per plot. The number of seeds per pod (NSP) was calculated as the number of seeds divided by the number of pods per plot. The number of seeds per plant (NSPL) was calculated by dividing the number of seeds produced by the number of plants per plot. Seed productivity (PROD) was determined as the seed mass, at a moisture content of 13%, per plot, in kg ha^{-1}.

After harvest, seeds were ground for randomized analyses in the lab, with four replicates for each. Amounts of Ca, Mg, S, Fe, Zn, and Mn were determined using an atomic absorption spectrophotometer (GBC, Avanta, 932AA). Phosphorus-content (P-content) in the seeds was measured using a spectrophotometer (Micronal, 8342), and that of potassium (K-content) using a flame photometer (Micronal, B262). Macronutrients (in g) and micronutrients (in mg) were quantified per kg of tissue. Crude protein-content was calculated using the Kjeldahl method, where the conversion from nitrogen to crude protein is done by multiplying by a factor of 6.25 (Association of Official Analytical Chemists [AOAC], 2012).

Total phenolic compound-content was assessed in plant-extract obtained as in Vázquez et al. (2008). Two grams of ground seed tissue was combined with 10 mL of 50% methanol and incubated for 60 min at room temperature. Subsequently, the mixture was centrifuged at 2,500 rpm for 5 min, after which the supernatant (plant extract) was isolated. A dilution was made with 1 mL each of the extract, distilled water, 0.2 N Folin-Ciocalteau reagent, and 10% sodium carbonate. The dilution was incubated for 30 minutes at room temperature, after which the absorbance at 720 nm was measured using a spectrophotometer (Micronal, 8342). Gallic acid, at concentrations 0-50 mg L^{-1} (in increments of 10), was used as a standard, and the results are expressed in mg of gallic acid per 100 g of sample (Swain & Hills, 1959).

Initially, individual analyzes of variance were performed for each experiment and, after checking the magnitudes of the residual mean squares, joint analysis was performed. The effects of sowing season and genotype were considered fixed. Joint analysis of variance was performed, followed by a Tukey's post hoc test with an α of 0.05. Statistical analyses were performed using software from SISVAR® software.

Results and Discussion

With regard to the number of seeds per plant (NSPL) and seed productivity (PROD), the interaction between genotype and sowing season (G×S) was highly significant ($p < 0.01$; Table 1).

UEL 2 produced the most seeds (per plant) in the spring-summer, differing from Isla Macarrão Baixo and Isla Manteiga Baixo, while Feltrin Macarrão Napoli produced the most in autumn-winter, which was higher than that of the Isla Manteiga Baixo and UEL 2. Comparing harvests between sowing seasons, there was a reduction in the NSPL of Isla Manteiga Baixo and UEL 2 grown in autumn-winter compared to spring-summer. For the remaining genotypes, the NSPL was similar between both sowing seasons (Table 2).

In the spring-summer, Isla Manteiga Baixo produced a large quantity of seeds (PROD) 2,140.14 kg ha^{-1} in contrast to Feltrin Macarrão Napoli. There was no difference in PROD between genotypes in the autumn-winter. Among the genotypes analyzed, Isla Manteiga Baixo showed the greatest sensitivity to change in sowing season, with a 54% reduction in seed productivity in autumn-winter. In contrast, the other genotypes proved to be suitable for cultivation in both seasons (Table 2).

Generally, as compared to the autumn-winter season, the production of seeds per plant and the productivity of snap beans was higher in the spring-summer season, which was characterized by regular precipitation throughout, in addition to higher atmospheric evaporative-demand (higher temperature and lower relative humidity) (Figure 1). In line with our findings, other work describes bean productivity (the number of seeds) as correlating with higher temperatures (Bevilaqua, Antunes, Eberhardt, Eicholz, & Grehs, 2013).

Table 1
Simplified analysis of variance of number of pods per plant (NPP), number of seeds per pod (NSP), number of seeds per plant (NSPL), seed productivity (PROD), crude protein content (PROT), macronutrients (Ca, Mg, K, P, and S), micronutrients (Fe, Zn, and Mn) and total phenolic compound-content (TPC) in bush snap beans sowed in different seasons

Sources of variation	Medium Square													
	NPP	NSP	NSPL	PROD	PROT	Ca	Mg	K	P	S	Fe	Zn	Mn	TPC[1]
Block (B)	7.19	0.67	154.85	230,264.23	48.31	0.47	0.09	5.13	0.17	0.04	585.19	136.48	114.22	0.09
Genotype (G)	32.94^{**}	1.10^{ns}	457.32^{**}	$117,102.53^{ns}$	92.52^{**}	1.23^{**}	0.08^{*}	16.44^{**}	1.62^{**}	0.03^{ns}	508.01^{ns}	39.12^{ns}	121.83^{**}	0.11^{**}
Season (S)	250.26^{**}	5.93^{**}	602.87^{**}	$850,716.22^{**}$	121.81^{*}	0.19^{ns}	0.05^{ns}	29.25^{**}	3.56^{**}	0.04^{ns}	$3,159.51^{**}$	134.32^{**}	169.74^{**}	0.72^{**}
G X S	15.98^{ns}	1.07^{ns}	440.78^{**}	$577,719.76^{**}$	70.10^{*}	0.34^{ns}	0.03^{ns}	9.18^{ns}	0.22^{ns}	0.06^{ns}	230.38^{ns}	72.12^{**}	33.56^{*}	0.01^{ns}
Residue	7.58	0.41	71.72	103,537.99	18.87	0.14	0.02	3.47	0.33	0.03	353.63	16.99	9.43	0.02
CV (%)	23.06	18.04	20.69	22.02	20.83	19.02	7,52	9.10	11.84	11.98	23.47	17.86	12.66	7.47

[1]Data were transformed using a base-10 logarithm.
*Significant at 5%; **Significant at 1%.

Table 2
Number of pods per plant (NPP), seeds per pod (NSP), plant seeds (NSPL), and seed yield (PROD) of pods across different genotypes and sowing seasons

Genotype	NPP			NSP			NSPL			PROD (kg ha^{-1})		
	[1]SS	[2]AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
Isla Macarrão Baixo	12.09	8.82	10.45 ab	3.29	4.88	4.09	38.22 bA	43.19 abA	40.71	1,504.86 abA	1,327.25 aA	1,416.06
Isla Manteiga Baixo	13.15	5.51	9.33 b	3.06	3.36	3.21	37.70 bA	18.79 cB	28.22	2,140.14 aA	1,000.63 aB	1,570.39
UEL 1	13.09	11.39	12.24 ab	3.17	3.79	3.45	42.92 abA	43.01 abA	42.99	1,534.92 abA	1,396.40 aA	1,465.66
UEL 2	18.24	10.01	14.13 a	3.29	3.17	3.23	59.01 aA	30.93 bcB	44.97	1,743.52 abA	1,401.88 aA	1,572.70
Feltrin Macarrão Napoli	15.62	11.46	13.54 a	3.01	4.34	3.72	46.19 abA	49.31 aA	47.75	1,112.46 bA	1,451.39 aA	1,281.92
Mean	14.44 A	9.47 B		3.15 B	3.92 A		44.81 A	37.04 B		1,607.18 A	1,315.51 B	

Averages followed by the same lowercase letter (across rows), and uppercase letter (down columns), are not significantly different (Tukey's test, $\alpha = 0.05$)
[1]SS denotes spring-summer season and [2]AW denotes autumn-winter season.

Previously, a study evaluating six genotypes of bush snap beans measured a yield of 1,750 kg ha^{-1} in autumn-winter-cultivated plants (Vidal, Junqueira, Peixoto, & Moraes, 2007), higher than the 1,315.51 kg ha^{-1} we obtained for the same season. In addition to the use of different genotypes, it is possible that the lower productivity in our experiment is related to lower atmospheric evaporative-demand (A. R. Pereira, Angelocci, & Sentelhas, 2002), in addition to reduced amounts of precipitation during intermediate reproductive phases, which reduces the absorption of water by the roots (Figure 1).

We found a relationship between the NSPL and PROD, which has been observed in other studies on common bean cultivars (Bonett et al., 2006). For both sowing seasons, genotypes with higher average NSPL in the spring-summer also had higher PROD. Additionally, we found that if there was a reduction in average NSPL, there was a corresponding reduction in PROD. For the number of plant pods (NPP), the isolated effects of genotype and sowing time were found to be significant, while the number of seeds per pod (NSP) appeared to only be affected by sowing time (Table 1).

UEL 2 and Feltrin Macarrão Napoli had the highest average NPP, though it did not differ from UEL 1 and Isla Macarrão Baixo. Isla Manteiga Baixo produced the fewest pods (Table 2). An inverse relationship was observed between NPP and NSP for different sowing seasons. In spring-summer, more pods per plant were produced, with fewer seeds per pod. In the autumn-winter, fewer pods per plant were produced, but with a greater number of seeds per pod (Table 2). This relationship can be explained by a change in the source-drain relationship as the plants produced more pods, fewer photo-assimilates were directed toward seed production. Conversely, plants that produced fewer pods were able to direct more photo-assimilates to the production of seeds, which explains the greater number of seeds per pod in plants sowed in the autumn-winter season. Previously, G. R. Gomes, Moritz, Freiria, Furlan and Takahashi (2016) reported an adjustment between supply and demand of photo-assimilates in snap beans grown in different environments, expressed by the inverse relationship between the number of pods per plant and unit mass of pods.

The interaction between G×S was found to be significant for the percentage of crude protein, and the levels of zinc and manganese in the seeds (Table 1). In the spring-summer, protein levels in the seeds were similar across all genotypes. In autumn-winter, Isla Manteiga Baixo and UEL 1 had significantly higher protein levels, differed from Isla Macarrão Baixo and UEL 2. Isla Macarrão Baixo seeds saw a reduction in protein content in autumn-winter compared to spring-summer, while Isla Manteiga Baixo and UEL 1 showed the opposite (Table 3). The percentage of protein in snap beans varied from 16.01-29.73% across growing season and genotype. According to Guzmán-Maldonado and Parede-López (1998), the percentage of protein in beans (*P. vulgaris* L.) can vary from 16-33%.

Table 3
Seed-content of crude protein (PROT), macronutrients (Ca, Mg, K, and P), and micronutrients (Fe, Zn, and Mn) in bush snap beans sowed in different seasons

Genotype	PROT (%)			Ca (g kg^{-1})			Mg (g kg^{-1})			K (g kg^{-1})		
	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
Isla Macarrão Baixo	19.99 aA	16.50 bB	18.25	1.54	2.23	1.88 b	1.96	2.13	2.05 ab	17.63	20.85	19.24 b
Isla Manteiga Baixo	17.79 aB	29.73 aA	23.76	1.37	1.71	1.54 b	2.00	2.21	2.10 a	20.81	24.75	22.78 a
UEL 1	19.99 aB	26.45 aA	23.22	1.92	1.97	1.95 b	1.87	1.85	1.86 b	19.29	19.41	19.35 b
UEL 2	16.01 aA	16.41 bA	16.21	1.82	1.82	1.82 b	1.94	1.99	1.97 ab	19.03	21.44	20.24 ab
Feltrin Macarrão Napoli	21.73 aA	23.89 abA	22.81	2.81	2.39	2.60 a	1.94	1.86	1.89 ab	21.32	20.17	20.75 ab
Mean	19.10 B	22.59 A		1.89	2.03		1.94	2.01		19.62 B	21.33 A	
Genotype	**P (g kg^{-1})**			**Fe (mg kg^{-1})**			**Zn (mg kg^{-1})**			**Mn (mg kg^{-1})**		
	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
Isla Macarrão Baixo	5.01	4.24	4.62 ab	104,45	71.63	88.04	26.17 aA	21.95 bA	24.06	20.25 bB	31.00 abA	25.63
Isla Manteiga Baixo	5.34	5.26	5.30 ab	77,70	68.53	73.11	22.15 abA	25.70 abA	23.93	22.00 abA	25.55 bcA	23.78
UEL 1	4.89	4.12	4.50 b	82,55	72.15	77.35	18.32 abB	30.70 aA	24.51	22.07 abA	21.55 cA	21.81
UEL 2	4.68	4.23	4.46 b	94,73	83.75	89.24	16.65 bA	21.67 bA	19.16	18.42 bA	21.47 cA	19.95
Feltrin Macarrão Napoli	5.83	4.93	5.38 a	85,70	60.20	72.95	22.97 abA	24.57 abA	23.78	28.22 aA	32.00 aA	30.11
Mean	5.15 A	4.55 B		89.03 A	71.25 B		21.26 B	24.92 A		22.20 B	26.32 A	

Averages followed by the same lowercase letter (across rows), and uppercase letter (down columns), are not significantly different (Tukey's test, $\alpha = 0.05$)
[1]SS denotes spring-summer season and [2]AW denotes autumn-winter season.

Genetic variation is the underlying cause for distinct protein accumulation in the seeds of different genotypes. As for sowing season, autumn-winter saw higher protein concentrations, but not seed yield. This dilution-effect, where higher protein levels correspond to lower yields, was also reported by F. G. Gomes et al. (2005) in common bean. The lower availability of water in the reproductive phase, as well as the lower average temperature in autumn-winter (18ºC) likely contributed to the higher amounts of protein found in the seeds. Zucareli, Silva, Gazola, Chavez and Nakagawa (2014) reported higher protein content in beans grown in the dry season, which is known to have a lower average temperature than the wet season. Generally, seed protein-content is associated with better initial seedling development in the field (Henning et al., 2010).

In spring-summer, Isla Macarrão Baixo beans accumulated more zinc than UEL 2, with 26.17 mg kg^{-1} and 16.65 mg kg^{-1}, respectively. In autumn-winter, the highest zinc content was found in UEL 1 (30.70 mg kg^{-1}), and the lowest in both Isla Macarrão Baixo (21.95 mg kg^{-1}) and UEL 2 (21.67 mg kg^{-1}). Comparison between sowing season, only UEL 2 had higher amounts of zinc in autumn-winter. For manganese, Feltrin Macarrão Napoli had the highest amount in the spring-summer, while in autumn-winter, Isla Macarrão Baixo had the highest. There was an increase in manganese-content in Isla Macarrão Baixo in autumn-winter. In general, as well as for protein content, zinc and manganese concentrations in seeds were higher in autumn-winter (Table 3).

The dilution-effect observed in protein-content also explains the higher concentrations of zinc and manganese in autumn-winter-sown beans. Additionally, the higher organic matter-content found in the autumn-winter soil may have complexed with, and reduced the availability of, these micronutrients. This phenomenon has been reported by Borkert, Pavan and Bataglia (2001). Beans with a higher zinc-content have been found to have longer shoots and roots, as well as more dry weight (Dorr et al., 2017). Seed manganese-content is known to provide adequate nutrition for legume seedlings in the field (Mann, Rezende, Carvalho, & Corrêa, 2001).

Analysis of variance showed that the potassium and phosphorus-content of the seeds were influenced, in isolation, by both genotype and sowing season (Table 1). Isla Manteiga Baixo accumulated more potassium, while Isla Macarrão Baixo and UEL 1 accumulated very little. In relation to sowing season, seeds harvested in the autumn-winter had higher concentrations of potassium. For phosphorus, Feltrin Macarrão Napoli (5.38 g kg^{-1}) differed from UEL 1 (4.50 g kg^{-1}) and UEL 2 (4.46 g kg^{-1}). In contrast, seeds harvested in the spring-summer accumulated more phosphorus (Table 3). Previously, T. Pereira, Coelho, Santos, Bogo and Miquelluti (2011) found higher levels of potassium in common beans grown under drought conditions, mainly during the reproductive phase of the crop. In addition to dilution, the nutrient content in beans varies depending on the genotype and environmental conditions relevant to plant and seed development (Lemos, Oliveira, Palomino, & Silva, 2004). Potassium is known to improve the physiological quality of legume seeds (Batistella et al., 2013). Costa, Barros, Albuquerque, Moura and Santos (2006) observed that the greater availability of water in the soil assists in the diffusion of phosphorus through the roots, facilitating the absorption of this nutrient by the plant. Therefore, the higher levels of phosphorus in spring-summer-harvested beans are likely due to the regular distribution of rainfall throughout the crop cycle.

We found that calcium and magnesium accumulation was significantly influenced by genotype (Table 1). Feltrin Macarrão Napoli beans contained more calcium than the other genotypes, while Isla Manteiga Baixo had the highest magnesium content, differing from UEL 1 (Table 3). Differences in the concentration of calcium in snap beans is attributed to genetic variation, as well as its availability in the soil, as reported by Miglioranza, Araujo, Endo, Souza and Montanari (2003) in snap bean cultivars of bush growth. Additional studies have reported that calcium is related to the physiological quality of seeds (Bevilaqua, Silva, & Possenti, 2002). Genetic variation was also attributed to the accumulation of magnesium in *P. vulgaris* L. (Buratto & Moda-Cirino, 2017). Magnesium plays an important role in the initial development of bean seedlings (Souza, Nascimento, & Martinez, 1998).

Iron accumulation was significantly affected by sowing season (Table 1), as spring-summer-harvested beans contained more (Table 3), likely due to the regular supply of water. These findings corroborate those described by V. G. C. Pereira et al. (2014), where the interaction between genotype and soil water availability influenced bean iron-content. Though the relationship between iron and physiological seed quality has been established, is not yet fully understood.

There was an isolated response between genotype and sowing season in relation to the amount of total phenolic compounds in the beans (Table 1). UEL 1 had the highest average amount of phenolic compounds, differing from Feltrin Macarrão Napoli, and the beans harvested in autumn-winter had a higher phenolic compound-content compared to spring-summer (Figure 2).

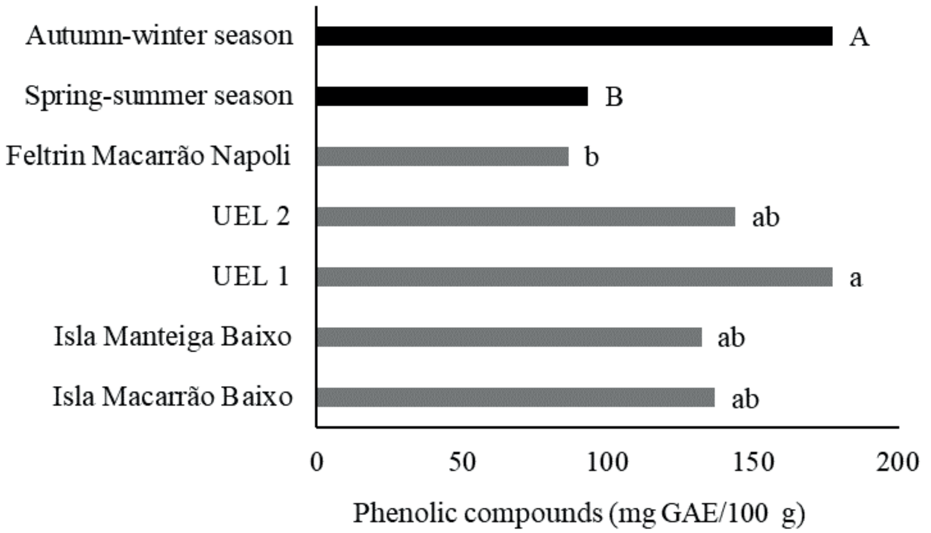

Figure 2. Total phenolic compound-content in seeds from different genotypes of bush snap beans, sowed during different seasons.

In vegetables, the production of phenolic compounds varies depending on the genotype (Luthria & Pastor-Corrales, 2005), as well as biotic and abiotic stresses in the environment (Angelo & Jorge, 2007). In autumn-winter, there was lower atmospheric evaporative-demand and water availability during the reproductive phase both of which reduce water uptake by the plants. Thus, the plants were under more stress in the autumn-winter in relation to the water harvest. This is evident quantitatively, as beans harvested in autumn-winter were less productive and contained more phenolic compounds. Ferrera, Heldwein, Santos, Somavilla and Sautter (2016) also reported higher levels of phenolic compounds in yerba mate leaves harvested in autumn compared to the summer.

In autumn-winter, the maximum daily temperatures did not exceed 30ºC. In contrast, several days throughout the spring-summer reached temperatures above 35ºC. According to Taiz and Zeiger (2013), the degradation of phenols in plant tissues is intensified at 35ºC— another explanation for the higher amounts of these compounds in autumn-winter beans.

Of the evaluated characteristics, bean sulfur content the only one not affected by the isolated effect of the sources of variation, and by the interaction between them (Table 1).

Sowing season affects the agronomic performance of bush beans. The proper employment of particular genotypes and cultivars during the seasons that they perform best in would maximize productivity and influence chemical composition the produce.

Conclusions

The interaction between genotype and sowing season affects the number of seeds per plant, seed productivity, and the concentrations of crude protein, zinc, and manganese in the seeds of bush beans. The Isla Manteiga Baixo cultivar had higher productivity during the spring-summer season, determined by the number of pods per plant, and the accumulation of phosphorus and iron in the seeds. Plants grown during fall-winter saw increased concentrations of potassium and total phenolic compounds in their seeds, while the concentration of calcium and magnesium depended on the cultivar used.

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