Selection of bean lineages regarding the use and response to phosphorus available in nutrient solution

Seleção de linhagens de feijão quanto ao uso e resposta ao fósforo disponível em solução nutritiva

Selección de cepas de frijol con respecto al uso y respuesta al fósforo disponible en la solución nutritiva

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Abstract

The objectives of this work were to evaluate the genetic variability of bean lineages in relation to phosphorus accumulation in plant tissues and yield, in addition to identifying efficient bean lineages in the use of phosphorus and responsive to the application of phosphorus in the crop environment. Work was carried out at Plant Science Department of the Federal University of Santa Maria. Concentrations of phosphorus in the nutrient solution between 1.33 and 1.84 mmol L^{-1} provide higher dry mass of pods, grains, number of grains and grain yield for the cultivars Pérola and IPR88 Uirapurú in the growing seasons autumn-winter and spring-summer. Concentrations between 1.37 and 1.96 mmol L^{-1} have the highest values of phosphorus in plant tissues, grain yield and phytic acid. Characteristics dry matter of leaves, stem and pods in pod filling, dry matter of grains on maturation, number of grains, number of pods and phosphorus concentration in plant tissues at the pod filling stage are promising because it allows for indirect selection. The nutritional value of leaves in young plants, for phosphorus, equivalent to that of grains. There is genetic variability among the bean lineages studied, for the production of dry mass, yield and accumulation of phosphorus in the tissues. Lineage L 2527 showed to be efficient and responsive to the use of phosphorus for the shoot of the plant. Lineage L 2225 showed to be efficient in the use of phosphorus in shoot, grains and grain production, besides maintaining this characteristic in the two growing seasons.

Keywords: *Phaseolus vulgaris* L.; Concentrations; Efficiency; Genetic variability.

Resumo

Os objetivos deste trabalho foram avaliar a variabilidade genética de linhagens de feijão em relação ao acúmulo de fósforo nos tecidos vegetais e produtividade, além de identificar linhagens de feijão eficientes no uso de fósforo e responsivas à aplicação de fósforo no ambiente de cultivo. O trabalho foi realizado no Departamento de Fitotecnia da Universidade Federal de Santa Maria. Concentrações de fósforo na solução nutritiva entre 1,33 e 1,84 mmol L^{-1} proporcionam maior massa seca de vagens, grãos, número de grãos e rendimento de grãos para as cultivares Pérola e IPR88 Uirapurú nas safras outono-inverno e primavera-verão. Porém, as concentrações entre 1,37 e 1,96 mmol L^{-1} apresentam os maiores valores de fósforo nos tecidos vegetais, rendimento de grãos e ácido fítico. As características matéria seca das folhas, caule, vagens no enchimento, matéria seca dos grãos na maturação, número de grãos, número de vagens e concentração de fósforo nos tecidos vegetais na fase de enchimento das vagens são promissoras por permitiram a seleção indireta. O valor nutricional das folhas das plantas jovens, em fósforo, é equivalente ao dos grãos. Há variabilidade genética entre as

linhagens de feijão estudadas, para a produção de massa seca, rendimento e acúmulo de fósforo nos tecidos. A linhagem L 2527 mostrou-se eficiente e responsiva ao uso de fósforo para a parte aérea da planta. A linhagem L 2225 mostrou-se eficiente no aproveitamento do fósforo na produção de parte aérea, grãos e produção de grão, além de manter essa característica nas duas safras.

Palavras-chave: *Phaseolus vulgaris* L.; Concentrações; Eficiência; Variabilidade genética.

Resumen

Objetivos fueron evaluar variabilidad genética de líneas de frijol en relación a la acumulación de fósforo en los tejidos vegetales y la productividad, identificar líneas de frijol eficientes en el uso de fósforo y sensibles a la aplicación de fósforo en el ambiente de cultivo. Trabajo se llevó a cabo en el Departamento de Fitotecnia de la Universidad Federal de Santa María. Concentraciones de fósforo en la solución nutritiva entre 1.33 y 1.84 mmol L-1 proporcionan mayor masa seca de vainas, número y rendimiento de granos para los cultivares Pérola e IPR88 Uirapurú en las temporadas otoño-invierno y primavera-verano. Concentraciones entre 1,37 y 1,96 mmol L-1 tienen los valores más altos de fósforo en los tejidos vegetales, rendimiento de grano y ácido fítico. Características de materia seca de las hojas, tallo, vainas en el relleno, número y materia seca de los granos en la maduración, número de vainas, concentración de fósforo en los tejidos durante la fase de llenado de las vainas son prometedoras porque permitieron la selección indirecta. Valor nutricional de las hojas de las plantas jóvenes, en fósforo, es equivalente al de los granos. Existe variabilidad genética entre las cepas, para producción de masa seca, rendimento, acumulación de fósforo en los tejidos. Cepa L 2527 demostró ser eficiente y sensible al uso de fósforo para la parte aérea. Cepa L 2225 demostró ser eficiente en el uso de fósforo en la producción de partes aéreas, granos y producción de granos, además de mantener esta característica en ambas temporadas.

Palabras clave: *Phaseolus vulgaris* L.; Concentraciones; Eficiencia; Variabilidad genética.

1. Introduction

Beans (*Phaseolus vulgaris* L.) are widely distributed in Brazil because of their good adaptation to the most varied edaphoclimatic conditions (Pereira *et al*., 2010). The importance of the crop goes beyond the economic aspect, playing a fundamental role in the food of Brazilians, and in the demand for labor for being part of the most diversified production systems, with small, medium and large farmers (Barbosa & Gonzaga, 2012).

A considerable factor that limits the nutrition of bean plants and disfavor to obtain high grain yields is the low availability and mobility of phosphorus (P) in Brazilian soils (Leal, Prado, 2008). The great majority of national soils are acidic, with low fertility and high phosphorus retention capacity (Novais & Smyth, 1999).

Among minerals, phosphorus is a non-renewable, finite-source resource that often limits crop production (Oliveira *et al*., 2012). It is a chemical element, which naturally is contained in sedimentary, igneous and biogenetic rocks (Martins *et al*., 2014). In 2010, the International Fertilizer Development Center conducted a study to assess world phosphate reserves and resources and found that phosphate reserves are low. The reserves of Morocco and Western Sahara are considered the largest on the planet, and have been reduced from 50 billion tonnes to 5.7 billion in the last decade.

Excessive use of correctives and phosphate fertilizers leads to increased production costs, a fact that has been largely avoided (Carvalho *et al*., 2019). As an alternative to avoiding too much application of phosphate fertilizers, which is an obstacle to plant production, there is the development of efficient cultivars in the absorption and utilization of phosphorus (Hinsinger, 2001). The effects of elemental deficiency can be minimized when using some practices such as correction of soil acidity, adequate phosphate fertilization and the use of efficient cultivars in the use of phosphorus. In this way, it is highlighted the search for the genetic potential of plants with the efficient use of minerals. The development and identification of efficient and responsive bean cultivars to phosphorus can be a strategy to obtain high grain yields, without increasing the costs of the productive system. Among the factors that contribute to this, there is plant breeding, through which superior cultivars are obtained (Bertoldo *et al*., 2009; Carvalho *et al*., 2016).

At present, economic and environmental challenges are addressed in the efficient use of nutrients (Baligar *et al*., 2001). Due to the small capacity of the phosphatic rocks in the world, the best use of these reserves is fundamental to maintain and increase agricultural production (Cordell *et al*., 2009). The efficient use of nutrients enables losses to be minimized without damaging air and water quality (eutrophication), especially of nitrogen (N) and phosphorus (P) (Srinivasar, 2006).

Essential and much explored by genetic breeding programs, the genetic variability between plants allows expressing genetic potential through selection (Bernardo, 2002). There are several proofs of plant species variability in nutrient utilization and absorption (Rao, 1996; Natani, 1996). As for phosphorus efficiency, different crops have already been evaluated as rice (Rotili *et al*., 2010); wheat (Silva *et al*., 2008) corn (Carvalho *et al*., 2012) and beans

(Oliveira *et al*., 1987). Fageria (1998), concluded that there is great genetic variability among bean genotypes, which presented different behavior regarding the phosphorus utilization efficiency. It is known that this difference in selection of genotypes for phosphorus efficiency and grain yield is related to the translocation of the nutrient from the roots to the shoot (Lana *et al*., 2006).

The term nutritional efficiency is used to characterize the ability of plants to absorb and utilize nutrients, being related to the efficiency of their absorption, utilization and translocation (Amaral *et al*., 2011). This efficiency refers to the amount of dry matter or grains produced per unit of nutrient applied, and its optimization is of great importance in the production of plant species (Fageria, 1998). Therefore, to increase yield and reduce the cost of production, it is necessary to improve nutritional efficiency (Carvalho *et al*., 2019). Phosphorus-efficient plants are those that produce the highest amount of dry mass per unit of absorbed phosphorus (Tomaz & Amaral, 2008). The concept of plant efficiency in the use of a nutrient encompasses processes by which plants absorb, translocate, accumulate and better utilize said nutrient for the production of dry matter and grains under normal nutritional conditions or with a limited supply of the nutrient in question. Föhse *et al*. (1988) defined the efficiency in the use of phosphorus as being the ability of a plant to produce a certain percentage of the maximum production with the lowest consumption of phosphorus.

The efficiency of the use of phosphorus by the plant is related to several internal and external mechanisms, such as aspects of root morphology, chemical changes in the rhizosphere, changes in the physiological characteristics of absorption kinetics, changes in biochemical processes, genetic variability and interactions with microorganisms that inhabit the soil (Lynch, 2007). In addition, it can be expressed and calculated in different ways, the index being proposed by Siddiqui e Glass (1981) is the most used to evaluate the efficiency in the use of nutrients, because it relates the efficiency in the use to the growth of the plants. Ramos *et al*. (2010) by evaluating the use of phosphorus and the production of bean grains, when cultivated in succession to forage grasses fertilized with different sources of this nutrient, used the Siddiqu e Glass index; to determine the efficiency of mineral use. Likewise, Procópio *et al*. (2005), also used the same index, when studying the efficiency in the absorption and use of phosphorus by soybean and bean crops and by weed species.

However, the response of the plants to the application is aimed at the observation of the behavior of the lineages in contrasting environments regarding the availability of the nutrient. This response is estimated by the relation between the production and biomass

differences and the availability of the nutrient, being originally considered for phosphorus by Fox (1978) and adapted by Furtini (2008) for the production of grains.

Furthermore, bean plants are considered to be poorly efficient in the absorption of this nutrient due to the low influx and requirement of phosphorus for the production of biomass (Fohse *et al.*, 1988). The selection of bean cultivars that have a greater efficiency in the use of phosphorus becomes a useful and viable alternative for crops installed under conditions of low availability of this nutrient.

Thus, the objectives of this work were to evaluate the genetic variability of bean lineages in relation to phosphorus accumulation in plant tissues and yield, in addition to identifying efficient bean lineages in the use of phosphorus and responsive to the application of phosphorus in the crop environment.

2. Material and Methods

The experimental study was carried out in an explanatory manner, seeking to identify and explain factors that determine or contribute to the occurrence of phenomena (Pereira *et al.*, 2018). The work was carried out at the Plant Science Department of the Federal University of Santa Maria (UFSM), in the municipality of Santa Maria, State of Rio Grande do Sul, Brazil (latitude 29º42S, longitude 53º49W and 95 m altitude), where the experiments were conducted in greenhouse. The experimental design was completely randomized, with sub-sub-divided plots. The treatments consisted of a 2x12x2 tri-factorial in the range, being two phosphorus concentrations in the main plot, given to the plants by means of fertigation (low: 0.9 and high: 1.9 mmol L^{-1}), which were determined based on the results of previous experiments on the dynamics of phosphorus accumulation in the tissues of bean plants. Twelve genotypes of beans with differences in phosphorus concentration in grains and yield were distributed in the subplot, two cultivars (Pérola, IPR88, Uirapurú), used as controls, and 10 advanced lineages provided by the UFSM Bean Breeding Program, these being: L 2225, L 2632, L 2527, L 2411, L 2519, L 2428, L 2244, L 2637, L 2528 and L 2625. These 10 lineages were obtained from controlled crosses between bean cultivars contrasting for the phosphorus concentration (Maziero *et al.*, 2016). In the sub-subplot, two cultivation periods were used, from autumn to winter with sowing on May 1st, 2014 (season 1) and spring-summer with sowing on September 10th, 2014 (season 2).

At each growing season there were four closed off-soil cultivation devices, which were constructed and described by Domingues *et al.* (2014). On top of those, a total of 48 black

polypropylene vats, with a capacity of 4 L, were filled with a layer of gravel and medium sand and seeding was carried out. In two devices the plants were fertirrigated with nutrient solution containing the low concentration of phosphorus (0.9 mmol L^{-1}) and in the other two, with the solution containing the high concentration of phosphorus ($1,9$ mmol L^{-1}). In the low and high phosphorus solutions, nitrogen was added 0.9 mg L^{-1} and 2.4 mg L^{-1} ($NH_4 NO_3$ formulation).

Only the concentration of phosphorus supplied varied from one device to another and the other nutrients, essential for the growth and development of plants, were supplied in the same quantities, namely potassium (KNO3, 404.40 mg L^{-1}), calcium (Ca (NO_3) 2, 318.74 mg L^{-1}), magnesium ($MgSO_4$, 197.12 mg L^{-1}), and micronutrients: molybdenum (Na_2MoO_4, 0.03 mg L^{-1}), boron (H_3BO_3; $0,26$ mg L^{-1}), copper ($CuSO_4$, 0.06 mg L^{-1}), manganese ($MnSO_4$, 0.50 mg L^{-1}), zinc ($ZnSO_4$, 0.22 mg L^{-1}), and iron ($Fe(NO_3)_3$; $1,0$ mg L^{-1}).

Every 20 days all solutions were redone and the pH and electrical conductivity (EC) of these were measured three times a week. The pH was maintained in the range of 5.5 to 6.5 by the addition of NaOH or $H_2 SO_4$ when the solution was outside this stipulated limit. The electrical conductivity was preserved between 1.0 and 1.5 mS, adding water or new solution aliquots when outside this range. The plants were fertigated with the aid of drip hoses interconnected to the closed circuit. In this way, the solutions were provided individually for each device, in three daily shifts of fertigation during the autumn / winter, and with four shifts in spring / summer, each lasting 15 minutes.

When the plants were at the development stage of pod filling (R8), according to the phenological scale described by Fernandez *et al*. (1982), two plants of each lineage were collected in each of the closed devices. Totalizing the withdrawal of four fertirrigated plants with the low concentration of phosphorus and four, with the high concentration. These were fractionated and, separately, leaves, stem and pods were packed in paper bags, transported to a forced circulation oven (Odontobras 1.5; Odontobras, São Paulo, Brazil) until a constant mass was obtained, determined the dry mass of the tissues, with the aid of a digital scale. On reaching maturation stage (R9), new plants were collected (two plants of each lineage) and of these, the number of pods per plant, the number of grains per pod and the grain yield per plant were quantified at 13 % humidity.

In order to determine the phosphorus concentration in the plant tissues, samples of leaves, stem and pods in R8 and grains in R9 were milled using an analytical knife micro-mill (Q298A21; Quimis, São Paulo, Brazil), until a flour with particles of approximately 1 mm was obtained. From these samples aliquots of 0.5 g were digested in 5 ml of acid solution composed of nitric acid (HNO_3) and perchloric acid ($HClO_4$), in the ratio 3:1, as

recommended by Miyazawa *et al.* (1999). The concentration of phosphorus, expressed in g kg $^{-1}$ of sample dry matter, was determined by reading in an optical emission spectrophotometer (AA-7000; Shimadzu, São Paulo, Brazil), with a wavelength of 660 nm.

The efficiency of phosphorus use was determined using the following indexes proposed and adapted by Siddiqui e Glas (1981) and Domingues *et al.* (2014):

1) efficiency in the use of phosphorus in the grains (EUGrains) = (g of dry mass of grains)^2. (mg of P accumulated in the grains)$^{-1}$.

2) efficiency in the use of phosphorus in the shoot (EUShoot) = (g of dry mass of shoot)^2. (mg of accumulated P in the shoot)$^{-1}$.

3) efficiency in the use of phosphorus in the plant (EUPlant) = (g dry mass of shoot and grains)^2. (mg of accumulated P in the shoot and grains)$^{-1}$.

4) efficiency in the use of phosphorus in grain production (EUProd) = (g dry matter of grains)^2. (mg of accumulated P in the shoot and grains)$^{-1}$.

The response of the bean lineages to the application of phosphorus in the nutrient solution was determined by the methodology adapted from Furtini (2008), from the expression: $IR = [(MSA - MSB) (A - B)^{-1}]$. From the equation of Furtini (2008) the indices were estimated:

1) phosphorus index of response to grain yield (IRGrains) = $[(MGP_A - MGP_B) (A - B) -1]$, where MGP_A and MGP_B correspond to the grain mass per plant (g) in high and low phosphorus concentration; and A - B is the difference between the concentrations of phosphorus in the nutrient solution.

2) index of response to shoot dry mass (IRShoot) = $[(MSPA_A - MSPA_B) (A - B) -1]$, where $MSPA_A$ and $MSPA_B$ correspond to shoot dry mass (g) in high and low phosphorus concentration; and A - B is the difference between the concentrations of phosphorus in the nutrient solution.

3) index of response of the plant dry mass production (IRPPlant) = $[(MSPl_A - MSPl_B) (A - B) -1]$, where $MSPl_A$ and $MSPl_B$ correspond to shoot and grains dry mass per plant (g) in high and low phosphorus concentrations; and A - B is the difference between the concentrations of phosphorus in the nutrient solution.

Based on the phosphorus efficiency indexes and response to the application of phosphorus in the nutrient solution, graphs were made relating the efficiency and the responsiveness of the lineages. Thus, the classification of bean lineages into efficient and responsive (ER), non-efficient and responsive (NER), non-efficient and nonresponsive

(NENR) and efficient and nonresponsive (ENR) was performed according to Batten *et al*. (1984).

The statistical analysis of the data was performed, considering all effects as fixed, except for the error that was random, with the aid of the Microsoft® Office Excel spreadsheet and the Sisvar software (Ferreira, 2011). The data were submitted to analysis of variance, considering three replicates. As the effect of the significant triple interaction, the deployment of the three double interactions was performed. When the significance of the double phosphorus concentration interaction in the nutrient solution x genotype (C x G) or genotype x growing season (G x E) occurred, the Scott-Knott test at 5% error probability was used for the comparison of the means. In the cases where there was a significance of the double interaction that included phosphorus concentration in the nutrient solution x growing season (C x E), Student's t test was used, at 5% probability for comparison of means.

3. Results and Discussion

In the analysis of variance, for all growth traits, phosphorus production and accumulation in the tissues, there was a significant interaction between the phosphorus concentration x genotypes x growing season (C x G x E), except for the phosphorus variable in the pod. (Appendix E). The same occurred for the isolated effects of the concentration of phosphorus in the nutrient solution, genotypes and growing season. This evidences the influence on the availability of phosphorus, the genetic variability among the bean lineages studied and the variation between the growing seasons on these characters.

Also, there were significant double interactions, phosphorus x genotype concentration, phosphorus x growing season, genotype x growing season, for the growth traits (dry mass of the stem-DMStem and dry mass of the pods DMPod) and productive characters (number of pods per plant-NPod, number of grains per plant-NGrain and grain yield -Yield) (Appendix E). Similar behavior was observed for the characters of phosphorus accumulation in the leaves (PLeaf), the stem (PStem), the pods (PPod) and the grains (PGrain). The exception occurred in the double interaction, concentration of phosphorus x growing season, for leaf dry matter (DMLeaf) and phosphorus accumulation in plant tissues. Different results were found by Fageria (1998), when evaluating the efficiency of phosphorus use in 15 bean genotypes at low, medium and high levels in a Red-Dark Latosol. The author concluded that, for the characters of shoot dry mass and accumulation of phosphorus in the shoot, the dose interaction of phosphorus x genotypes was not significant, so that the genotypes analyzed

showed stability of adaptation, both for the low as for the high phosphorus level. However, Lana *et al*. (2006), studying eight bean genotypes regarding the efficiency of phosphorus uptake and utilization in the nutrient solution, detected significance in the interaction between phosphorus x genotype concentration for the characteristics of shoot dry mass and accumulation of phosphorus in shoot.

In relation to the phosphorus efficiency indexes in the shoot of the plant (EUShoot), grains (EUGrain), plants (EUPlant) and production (EUProd), all double interactions (C x G, C x E and G x E) and triple (C x G x E) were significant (Table 1). Thus, because the phosphorus concentrations in the nutrient solution are distinct, it is evident the possibility of selection of bean lineages for low and high phosphorus cultivation. In addition, there is genetic variability among the studied lineages, allowing selection for phosphorus efficiency.

Table 1 - Analysis of variance for the efficiency of phosphorus in the shoot (EUShoot, g^2 mg^{-1}), efficiency in the use of phosphorus in grains (EUGrain, g^2 mg^{-1}), efficiency in the use of phosphorus in the plant (EUPlant, g^2 mg^{-1}), and efficiency in the use of phosphorus in grain production (EUProd, g^2 mg^{-1}); Phosphorus index of response to shoot dry matter production (IRShoot), phosphorus index of response to grain yield (IRGrain) and phosphorus index of response to the production of dry mass in the plant (IRPlant); evaluated in 12 bean genotypes, submitted to two concentrations of phosphorus in the nutrient solution in two growing seasons. Santa Maria - RS, UFSM.

Variation Source	Degree of freedom	Mean Square							
		EUShoot		EUGrain		EUPlant		EUProd	
Conc (C)	1	1611,767	*	0,568	ns	592,235	*	0,1370	ns
Error C	2	2,100		0,100		1,570		0,010	
Gen (G)	11	97,090	*	2,160	*	38,810	*	0,920	*
Error G	44	1,110		0,090		0,380		0,020	
Season (E)	1	1951,040	*	2,240	*	1002,820	*	0,020	ns
Error (E)	4	0,490		0,040		0,730		0,030	
C x G	11	56,060	*	0,900	*	19,110	*	0,600	*
C x E	1	1284,080	*	8,000	*	642,000	*	2,570	*
G x E	11	67,980	*	3,080	*	23,310	*	1,460	*
C x G x E	11	72,770	*	2,290	*	27,490	*	0,860	*
Error	46	1,550		0,100		0,520		0,020	
Average		7,210		1,820		7,660		0,910	
CV		$12,1^1$- $14,6^2$ -$9,7^3$ - $17,2^4$		$17,2^1$- $16,3^2$ -$10,8^3$ - $17,1^4$		$16,3^1$ – $8,1^2$ – $11,1^3$ -$9,4^4$		$10,7^1$ – $15,3^2$ – $19,4^3$ -$15,6^4$	

Variation Source	Degree of freedom	IRShoot		IRGrain		IRPlant	
Gen (G)	11	0,004	*	0,037	*	0,109	*
Erro G	22	0,006		0,002		0,007	
Época (E)	1	0,004	ns	0,010	*	0,027	*
Erro (E)	2	0,001		0,000		0,001	
G x E	11	0,005	*	0,050	*	0,161	*
Erro	24	0,0002		0,003		0,011	
Average		0,070		0,060		0,120	
CV (%)		$15,0^1 – 18,3^2 – 13,2^3$		$18,2^1 – 14,7^2 – 9,2^3$		$14,5^1 – 9,4^2 – 18,1^3$	

* Significant at 5% probability by F test; ns = not significant. 1 Coefficient of variation of the subplot. 2 Coefficient of variation of sub-sub-plot. 3 Coefficient of variation of the G x E interaction. Source: Authors.

For the indexes of phosphorus response in shoot (IRShoot), grain (IRGrain) and plants (IRPlant), the genotype x growing season interaction (G x E) presented significance, so that it is possible to verify that the bean lineages presented a response regarding the application of phosphorus differentiated by virtue of the growing season (Table 1) The results showed that the yield of phosphorus was higher than that of the cultivar. Knowing that response to fertilization is associated with the capacity to increase biomass production with the highest nutrient supply (Fidelis *et al*., 2005; Vargas *et al*., 2018) and that, when the plant is cultivated, it also exerts influence on biomass production, there is a clear difference between the environments. The radiation, which was distinct in the two growing seasons, is one of the climatic factors that has a direct influence on the biomass production in the bean crop, since it is directly related to the photosynthetic rate of the plants (Teixeira *et al*., 2015).

When considering the average values of the growth characters shown in Table 2, it can be seen that for the production of dry mass in the leaves, the lineages L 2225, L 2632 and L 2527 constituted the group of the highest averages in the low concentration of phosphorus, which did not occur in the high concentration. With the exception of the lineage L 2527, which formed the group with the highest averages for this character in both the low P and the high P, indicating good adaptation to both environments.

For the dry mass of the stem, in the low concentration of phosphorus there were three groups of lineages formed, already in the high concentration, it was verified the formation of four groups, according to the Skott Knott test. Only the cultivar Pérola remained in the group with the highest dry stem mass production at both phosphorus concentrations. The lineages L

2225, L 2632, L 2527 and L 2411, were distinguished by their high yield of stem dry mass, only when submitted to low phosphorus concentration. However, for the pods dry mass production (DMPod) there was no difference between the low and the high phosphorus concentrations in the lineages L 2632, L 2411, L 2244 and L 2528.

In both growth and yield characters, the general averages of all genotypes studied were lower in nutrient solution with low phosphorus and higher in high phosphorus (Table 2). Knowing the existence of the direct relationship between the production of biomass and the final productivity, the condition that favors plant growth, also leads to higher production. The decrease in the biomass production under the lowest phosphorus concentration is related to the high carbohydrate partition allocated to the roots in phosphorus-deficient plants (Fontes, 2016). This fact can be explained, because plants developed with low concentrations of phosphorus present a lower content of total soluble carbohydrates and reducing sugars in the composition of their vegetal tissues, in this way, the less they develop (Coutinho *et al*., 2000).

Table 2 - Mean values obtained for the characters dry mass of the stem (DMStem, g), leaves (DMLeaf, g), pods (DMPod, g); number of pods (NPod), number of grains (NGrain) and grain yield (Yield, g plant^{-1}), obtained for 12 bean genotypes, submitted to two concentrations of phosphorus (Low P - 0.9 mmol L^{-1} and High P - 1.9 mmol L^{-1}) in the nutrient solution. Santa Maria - RS, UFSM.

Lineage	DMLeaf				DMStem				DMPod			
	Low P		High P		Low P		High P		Low P		High P	
Pérola	3,18	b B	8,90	a B	5,13	b A	8,56	a A	4,00	b B	5,00	a B
L 2225	4,05	b A	6,69	a D	4,54	b A	6,46	a C	2,53	b D	6,05	a A
L 2632	3,90	b A	6,20	a E	4,50	b A	5,65	a C	4,64	a A	3,34	a D
L 2527	4,66	b A	10,25	a A	4,28	b A	7,75	a B	2,13	b D	5,94	a A
L 2411	3,31	b B	6,34	a D	4,20	b A	5,68	a C	3,73	a B	4,23	a C
L 2519	3,11	b B	6,37	a D	3,96	b B	7,05	a B	2,79	b C	4,86	a B
IPR88 Uirapurú	3,35	b B	7,64	a C	3,63	b B	5,84	a C	1,08	b F	2,68	a E
L 2428	3,09	b B	5,11	a F	3,41	b B	5,73	a C	3,03	a C	3,43	a D
L 2244	2,91	b B	5,64	a F	3,33	b B	5,51	a C	2,16	a D	2,54	a E
L 2637	2,84	b B	6,23	a E	3,09	b C	5,95	a C	2,29	b D	6,19	a A
L 2528	3,05	b B	7,01	a D	3,03	b C	5,65	a C	1,86	a D	2,34	a E
L 2625	3,91	b A	6,23	a E	2,33	b C	4,31	a D	1,40	b F	4,01	a C
Average	3,45		6,88		3,78		6,18		2,63		4,22	
Cv			15,0				14,3				16,1	
Lineage	NPod				NGrain				Prod			
	Low P		High P		Low P		High P		Low P		High P	
Pérola	4,75	b B	9,63	a B	13,50	b E	40,75	a B	6,83	b A	17,05	a B
L 2225	5,75	b B	11,00	a A	25,25	b B	38,50	a C	7,66	b A	13,99	a C
L 2632	8,13	b A	10,50	a A	30,50	b A	42,88	b B	8,18	b A	14,23	a C

L 2527	3,50	b C	6,38	a C	12,88	b E	23,13	a F	4,18	b C	7,69	a F
L 2411	7,13	b A	10,50	a A	22,25	b C	31,88	a D	7,31	b A	9,54	a E
L 2519	3,63	b C	8,50	a B	9,75	b E	35,75	a D	3,33	b C	15,50	a C
IPR88 Uirapurú	2,75	b C	9,13	a B	11,25	b E	34,00	a D	3,70	b C	13,79	a C
L 2428	5,75	b B	11,13	a A	17,75	b D	37,38	a C	4,71	b B	11,86	a D
L 2244	5,13	b B	8,75	a B	18,00	a D	34,25	b D	6,19	b A	11,60	a D
L 2637	5,00	b B	12,00	a A	20,38	b C	51,38	a A	5,39	b B	19,05	a A
L 2528	4,00	b C	9,13	a B	14,38	b E	41,63	a B	5,13	b B	16,93	a B
L 2625	8,00	b A	9,50	a B	19,38	b C	27,50	a E	6,55	b A	14,29	a C
Average	5,29		9,68		17,94		36,58		5,76		13,79	
Cv		15,6			13,6			15,4				

* Means followed by the same lowercase letter in the horizontal constitute a statistically homogeneous group by the F test (value of p ≤ 0.05) and, uppercase in the vertical, constitute a statistically homogeneous group by the Scott Knott test (p ≤ 0.05). Source: Authors.

The lineages L 2632 and L 2411 presented the highest mean number of pods per plant at the two concentrations of phosphorus supplied in the nutrient solution (high and low concentration) (Table 2). These, together with L 2625, formed the group with the highest number of pods per plant. However, the latter was highlighted for the production of pods only when grown under low availability of phosphorus, since in high concentration it does not constitute the group of higher averages. A similar result to that of L 2625 can be observed for L 2632 for the number of grains per plant, so that this lineage formed the group isolated in terms of grain number, distinguishing itself from the others.

The highlight for the number of grains and / or number of pods of lineages L 2632, L 2411, L 2625, under low concentration of phosphorus in the nutrient solution may have contributed to the fact that these, together with Pérola, L 2225 and L 2244, were the most productive under these low phosphorus conditions. However, none of them proved to be more productive when grown under high concentration of phosphorus in the nutrient solution. This fact may be indicative of efficient lineages in the use of phosphorus. According to Fageria (1998), efficient cultivars in the use of the mineral usually decrease their production with the increase of nutrient levels; this means that phosphorus utilization efficiency is highest at the lowest nutrient level and lowest at the highest level.

Table 3 - Mean values for the phosphorus concentration in the stem (PStem, g kg^{-1} of dry matter - DM), leaves (PLeaf, g Kg^{-1} of DM), pods (PPod, g Kg^{-1} of DM) and in the grains (PGrain, g Kg^{-1} of DM), obtained for 12 bean genotypes, submitted to two phosphorus concentrations (low P = 0.9 mmol L^{-1} and high P = 1.9 mmol L^{-1}) in the nutrient solution. Santa Maria - RS, UFSM.

Lineage	PLeaf				PStem			
	Low P		High P		Low P		High P	
Pérola	1,01	b A	3,92	a D	0,99	b B	4,09	a B
L 2225	1,26	b A	3,68	a D	1,21	b B	3,47	a B
L 2632	1,30	b A	5,92	a B	1,11	b B	5,02	a A
L 2527	1,11	b A	5,27	a B	0,53	b C	4,77	a A
L 2411	1,87	b A	3,02	b D	0,74	b C	4,41	a A
L 2519	1,62	b A	5,86	a B	1,87	b A	4,99	a A
IPR88 Uirapurú	2,15	b A	5,42	a B	0,78	b C	4,10	a B
L 2428	1,37	b A	6,48	a A	1,21	b B	5,01	a A
L 2244	1,15	b A	4,75	a C	0,91	b B	3,93	a B
L 2637	0,92	b A	4,38	a C	1,00	b B	3,97	a B
L 2528	1,38	b A	5,12	a B	0,80	b C	4,71	a A
L 2625	1,60	b A	7,03	a A	0,57	b C	3,82	a B
Média	1,40		5,07		0,97		4,36	
Cv	12,6				9,8			
Lineage	PPod				PGrain			
	Low P		High P		Low P		High P	
Pérola	1,84	b B	4,34	a C	3,12	b C	6,18	a A
L 2225	2,31	b B	4,51	a C	2,66	b C	5,47	a A
L 2632	2,77	b A	5,08	a B	4,91	a A	5,14	a A
L 2527	1,94	b B	4,79	a C	2,64	b C	5,99	a A
L 2411	1,70	b B	4,18	a C	4,23	b B	5,71	a A
L 2519	2,07	b B	4,76	a C	2,84	b C	5,82	a A
IPR88 Uirapurú	2,05	b B	4,71	a C	2,60	b C	5,91	a A
L 2428	2,01	b B	5,19	a B	3,08	b C	6,73	a A
L 2244	2,70	b A	4,88	a C	2,39	b C	5,81	b A
L 2637	1,92	b B	4,34	a C	2,78	b C	6,00	a A
L 2528	2,13	b B	5,72	a A	2,61	b C	6,20	a A
L 2625	2,27	b B	4,67	a C	2,50	b C	5,81	a A
Average	2,14		4,76		3,03		5,90	
Cv	13,1				12,4			

* Means followed by the same lowercase letter in the horizontal constitute a statistically homogeneous group by the F test (value of p ≤ 0.05) and, uppercase in the vertical, constitute a statistically homogeneous group by the Scott Knott test (p ≤ 0.05). Source: Authors.

In Table 3 it was observed that the concentration of phosphorus in the nutrient solution influenced the accumulation of phosphorus in the plant tissues, where irrigated plants with low concentration accumulated less this nutrient in the stem (PStem), leaf (PLeaf), pods (PPod) and grains (PGrain), than those irrigated with the highest concentration. For Malavolta *et al*. (1997) the adequate phosphorus content in bean leaves, so that the plant does not present

symptoms of nutritional deficiency, is from 2 to 3 g Kg^{-1}. In the present study, it can be observed that in the low P, the content of phosphorus accumulated in the leaves was lower than the values suggested by the authors, however, there were no apparent symptoms of phosphorus deficiency.

For the phosphorus accumulation in the grain, the L 2632 lineage was the only one that was in the group with the highest averages, in both concentrations of phosphorus, and in the lower phosphorus in the solution, it differed from all other lineages, overcoming the controls. This may be evidence that the L 2632 lineage is efficient and responsive in absorption and phosphorus utilization. The amount of minerals present in the grains depends on the uptake of roots in the rhizosphere, transport by xylem, transfer to leaves, grains and other tissues (Buratto, 2012). The phosphorus absorption and mobilization efficiency for the grains can be limited by the availability of this mineral in the soil (Aisenberg *et al*., 2018). Considering the importance of beans in human nutrition, there is a need to characterize how nutrients may interfere with the nutritional quality of the grain, which may result in the indication of the use of the grains for consumption, or be indicated for crosses in breeding programs of the crop (Alves, 2013; Rigo *et al*., 2018).

When looking at Figure 1A, it was observed that in the condition of cultivation of season 1, only the lineage L 2527 showed to be efficient and responsive to the use of phosphorus for the shoot, that is, it produced above average under conditions of low concentration of phosphorus in the growing environment and responds well to the increase in production, at high nutrient level. In the second growing season (Figure 1B) no lineage expressed its potential for efficiency and response to phosphorus use at the same time. However, lineages 2244, 2411, 2625, 2225 and 2428 were efficient in the use of phosphorus for the shoot of the plants in season 1, but did not maintain this behavior in season 2, where the lineages 2528, Pearl and 2637 were the efficient ones.

Only the lineages L 2527 and L 2225 repeated the behavior for the phosphorus efficiency in the shoot of the plants, since they were efficient in both growing seasons (autumn-winter: season 1, spring-summer: season 2), Figure 1A and 1B, respectively. Therefore, these genotypes produce above average in low phosphorus concentration in the growing season. The preference for cultivars with wide adaptation to the various growing environments should be considered (Carbonell *et al*., 2001; Szareski *et al*., 2017). Fageria (1998), when evaluating the 15 bean genotypes in the use of phosphorus in a Dark Red Latosol, also found that the genotypes showed a different behavior in relation to the efficiency of phosphorus use, with Rio Doce, São José, IPA 9, Aporé, Goytacazes, Carioca-MG,

Carioca-IAC, Serrano, Safira and Roxo 9 being considered efficient in the use of phosphorus in the shoot.

Figure 1 - Classification of 12 bean genotypes regarding the efficiency in the use of phosphorus in the shoot (EUShoot, g^2 mg^{-1}) in relation to the phosphorus index of response to shoot dry mass production (IRShoot, g mg^{-1}) and phosphorus efficiency in grains (EUGrain, g^2 mg^{-1}) in relation to the phosphorus index of response in grains (IRGrain, g^2 mg^{-1}) obtained in low concentration of phosphorus in nutrient solution in two crops (autumn / winter - Season 1 and spring / summer - Season 2). Santa Maria - RS, UFSM.
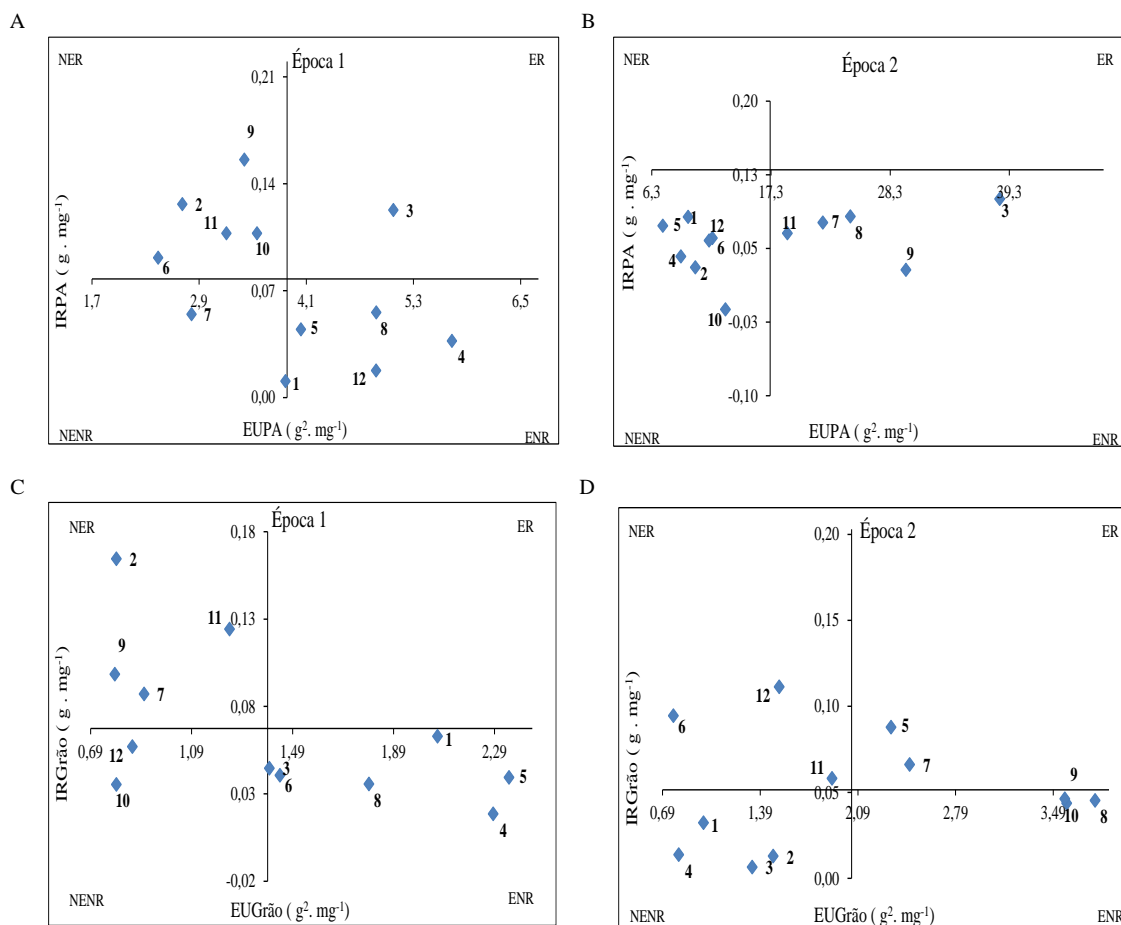
ER: efficient and responsive; NER: not efficient and responsive; NENR: not efficient and non responsive and ENR: efficient and non responsive.
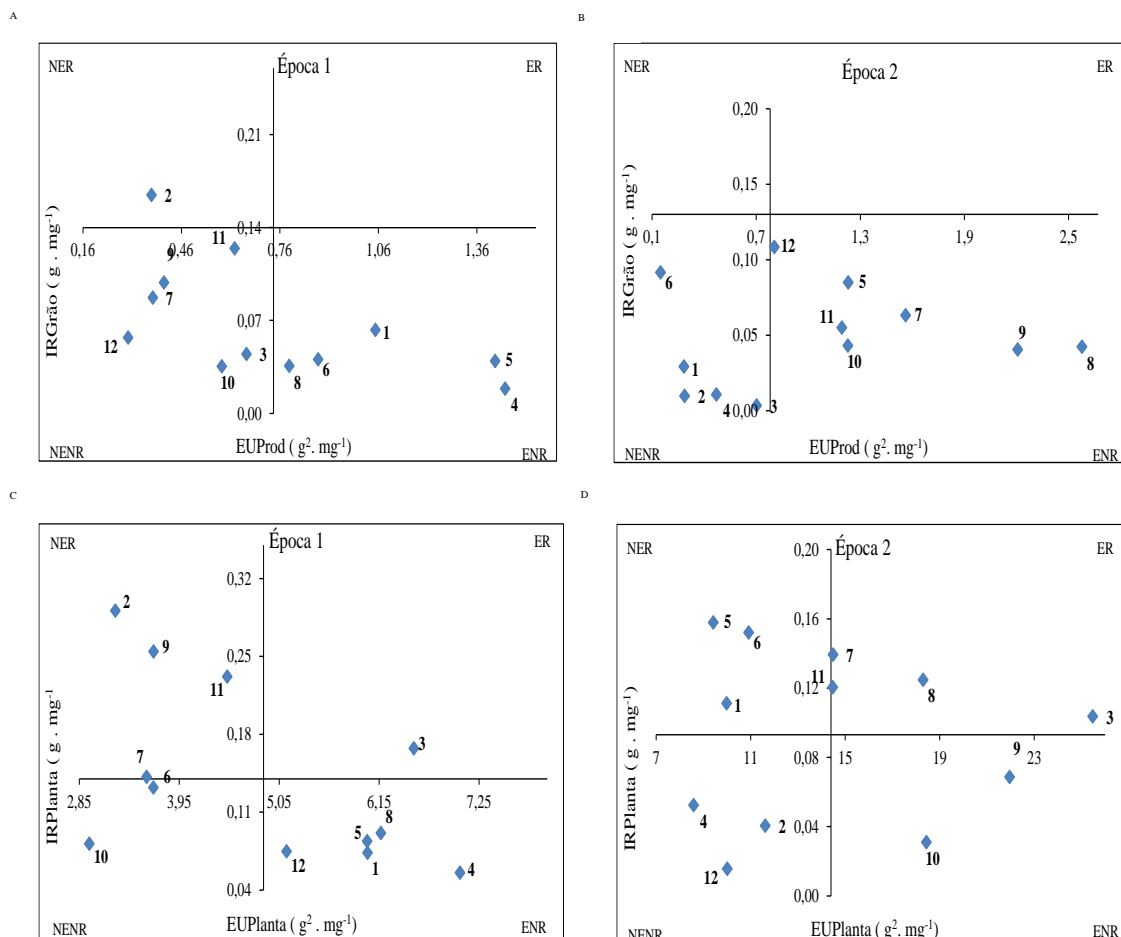1 – L2244; 2 – L2519; 3 – L2527; 4 – L2411; 5 –L2625; 6 - IPR88 Uirapurú; 7 – L2528; 8 – L2225; 9 – Pérola; 10 – L2632; 11 – L2637 and 12 – L2428.
Source: Authors.

Although the lineage L 2527 has been highlighted as efficient and responsive in the use of phosphorus to the shoot, that is to say, having produced greater biomass of shoot in the lower concentration of phosphorus in the solution and to have responded positively to the increment of the nutrient, this did not make the plant convert biomass into production, and the

lineage remained in the quadrant not efficient and not responsive to phosphorus as grain yield (Figures 2A and 2B).This result corroborates those found by Zucarelli *et al*. (2011), in order to identify genetic effects that control the inheritance of characters associated to phosphorus utilization efficiency in beans, performed a study with two levels of phosphorus availability (high and low). The efficiency of use, in low phosphorus availability, did not correlate with grain yield. However, under high nutrient availability, these parameters correlated.

Figure 2 - Classification of 12 bean genotypes regarding phosphorus efficiency in grain yield (EUYield, g^2 mg^{-1}) in relation to the phosphorus index of response in grains (IRGrain, g^2 mg^{-1}) and efficiency in phosphorus use in plants (EUPlant, g^2 mg^{-1}) in relation to the phosphorus index of response to the production of dry mass in the plant (IRPlant, g mg^{-1}) obtained in low concentration of phosphorus in nutrient solution in two crops (autumn / winter - Season 1 and spring / summer - Season 2). Santa Maria - RS, UFSM.

ER: efficient and responsive; NER: not efficient and responsive; NENR: not efficient and non responsive and ENR: efficient and non responsive.
1 – L2244; 2 – L2519; 3 – L2527; 4 – L2411; 5 –L2625; 6 - IPR88 Uirapurú; 7 – L2528; 8 – L2225; 9 – Pérola; 10 – L2632; 11 – L2637 and 12 – L2428.
Source: Authors.

However, the lineage L 2225, which showed to be efficient in the use of phosphorus in the shoot (EUShoot) (Figures 1A and 1B), and grains (EUGrain) (Figures 1C and 1D) and maintained this characteristic in the two growing seasons, was also present, in the growing seasons 1 and 2, in the efficient group but not responsive to the use of phosphorus in the production of grains (Figures 2A and 2B). This lineage, along with 2244, 2411, IPR88 Uirapurú (in season 1), 2528, Pérola, 2632, 26,37 and 2428 (season 2) and 2625 (seasons 1 and 2) were the most efficient in the conversion of phosphorus for production in low availability of phosphorus, so they are promising for cultivation in phosphorus restricted environments and may be useful for breeding programs aiming at phosphorus efficiency in beans. Among the characteristics considered favorable in a bean genotype that is efficient in the use of phosphorus, the translocation of the phosphorus from the roots to the growing tissues and a suitable reproductive development, so that more possible amount of phosphorus is used in the grain production are included (Youngdahl, 1990).

4. Final Considerations

Concentrations of phosphorus in the nutrient solution between 1.33 and 1.84 mmol L^{-1} provide higher dry mass of pods, grains, number of grains and grain yield for the cultivars Pérola and IPR88 Uirapurú in the growing seasons autumn-winter and spring-summer. However, the concentrations between 1.37 and 1.96 mmol L^{-1} have the highest values of phosphorus in plant tissues, grain yield and phytic acid.

The characteristics dry matter of leaves, stem and pods in pod filling, dry matter of grains on maturation, number of grains, number of pods and phosphorus concentration in plant tissues at the pod filling stage are promising because it allows for indirect selection. The nutritional value of leaves in young plants, for phosphorus, is equivalent to that of grains.

There is genetic variability among the bean lineages studied, for the production of dry mass, yield and accumulation of phosphorus in the tissues. The lineage L 2527 showed to be efficient and responsive to the use of phosphorus for the shoot of the plant. Lineage L 2225 showed to be efficient in the use of phosphorus in shoot, grains and grain production, besides maintaining this characteristic in the two growing seasons.

Studies like this should be of paramount importance and should be valued. Increasingly, research aimed at efficiency in the use of minerals in general should be prioritized. This is because this is an important way of producing food consciously, thinking about future generations and the environment.

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