Expected values and predictive model for black seed (*Plaseolus vulgaris* L.) production

Ivan Ricardo Carvalho*[1], Vinícius Jardel Szareski[2], Luiz Leonardo Ferreira[3], Gustavo Henrique Demari[2], José Antonio Gonzalez da Silva[1], Mauricio Horbach Barbosa[2], Tiago Corazza da Rosa[2], Jerffeson Araujo Cavalcante[2], Ester Mafalda Matter[1], Devid Araujo Magano[1], Velci Queiróz de Souza[4]

[1]Universidade Regional do Noroeste do Estado do Rio Grande do Sul, Ijuí, RS, Brasil
[2]Universidade Federal de Pelotas, Capão do Leão, RS, Brasil
[3]Centro Universitário de Mineiros, Mineiros, GO, Brasil
[4]Universidade Federal do Pampa, São Gabriel, RS, Brasil

*Corresponding authors: carvalho.irc@gmail.com

Abstract

The objective of this work was to determine the tendencies of expected values, linear associations, and to define which traits compose the best predictive model for mass of seeds per plant of black and pinto bean genotypes from different regions of Rio Grande do Sul. The experiments were conducted in the agricultural years of (2015-2017). The expected values are increased as function of the segregating generation of F2, F3, F4 for first pod insertion height and plant height. Furthermore, black commercial group determines superiority for number of seeds per plant, while pinto genotypes are closely related to increments of mass of seeds per plant. Linear associations are specific to germplasm origin, commercial group and segregating generations of bean genotypes regarding traits of agronomic interest. The predictive model created to increase mass of seeds per plant is specific for germplasm origins and commercial group of beans. Seed yield of pinto genotypes is maximized by plant height and number of seeds per plant. For genotypes of black commercial group, this increase is achieved through plant height, number of pods and seeds per plant in F3 and F4 segregating generations.

Keywords: *Phaseolus vulgaris* L., Germplasm*,* commercial group*,* select of genotype.
Abbreviations: FPH_first pod insertion height; PH_plant height; NPP_number of pods per plant; NSP_number of seeds per plant; MSP_mass of seeds per plant;

Introduction

Bean (*Phaseolus vulgaris* L.) is considered a staple food for human diet and one of the main protein sources used by the population. It is also an agricultural product of great socioeconomic importance due to its large volume of labor-demand employed during its productive cycle (Plans et al., 2013). In this sense, genetic breeding programs of beans are aimed at identifying high seed yielding genotypes adapted and stable to the most varied growing conditions (Ramalho and Araujo, 2011).

The largest proportion of beans produced in Brazil comes from the Southern Region, with more than one million tons and 30% of the total grain production. Majority of the country´s production comes from family farming, which represents around 60% of the production (CTSBF, 2012). Therefore, in order to achieve high yields, the use of high performance seeds is indispensable, which combine genetic, physical, sanitary and physiological attributes that determine their ability to originate productive plants with vital functions such as germination, vigor and longevity, besides the recommended growing techniques (Peske, et al., 2012). Among several factors that determine seed physiological potential, the characteristics of genotypes and

growing environments exert great effects on yield and agronomic attributes of interest (Szareski et al., 2017).

The high magnitude of data obtained along several breeding generations demands effective biometric tools to identify specific traits or to predict the most suitable populations or families. Therefore, linear associations are important to identify tendencies between traits of interest, as well as which of them should be prioritized for selection. However, the knowledge of yield components with the greatest contribution for seed production should not be based only on simple linear correlation, since its interpretation might lead to errors or misunderstandings, compromising the success of selection (Cruz et al., 2014). In this way, understanding linear correlations between traits allows only identifying tendencies, but it does not formulate cause and effect relationships (Carvalho et al., 2017). Due to this fact, multiple regressions (Stepwise) are used to determine which traits are essential to the dependent trait (Balbinot et al., 2005). Therefore, the objective of this work was to determine the tendencies of expected values, linear associations, and to define which traits compose the best predictive model for mass of seeds per plant of black and

pinto bean genotypes from different regions of Rio Grande do Sul.

Results and discussion

Expected values for the traits of agronomic interest

In order to understand the expected values of the set of measured traits along the segregating generations, 120 bean genotypes of the black commercial group and 80 bean genotypes of the Pinto commercial group were used. The average patterns for the traits such as first pod insertion height (FPH), plant height (PH), number of pods per plant (NPP), number of seeds per plant (NSP) and mass of seeds per plant (MSP) were measured. These results allowed inferring patterns for traits tendency across generations in each commercial type of beans.

For the commercial group black, first pod insertion height (FPH) was 11.6, 15.5 and 19.0 cm in the F2, F3 and F4 generations, respectively (Figure 1). An increment of 3.9 cm was observed between F2 and F3 generations, and 3.5 cm generations between F3 and F4, confirming that the selection strategies applied according to the best individuals and families provided increases of 7.4 cm over the generations (F2 - F4). Researches on beans of the commercial group black revealed genetic gain of 9 to 25 cm for plant height (Ribeiro et al., 2000).

Regarding the Pinto commercial group, first pod insertion heights (FPH) were 13.7, 16.7 and 20.1 cm for F2, F3 and F4 generations, respectively. The selection of the best F_2 individuals for the formation of F3 families increased the mean of this character by 3.0 cm, maintaining the tendency among F3 - F4 generations. In the general context for this scenario, we observed average increments of 6.4 cm for first pod insertion height between intermediary selection cycles of F2 to F4. When comparing the expected tendencies among commercial groups of beans, even with similar increment rates for this trait, plants from Pinto commercial group expressed higher first pod insertion height (FPH) in each segregating generation.

Studies with commercial genotypes of Pinto beans presented averages of first pod insertion height (FPH) between 7.1 cm and 21.6 cm (Bertoldo et al., 2014). In general, commercial bean genotypes present low first pod insertion height, which might compromise mechanized harvesting rates, resulting in low plant height (Souza et al., 2010). Thereby, increasing first pod insertion height may ease mechanized harvesting of beans, reducing losses and negative effects on the physiological quality of seeds (Terasawa et al., 2009), as well as preventing deterioration of legumes in contact with soil (Ribeiro et al., 2000).

For commercial group black, the plant height (PH), presented 33.5, 32.2 and 47.1 cm in the F2, F3 and F4 generations, respectively (Figure 1). The selection of superior families allowed increasing of this trait in 14.9 cm between F3 and F4 generations, establishing the possibility of achieving agronomically adequate genotypes regarding plants stature using only the selection directed to superior families. Between the population generation (F2) and the advanced generation of families (F4), increase of 13.6 cm was verified. Black bean commercial genotypes show statures up to 80 cm, being this trait dependent on genetic

characteristics and edaphoclimatic conditions (Rocha et al., 2014).

Pinto commercial group presented plants with 37.7, 32.1 and 49.4 cm of height (AP) for the generations F2, F3 and F4 (Figure 1), respectively. There was a mean decrease of 5.6 cm in this trait between F2 - F3 generations, due to the restriction in genetic variability caused by selection. In contrast, it was possible to increase plant height up to 14.9 cm by selecting the best F3 - F4 families. This study determined that greater general additions (F2 - F4) for genotypes of the black commercial group, with 1.9 cm higher than the Pinto commercial group. However, it was among F3 and F4 generations that Pinto genotypes could stand out. Pinto genotypes presented 76 cm of height (Iapar, 2008). In contrast, genotypes of the black commercial group revealed smaller magnitudes for this trait (Santi et al., 2006). The number of pods per plant (NPP) for pinto and black bean genotypes (Figure 2) showed average increases superior to one legume per plant. It was due to the selections between the segregating generations of F2 and F4. Even though there is similarity between trends of commercial groups, black bean genotypes express more pods per plant. Gonçalves et al. (2003) reported that the number of pods per plant is positively associated with the yield of bean seeds.

Number of seeds per plant (NSP) for the commercial group black was 23.9, 29.7 and 30.7 viable seeds per plant in the F2, F3 and F4 generations, respectively (Figure 2). Under these conditions, satisfactory additions of 5.8 seeds per plant were obtained through selections between F2 and F3, as well as increases of 6.8 seeds were expressed in relation to the F2 population generation to F4 families. The identification of the best individuals within the population of interest results in the obtaining of transgressive families and genetic gains for magnitude of seeds. However, for pinto commercial group, a cumulative increase was evidenced through the segregating generations, since there is an increment of 7.9 seeds per plant between F2 and F4. This average is higher than the commercial group of black beans. Considering direct effects on bean yield, the number of seeds per plant is an extremely important trait, and one of the main yield components (Zilio et al., 2011; Cabral et al., 2011).

The mass of seeds per plant (MSP) expressed reduction of 1.7 grams of seeds across the segregating generations F2 - F4 for black beans commercial group. Certain increases occurred in the initial generations, but these mean superiorities were minimized because selection was directed to superior families in F3 and F4 for number of seeds per plant, resulting in more reproductive structures and seeds formed, but with smaller unitary mass.

Yield components contribute in different ways to beans productivity. Researches affirmed that higher yields may be achieved by reducing the first pod height, increasing the number of pods per plant, and the unitary mass of seeds (Mambrin et al., 2015). It should be noted that yield components are strongly determined by the genotype´s features, and also by effects of growing environment, cycle, agronomic practices and management (Bezerra et al., 2007). For pinto commercial group, we observed increments of 2.6 grams of seeds per plant along F2 - F4 generations, proving that the main yield components are intrinsic to the commercial group that the genotypes belong to. Whereas black bean genotypes prioritized the increase in magnitude

of formed seeds, bean genotypes of Pinto commercial group established less seeds, but these seeds present greater mass. In general, majority of bean breeding programs prioritize the trait yield, which presents great economic importance, being controlled by a considerable fraction of genetic effects (Ramalho et al., 2012), it is influenced by genotype x environment interaction (Gomes et al., 2008), as well as, biotic and abiotic stresses (Dourado Neto and Fancelli, 2000).

Linear associations between traits of agronomic interest

In order to identify the trends of linear association between traits of agronomic interest, as well as their associations between F2, F3 and F4 segregating generations, a stratified linear correlation was performed for each origin of germplasm and commercial group of each bean genotype (Table 2, 3 and 4). For each scenario, 105 linear associations were performed, referring to the traits PH. F2, FPH.F2, NPP.F2, NSP.F2, MSP.F2, PH. F3, FPH.F3, NPP.F3, NSP.F3, MSP.F3, PH.F4, FPH.F4, NPP.F4, NSP.F4, MSP.F4 stratified for germplasm of the pinto commercial group from Campos Borges - RS and Santa Rosa - RS, and germplasm of the black commercial group from Cruz Alta - RS, Braga - RS, Pejuçara - RS and Palmeira das Missões - RS. The significance of correlation coefficient was verified through the t-test at 5% of probability.

Linear associations verified for germplasm of the Pinto commercial group from Campos Borges - RS (Table 2) evidenced 21 significant correlations, of which 13 expressed positive, and eight negative. The number of pods per plant measured in F2 (NPP.F2) positively influenced the number (NSP.F2) and mass of seeds per plant (MSP.F2) in the F2 generation. Plants with greater heights in the F3 segregating generation (AP. F3) tend to increase the number of pods and seeds, as well as seed mass per plant in the F3 segregating generation.

It is possible that superior plants for number of pods (NPP. F2), seeds (NSP. F2) and mass of seeds (MSP.F2) in the F2 segregating generation would face reduced height, number and mass of seeds in the F4 segregating generation. These trends indicate that, for some genetic constitutions of the pinto commercial group, superior individuals in the population generation may not generate progenies of equal or greater magnitude for the subject trait. However, families that reveals higher mass of seeds per plant (MSP. F3) in the F3 segregating generation might be considered as an indicative that number of pods per plant (NPP. F4), seeds (NSP. F4) and mass of seeds per plant (MSP. F4) will be higher in the F4 generation.

Linear associations verified for germplasm of the pinto commercial group from Santa Rosa - RS (Table 2) presented 36 significant correlation coefficients, of which 22 were positive and 14 negative. Regarding principal effects, plants of higher stature in the F2 and F3 segregating generations (PH. F2 and PH. F3) have better potential for the first pod insertion height (FPH. F2 and (FPH. F3), number of pods per plant (NPP. F2 and NPP. F3), number of seeds per plant (NSP. F2 and NSP. F3) and mass of seeds per plant (MSP. F2 and MSP. F3) in both generations. Under these conditions, early selection of plants with higher stature may be indicative of high yielding genotypes. However, the tendencies indicate that a higher number of pods per plant in F2 (NPP.F2) will

not necessarily generate a F4 segregating generation with high number of pods (NPP.F4). Regarding plant height in the F4 generation (PH.F4), it is closely related to first pod insertion height in the same generation (FPH.F4), as well as when selecting families with more pods per plant (NPP.F4), there is an increase in seed magnitude (NSP.F4) and mass of seeds per plant (MSP.F4) in this generation.

Regarding linear associations verified for beans germplasm of black commercial group from Cruz Alta - RS (Table 3), only 18 significant linear correlation coefficients was evidenced, of which 14 evidenced positive tendencies and only four expressed inverse effects. Plants with higher stature (PH.F2) and first pod insertion height (FPH.F2) in the F2 segregating generation increase the number of pods (NLP.F2), number (NSP.F2) and mass of seeds per plant (MSP.F2). In these generations of black commercial groups, the plant height might be considered an interesting morphological marker for selecting the best individuals in the population. According to the expressed tendencies, it is possible to increase the yield of seeds per plant through the identification of plants with greater stature that possibly present greater number of reproductive nodes, flowers, pods and seeds formed.

The three main components that compose seed yield of beans are number of pods per unit of area, number of seeds per pod and mass of seeds per plant. Therefore, the population of plants per unit of area will determine the number of pods, flowers per plant and number of flowers that effectively form legumes (Zilio et al., 2011). Ramos Junior et al. (2005), reported that seed size and number of seeds per pod correspond to the components with higher effects on bean yield.

It is observed that the increase in first pod insertion height (FPH.F3) and number of pods per plant (NPP.F3) in the F3 segregating generation may determine the increase in seeds (NSP.F3) and mass of seeds per plant (MSP.F3). In order to achieve higher seed yields (MSP.F4) in the F4 generation, the tendencies indicate that selections cannot be based on height (PH.F3), number of pods (NPP.F3), seeds (NSP.F3) and mass of seeds (MSP.F3) measured in the F3 generation. In this situation, the early selection may lead to misunderstandings and less efficiency in obtaining superior genotypes. However, families expressing higher plant height (PH.F4) in the F4 segregating generation result in an increase of first pod insertion height (FPH.F4), number of pods (NPP.F4) and seeds per plant (NSP.F4) in this same generation.

For the germplasm of black commercial group from Braga - RS (Table 3), 25 significant associations were found, of which, 21 indicated positive trends and only four were inverse. Plants with higher stature (PH.F2) and first pod insertion height (FPH.F2), as well as, greater number of pods per plant (NPP.F2) in the F2 segregating generation, indicate increases in the number of seeds per plant (NSP .F4) in F4 families. Plant stature (PH.F3 and FPH.F3) was determinant for F3 segregating generation, which resulted in the increase of number of pods (NPP.F3), seeds (NSP.F3) and mass of seeds per plant (MSP.F3) in the same generation.

Essential tendencies were evidenced between F3 and F4 generations, which should be considered for selecting strategies to minimize errors, as it was verified that F3 families were superior in number of pods (NPP.F3), seeds (NSP.F3) and mass of seeds per plant (MSP.F3) do not reflect

Table 1. Information regarding the environment of origin, commercial group, geographical coordinates and altitude.

	Commercial group	Latitude	Longitude	Altitude
Campos Borges – RS	Pinto	28° 52' 31''S	53° 00' 55''W	513m
Santa Rosa – RS	Pinto	27° 52' 16'' S	54° 28' 55'' W	277m
Palmeira das Missões – RS	Black	27° 53' 19''S	53° 18' 19'' W	639m
Braga – RS	Black	27° 37' 16'' S	53° 44' 17'' W	430m
Cruz Alta – RS	Black	28° 38' 22'' S	53° 36' 22'' W	452m
Pejuçara – RS	Black	28° 25' 24'' S	53° 39' 21'' W	449m

*Carvalho et al. (2016).
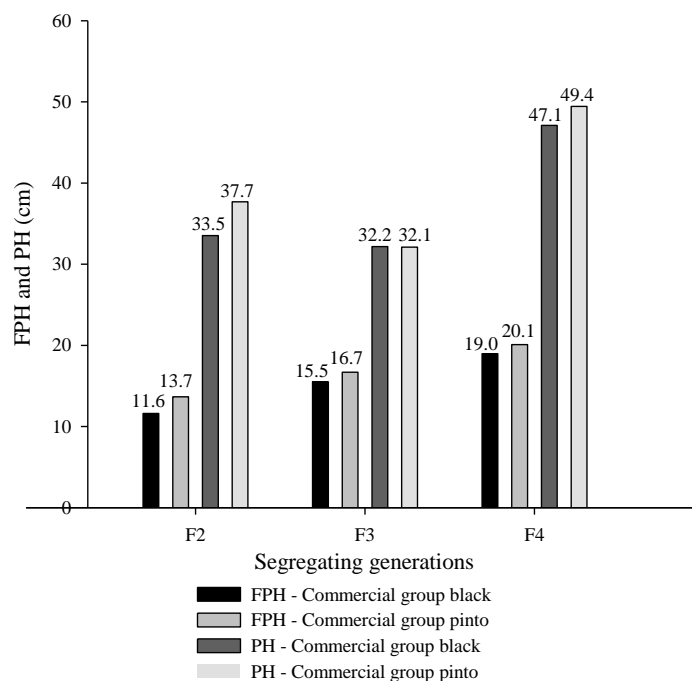
Fig 1. Expected values for the traits first pod insertion height (FPH) and plant height (PH), for black and pinto commercial groups of beans across segregating generations.

Table 2. Linear correlation coefficient for plant height (PH), first pod insertion height (FPH), number of pods per plant (NPP), number of seeds per plant (NSP) and mass of seeds per plant (MSP), obtained for F2, F3 and F4 segregating generations of beans from pinto commercial group.

	PH.F₂	FPH.F₂	NPP.F₂	NSP.F₂	MSP.F₂	PH.F₃	FPH.F₃	NPP.F₃	NSP.F₃	MSP.F₃	PH.F₄	FPH.F₄	NPP.F₄	NSP.F₄	MSP.F₄
	Germplasm of the pinto commercial group from Campos Borges - RS														
PH.F$_2$	-	-0.12	0.17	0.34	0.23	-0.04	-0.08	0.15	0.28	0.12	0.01	0.10	0.28	0.11	0.23
FPH.F$_2$	0.56*	-	0.12	0.16	0.17	0.04	0.15	-0.09	-0.07	-0.31	-0.13	-0.01	-0.06	-0.08	-0.09
NPP.F$_2$	0.66*	0.28*	-	0.92*	0.90*	-0.26	-0.02	-0.09	-0.08	-0.19	-0.52*	-0.40*	-0.32	-0.41*	-0.44*
NSP.F$_2$	0.63*	0.30*	0.91*	-	0.96	-0.17	-0.13	0.16	0.14	0.00	-0.50*	-0.43*	-0.18	-0.27	-0.31
MSP.F$_2$	0.61*	0.15	0.92*	0.91*	-	-0.19	-0.09	0.10	0.09	0.07	-0.42*	-0.45*	-0.19	-0.28	-0.31
PH.F$_3$	0.13	0.22	0.07	0.14	0.02	-	0.04	0.77*	0.74*	0.50*	0.06	0.00	0.00	0.01	0.10
FPH.F$_3$	0.24	0.16	0.19	0.27	0.20	0.48*	-	-0.32	-0.29	-0.38	0.14	0.07	-0.07	0.01	-0.11
NPP.F$_3$	0.14	0.15	0.11	0.20	0.18	0.56*	0.09	-	0.95*	0.87*	-0.13	-0.08	-0.02	-0.06	0.04
NSP.F$_3$	0.13	0.12	0.08	0.19	0.13	0.60*	0.12	0.82*	-	0.87	-0.07	0.00	-0.06	-0.11	-0.01
MSP.F$_3$	0.00	0.00	0.02	0.10	0.10	0.49*	0.13	0.83*	0.90*	-	0.07	0.10	0.08	0.01	0.14
PH.F$_4$	0.09	0.03	0.03	0.04	0.03	0.20	-0.07	0.16	0.21	0.06	-	0.30	0.47*	0.69*	0.46*
FPH.F$_4$	-0.10	-0.06	-0.19	-0.17	-0.16	-0.11	0.06	-0.12	-0.15	-0.20	0.29*	-	0.01	0.02	0.12
NPP.F$_4$	-0.25	-0.31*	-0.31*	-0.44	-0.34*	-0.33*	0.00	-0.35*	-0.33*	-0.26	0.09	0.35*	-	0.91*	0.90*
NSP.F$_4$	-0.11	-0.12	-0.27	-0.33*	-0.25	-0.21	0.07	-0.35*	-0.28*	-0.31	0.18	0.50*	0.91*	-	0.92*
MSP.F$_4$	-0.13	-0.22	-0.25	-0.33*	-0.19	-0.30*	0.06	-0.43*	-0.41*	-0.36*	0.03	0.27	0.88*	0.89*	-
*Germplasm of the pinto commercial group from Santa Rosa – RS															

*Significant correlation coefficient at 5% of probability by t test adjusted to effects of 80 observations associated to the model.
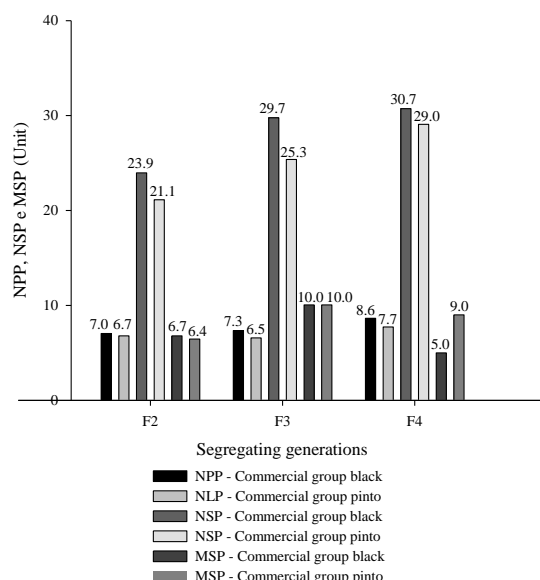
Fig 2. Expected values for the traits number of pods per plant (NPP) number of seeds per plant (NSP), and mass of seeds per plant (MSP) of black and pinto commercial groups of beans across segregating generations.

Table 3. Linear correlation coefficient for plant height (PH), first pod insertion height (FPH), number of pods per plant (NPP), number of seeds per plant (NSP) and mass of seeds per plant (MSP), obtained from F2, F3 and F4 segregating generations of beans from black commercial group.

	$PH.F_2$	$FPH.F_2$	$NPP.F_2$	$NSP.F_2$	$MSP.F_2$	$PH.F_3$	$FPH.F_3$	$NPP.F_3$	$NSP.F_3$	$MSP.F_3$	$PH.F_4$	$FPH.F_4$	$NPP.F_4$	$NSP.F_4$	$MSP.F_4$
						Germplasm of the black commercial group from Cruz Alta– RS									
$PH.F_2$	-	0.36	0.30	0.43*	0.32	-0.07	0.21	-0.40	-0.40	-0.34	0.18	0.05	0.11	0.17	-0.01
$FPH.F_2$	0.19	-	0.32	0.43*	0.07	-0.07	0.07	-0.25	-0.30	-0.34	0.15	0.16	0.01	0.04	-0.09
$NPP.F_2$	0.76*	-0.21	-	0.80*	0.67*	-0.04	0.02	0.35	0.27	0.22	0.18	0.07	-0.11	-0.02	-0.23
$NSP.F_2$	0.83*	-0.21	0.95*	-	0.82*	-0.19	-0.13	0.08	0.02	-0.07	0.18	0.09	-0.08	0.04	-0.11
$MSP.F_2$	0.49*	-0.12	0.79*	0.76*	-	-0.26	-0.27	0.16	0.14	0.07	0.23	0.11	-0.09	0.13	-0.07
$PH.F_3$	-0.05	0.07	0.30	0.12	0.47*	-	0.39	0.18	0.21	0.27	-0.38	-0.39	-0.35	-0.46*	-0.24
$FPH.F_3$	-0.06	0.23	-0.10	-0.09	-0.14	0.18	-	-0.15	-0.09	-0.07	0.05	-0.35	0.04	-0.03	0.25
$NPP.F_3$	-0.05	0.21	0.09	-0.04	0.02	0.64*	0.34	-	0.97*	0.94*	0.11	0.00	-0.29	-0.27	-0.47*
$NSP.F_3$	-0.01	0.23	0.06	-0.05	0.03	0.62*	0.36	0.97*	-	0.97*	0.15	0.02	-0.26	-0.23	-0.43*
$MSP.F_3$	-0.10	0.22	0.02	-0.10	0.04	0.63*	0.40*	0.93*	0.96*	-	0.13	0.04	-0.29	-0.26	-0.43*
$PH.F_4$	-0.18	-0.40*	-0.01	-0.04	0.02	0.27	0.13	0.21	0.12	0.16	-	0.51*	0.47*	0.62*	0.21
$FPH.F_4$	-0.14	-0.21	0.39*	0.29	0.19	0.16	0.09	0.11	-0.01	0.00	0.55*	-	0.28	0.39	0.24
$NPP.F_4$	0.30	0.00	0.12	0.13	0.39*	0.24	-0.21	-0.32	-0.27	-0.28	0.15	-0.03	-	0.92*	0.82*
$NSP.F_4$	0.40*	0.05	0.17	0.21	0.00	0.12	-0.13	-0.37	-0.34	-0.32	0.16	0.06	0.88*	-	0.82*
$MSP.F_4$	0.27	0.07	0.08	0.14	0.25	-0.12	-0.23	-0.51*	-0.49*	-0.44*	0.05	-0.04	0.81*	0.90*	-
						Germplasm of the black commercial group from Braga– RS									

* significant correlation coefficient at 5% of probability by t test adjusted to effects of 80 observations associated to the model.

Table 4. Linear correlation coefficient for plant height (PH), first pod insertion height (FPH), number of pods per plant (NPP), number of seeds per plant (NSP) and mass of seeds per plant (MSP), obtained for F2, F3 and F4 segregating generations of beans from black commercial group.

	$PH.F_2$	$FPH.F_2$	$NPP.F_2$	$NSP.F_2$	$MSP.F_2$	$PH.F_3$	$FPH.F_3$	$NPP.F_3$	$NSP.F_3$	$MSP.F_3$	$PH.F_4$	$FPH.F_4$	$NPP.F_4$	$NSP.F_4$	$MSP.F_4$
						Germplasm of the black commercial group from Pejuçara – RS									
$PH.F_2$	-	0.17	0.68*	0.64*	0.61*	0.11	0.28	0.07	0.25	0.23	0.32	-0.26	0.04	-0.01	-0.03
$FPH.F_2$	0.53*	-	0.00	0.06	-0.19	-0.39*	-0.35*	-0.16	-0.13	0.19	-0.30	0.08	-0.37*	-0.31*	-0.22
$NPP.F_2$	0.58*	0.12	-	0.93*	0.83*	0.23	0.20	0.11	0.29	0.11	0.17	-0.26	0.12	-0.05	-0.07
$NSP.F_2$	0.75*	0.25	0.92*	-	0.80*	0.16	0.20	0.02	0.22	0.07	0.09	-0.17	0.05	-0.13	-0.14
$MSP.F_2$	0.38*	-0.15	0.67*	0.75*	-	0.33	0.26	0.12	0.19	0.01	0.38*	0.03	-0.02	-0.10	-0.20
$PH.F_3$	-0.27	0.08	-0.30	-0.23	-0.13	-	0.59*	0.10	0.30	-0.34*	0.18	-0.28	0.11	0.03	0.07
$FPH.F_3$	0.13	0.27	-0.04	0.05	-0.04	0.46*	-	-0.01	0.16	-0.26	0.19	-0.17	0.24	0.12	0.21
$NPP.F_3$	-0.36*	-0.11	-0.11	-0.18	0.01	0.26	-0.21	-	0.86*	0.64*	0.09	0.03	0.21	0.21	0.18
$NSP.F_3$	-0.38*	-0.17	-0.14	-0.19	0.01	0.42*	-0.09	0.94*	-	0.63*	0.01	-0.12	0.19	0.14	0.11
$MSP.F_3$	-0.25	-0.25	-0.09	-0.18	-0.01	0.24	-0.11	0.81*	0.87*	-	-0.08	-0.06	0.11	0.11	0.09
$PH.F_4$	0.20	0.24	0.20	0.28	-0.05	-0.01	0.13	-0.31	-0.27	-0.20	-	0.02	0.31	0.45*	0.21
$FPH.F_4$	-0.14	0.03	-0.02	-0.06	-0.19	0.14	0.31	-0.23	-0.16	-0.25	0.31	-	-0.52*	-0.16	-0.50*
$NPP.F_4$	-0.02	0.03	-0.05	-0.07	-0.11	-0.32	-0.17	0.16	0.15	-0.10	-0.09	-0.23	-	0.89*	0.82*
$NSP.F_4$	0.00	0.07	0.01	0.01	-0.14	-0.31	-0.06	-0.10	-0.08	-0.24	0.19	0.01	0.89*	-	0.90*
$MSP.F_4$	-0.26	0.05	-0.16	-0.21	-0.19	-0.22	0.02	0.28	0.26	-0.02	-0.08	-0.17	0.96*	0.84*	-
						Germplasm of the black commercial group from Palmeira das Missões– RS									

*Significant correlation coefficient at 5% of probability by t test adjusted to effects of 80 observations associated to the model.

Table 5. Predictive model based on multiple linear regression (Step Wise) for mass of seeds per plant (MSP) regarding F4 segregating generation, considering the other traits as explanatory.

Origin of germplasm	Commercial group	Dependent trait mass of seeds per plant in F_4 (Y = $MSP.F_{4**}$)
Campos Borges - RS	Pinto	Y = 5.99 - 0.298($NPP.F_2$) - 0.061 ($PH.F_4$) + 0.225 ($NSP.F_4$) R^2: 0.91*
Santa Rosa - RS	Pinto	Y = 3.717 - 0.051 ($PH.F_3$) - 0.109 ($FPH.F_4$) +0.233($NSP.F_4$) R^2:0.87
Palmeira das Missões - RS	Black	Y = 4.2887 -0.105($PH.F_2$) +0.103($NSP.F_2$) -0.133($MSP.F_2$) -0.131($PH.F_3$) +0.278($FPH.F_3$) -0.183($FPH.F_4$) +0.889($NPP.F_4$) R^2:0.95*
Braga - RS	Black	Y = 2.525 -0.055($PH.F_3$) +0.147($NSP.F_4$)R^2:0.85*
Cruz Alta - RS	Black	Y = 3.959 -0.210($NPP.F_2$) -0.083($PH.F_4$) +0.315($NSP.F_4$) R^2:0.92*
Pejuçara - RS	Black	Y = 0.386 +0.096($FPH.F_3$) -0.035($PH.F_4$) +0.229($NSP.F_4$) R^2:0.82*

*significant at 5% by the t test.**$PH.F_2$: Plant height measured in the F_2segregating generation, $PH.F_3$: Plant height measured in the F_3segregating generation, $PH.F_4$: Plant height measured in the F_4segregating generation, $FPH.F_3$: first pod insertion height measured in the F_3segregating generation, $FPH.F_4$: first pod insertion height measured in the F_3 segregating generation, $NPP.F_2$: number of pods per plant measured in the F_2 segregating generation, $NPP.F_4$: number of pods per plant measured in the F4 segregating, $NSP.F_2$: number of seeds per plant measured in the F_2segregating generation, $NSP.F_4$:number of seeds per plant measured in the F_4segregating generation, $MSP.F_2$: mass of seeds per plant measured in the F_2 segregating generation.

in F4 families with the highest mass of seeds per plant (MSP.F4). These distortions in association between traits are due to genic events determinant for their expression, as these traits express quantitative inheritance, low heritability and high influence of the environment (Melo et al., 2007; Pereira et al., 2012, Domingues et al., 2013; Torga et al., 2013). Furthermore, it is notorious that in initial generations of breeding, there is predominance of non-additive effects, which can result in biases in the inferences about superior genotypes. Thus, difficulties are faced in order to select superior genotypes, which are originated from the growing environment and the genotypes response to edaphoclimatic changes (Coimbra et al., 2008; Lima et al., 2012).

Regarding the bean germplasm of black commercial group from Pejuçara - RS (Table 4), 23 significant coefficients were observed, 15 of them were positive and only eight, negative. In this situation, the larger plants of the F2 segregating generation (PH.F2) result in the increase of number of pods (NPP.F2), seeds (NSP.F2) and mass of seeds (MSP.F2) for this generation. However, first pod insertion height in the F2 generation (FPH.F2) cannot be considered a good selection criterion because it results in the decrease of plant stature in F3 (PH.F3 and FPH.F3), magnitude of pods (NPP.F4) and seeds (NSP.F4) in the F4 segregating families. It is consolidated that the selection of superior individuals for mass of seeds per plant in the F2 generation (MSP.F2) does not necessarily result in superior F3 families for this trait (MSP.F3). However, plants with smaller stature in F4 generation (PH.F4) are indication of increased seed yield components (NLP.F4, NSP.F4 and MSP.F4) in this generation. For the germplasm of black commercial group from Palmeira das Missões - RS (Table 4). Only 17 significant associations were observed, 15 of which were positive and only two were inverses. In view of the most informative correlations, plants with higher stature in F2 generation (PH.F2) indicate a reduction in number of pods (NPP.F3) and seeds per plant (NSP.F3) in F3 segregating families. In contrast, higher plants in F3 (PH.F3) potentiate the emission of pods per plant (NPP.F3) in this same generation.

Considering the six scenarios of associations weighted by germplasm origin and commercial type, we verified that most correlations are specific and should be considered as isolated situations to avoid confusion of interpretations. However, regardless of the commercial type of bean analyzed, plant heights measured in F2 generations (PH.F2) are associated with number of pods (NPP.F2) and seeds per plant (NSP.F2) in this generation. Specific association was found between number of pods per plant (NPP.F2), number of seeds (NSP.F2) and mass of seeds per plant (MSP.F2) measured in the pinto commercial group. In contrast, for black commercial group, specificity of association was

verified between plant height in F2 and F3 generations (PH.F2 and PH.F3) with number of pods per plant (NPP.F2 and NPP.F3). The association between traits is of extreme importance for plant breeding, since several of them are considered of economic importance and are determined jointly (Cruz and Regazzi, 2001). Jost et al. (2013), reported that selection strategies adequately determined the positive increases in agronomic attributes, such as higher yield, shorter cycle, lodging tolerance and higher height of the first pod.

Predictive model for black and pinto beans commercial group

The predictive model was established to present which explanatory traits are determinant for mass of seeds per plant, measured in F4 generation (MSP.F4). The estimates were stratified for germplasm origin and commercial groups due to the specificity of linear associations for the measured traits (Table 5). For germplasm of Campos Borges - RS, characterized as pinto commercial group, we evidenced that selections should be directed jointly to number of pods per plant in the F2 generation (NPP.F2), plant height (PH.F4) and number of seeds per plant (NSP.F4) on F4 generation. For the same commercial type of beans, but with seeds from Santa Rosa – RS, the tendencies were similar, with plant height measured in F3 generation (PH.F3) attached to the predictive model as a possible trait for selection.

Prediction aimed at incrementing seed yield for bean genotypes of the black commercial group for germplasm from Palmeira das Missões – RS showed that seven traits were required to compose the model. In these conditions, selection should be cautious because there are many dependences among traits and segregating generations for the maximum expression of the dependent trait. On the other hand, for genotypes from Braga - RS, Cruz Alta - RS and Pejuçara - RS, the number of pods per plant obtained in F2 (NPP.F2), plant height at F3 (PH.F3), first pod insertion height in F3 (FPH.F3), plant height in F4 (PH.F4) and number of seeds per plant (NSP.F4) measured in the F4 generation should be considered along for selection in order to achieve superior genotypes for seed yield of beans from black commercial group.

Materials and methods

Conduction of study and experimental design

The experiments were conducted in the agricultural years of 2015, 2016 and 2017, in the municipality of Tenente Portela - RS, located at Latitude 27°23'31.04"S and Longitude 53°

46'50.71" W, with average altitude of 420 meters. The climate is classified by Köppen as Cfa subtropical humid, and the soil is characterized as typical red alumino-ferric latosol (STRECK, 2008). Bean genotypes were collected from different regions of Rio Grande do Sul state, Brazil. The detailed information about the environments of origin of the used seeds is shown in Table 1.

The experimental design was augmented blocks design (Federer, 1956), with the genotypes BRS Esplendor, BRS Supremo and IPR Tiziu being used as checks arranged in four replicates. The other treatments were arranged in a unique way in the experiment, being the F_2 segregating generation (2015) composed by 20 bean populations from the commercial group black, and 20 bean populations from the commercial group Pinto. The F_3 segregating population was composed by 69 families (2016) selected from the segregating populations, and the F_4 segregating generation was composed by 41 families from the selection among the best F_3 families.

The experimental units were composed of two lines with five meters length and spaced 0.45 m. Seed density was 20 seeds (m^2). For all agricultural years, the sowings were carried out in the second half of November, through direct sowing system. The base fertilization was composed of 250 kg ha^{-1} of N, P_2O_5, K_2O in the formulation (10-20-20). As topdressing, we used 90 kgha^{-1} of nitrogen in the form of urea (46% of N) at the V_4 phenological stage. Preventive practices were prioritized to minimize effects of weeds, pest insects and diseases that could influence the experiments results.

Traits measured

The traits of agronomic interest were measured in 10 plants randomly collected in the useful area of the experimental unit, such as First pod insertion height (FPH), measured through the distance between soil level and the insertion of the first viable pod, results in centimeters (cm). Plant height (PH), measured through the distance between soil level and the last fully expanded trifolium, results in cm. Number of pods per plant (NPP), obtained by the magnitude of viable pods contained in the plant, results in units. Number of seeds per plant (NSP), measured after pod´s threshing, counting the number of seeds, results in units. Mass of seeds per plant (MSP), seeds absent of residues were submitted to mass measurement, with posterior adjust for 13% of humidity, results expressed in grams (g).

Statistical analysis

The data were submitted to descriptive analysis, determining the expected values for each segregating generation and trait of interest stratified for bean commercial group. After the analysis of variance at 5% of probability (Ramalho, 2012), linear correlation was performed to verify the association tendency between traits, segregating generations and origin of germplasm used. Subsequently, a predictive model based on the Stepwise multiple regression was developed, considering the statistical model:

$\hat{Y} = A+B$ (PHF2, PHF3, PHF4) $+ C$ (FPH F2, FPH F3, FPH F4) $+ D$ (NPPF2, NPPF3, NPPF4) $+ E$ (NSPF2, NSPF3, NSPF4) $+ F$ (MSPF2, MSPF3). Where: $\hat{Y}$: dependent trait (MSPF4); A: point of data sources (intercept); B, C, D, E

and F: multiple angular coefficients; PH (F2, F3 and F4); FPH (F2, F3 and F4); NPP (F2, F3 and F4); NSP (F2, F3 and F4) and MSP (F4): were considered as explanatory traits of the stochastic model.

Conclusion

The expected values are increased as function of the segregating generation F2, F3, F4 for first pod insertion height and plant height. Furthermore, black commercial group determines superiority for number of seeds per plant, while pinto genotypes are closely related to increments of mass of seeds per plant. Linear associations are specific to germplasm origin, commercial group and segregating generations of bean genotypes regarding traits of agronomic interest. The predictive model was created to increase mass of seeds per plant which is specific for germplasm origins and commercial group of beans. Seed yield of pinto genotypes is maximized by plant height and number of seeds per plant. For genotypes of black commercial group, this increase is achieved through plant height, number of pods and seeds per plant in F3 and F4 segregating generations.

Acknowledgements

References

Balbinot JRAA, Backes RL, Alves AC, Ogliari JB, Fonseca JA da (2005) Contribuição de componentes de rendimento na produtividade de grãos em variedades de polinização aberta de milho. R Bras Agrociência. (2): 161-166.

Bertoldo JG, Coimbra JLM, Guidilin AF, Andrade LRB, Nodari RO (2014) Agronomic potential of gene bank landrace elite accessions for common bean genetic breeding. Scientia Agricola. (71): 120-125.

Bezerra APA, Pitombeira JB, Távora JAF, Neto FDCV (2007) Rendimento, componentes da produção e uso eficiente da terra nos consórcios sorgo x feijão-de-corda e sorgo x milho. Revista Ciência Agronômica. (01): 104-108.

Cabral PDS, Soares TCB, Lima ABP, Soares YJB, Silva JA (2011) Análise de trilha do rendimento de grãos de feijoeiro (*Phaseolus vulgaris* L.) e seus componentes. Revista Ciência Agronômica, Fortaleza. 42(1): 132- 138.

Carbonell SAM, Chiorato AF, Gonçalves JGR, Perina EF, Carvalho CRL (2010) Tamanho de grão comercial em cultivares de feijoeiro. Ciência Rural. 40(10): 2067-2073.

Carvalho FIF, Lorencetti C, Benin G (2004) Estimativas e implicações da correlação no melhoramento vegetal. Pelotas: UFPel, 142p.

Carvalho IR, Nardino M, Follmann DN, Demari G, Olivoto T, Pelegrin AJ, Szareski, VJ, Ferrari M, Rosa TC, Koch F, Aisenberg GR, Pedo T, Aumonde TZ, Souza VQ (2017) Path analysis of grain yield associated characters in Brazilians wheat (*Triticum aestivum* L.). Australian Journal of Crop Science. (11): 1406-1410.

Coimbra JLM, Barili LD, Vale ND, Guidolin AF, Bertoldo JG, Rocha FD, Toaldo D (2008) Seleção para caracteres adaptativos em acessos de feijão usando REML/BLUP. Magistra. 20(8): 177-185

Cruz CD, Regazzi AJ (2001) Modelos biométricos aplicados ao melhoramento genético. (1): Viçosa: UFV, 390.

Cruz CD, Carneiro PCS, Regazzi AJ (2014) Modelos biométricos aplicados ao melhoramento genético. (3) Viçosa: Editora da UFV, 668.

CTSBF - Comissão Técnica Sul-Brasileira de Feijão (2012) Informações técnicas para o cultivo de feijão na Região Sul brasileira. Disponível em:http://www.epagri.sc.gov.br/wp-content/uploads/2013/10/informacoes_tecnicas_cultivo_feijao.pdf.

Domingues LS, Ribeiro ND, Minetto C, Souza JF, Antunes IF (2013) Metodologias de análise de adaptabilidade e de estabilidade para a identificação de linhagens de feijão promissoras para o cultivo no Rio Grande do Sul. Semina: Ciências Agrárias, Londrina. 34(3): 1065-1076.

Dourado-Neto D, Fancelli AL (2000) Produção de feijão. Guaíba: Agropecuária, 386.

Federer WT (1956) Augmented (hoo nuiaku) designs. Haw Plan Rec. 55:191-208.

Goncalves MC, Correa AM, Destro D, Suza LD, Alves ST, Suza LCF (2003) Correlations and path analysis of common bean grain yield and its primary components. Crop Breeding and Applied Biotechnology. 3(03): 217-222.

Jost E, Ribeiro ND, Maziero SM, Possobom MTDF, Rosa DP, Domingues LS (2013) Comparison Among direct, indirect tand index selections on agronomic traits and nutritional quality traits in common bean. Journal of the Science Foodand Agriculture. 93(5): 1097-1104.

Lima KL, Ramalho MAP, Abreu AFB (2012) Implications of the progeny x environment interaction in selection index in volving characteristics of the common bean. Genetics and Molecular Research, Ribeirão Preto. 11(4): 4093-4099.

Mambrin RB, Ribeiro ND, Storck L, Domingues LDAS, Barkert KA (2015) Seleção de linhagens de feijão (*Phaseolus vulgaris* L.) baseada em caracteres morfológicos, fenológicos e de produção. Revista de Agricultura. 90: 141-155.

Melo LC, Melo PGS, Faria LC, Diaz JLC, Del Peloso MJ, Rava CA, Costa JGC (2007) Interação com ambientes e estabilidade de genótipos de feijoeiro-comum na Região Centro-Sul do Brasil. Pesquisa Agropecuária Brasileira Brasília. 42(5): 715-723.

Menezes Júnior JAN, Ramalho MAP, Abreu AFB (2008) Seleção recorrente para três caracteres do feijoeiro. Bragantia. (67): 833-838.

Pereira HS, Almeida VM, Melo LC, Wendl A, Faria FC, Del Peloso MJ, Magaldi MCS (2012) Influência do ambiente em cultivares de feijoeiro-comum em cerrado com baixa altitude. Bragantia. 71(2): 165- 172.

Peske ST, Villela FA, Meneghello GE (2012) Sementes: Fundamentos Científicos e Tecnológicos.3.ed. Pelotas: Editora Universitária/UFPel, 573p.

Plans M, Simó J, Casañas F, Sabaté J, Rodriguez-Saona L (2013) Characterization of common beans (*Phaseolus vulgaris* L.) by infrared spectroscopy: Comparison of MIR, FT-NIR and dispersive NIR using portable and benchtop instruments. Food Research International. 54(2): 1643-1651.

Ramalho MAP, Abreu AFB, Santos JB, Nunes JAR (2012) Aplicações da genética quantitativa no melhoramento de plantas autógamas. Lavras: Ufla,522 p.

Ramalho MAP, Ferreira DF, Oliveira AC (2012) Experimentação em genética e melhoramento de plantas. 3:305p.

Ramalho MAP, Araújo LCAD (2011) Breeding self-pollinated plants. Crop Breeding and Applied Biotechnology. (11): 1-7.

Ramos Junior EU, Lemos LB, Silva TRB (2005) Componentes da produção, produtividade de grãos e características tecnológicas de cultivares de feijão. Bragantia. 64(01): 75-82.

Ribeiro ND, Possebon SB, Storck L (2003) Genetic gain in agronomic traits in common bean breeding. Ciência Rural. (33): 629-633.

Rocha F da, Stinghen JC, Gemeli MS, Coimbra JLM, Guidolin AF (2014) Análise dialélica como ferramenta na seleção de genitores em feijão. Revista Ciência Agronômica. (45): 74-81.

Santi AL, Dutra LMC, Martin TN, Bonadiman R, Bellé GL, Della Flora LP, Jauer A (2006) Adubação nitrogenada na cultura do feijoeiro em plantio convencional. Ciência Rural Santa Maria. 36(4):10791085.

Searle SR (1971) Linear models. New York: John Wiley and Sons,531p.

Souza CA, Coelho CMM, Guidolin AF, Engelsing MJ, Bordin LC (2010) Influência do ácido giberélico sobre a arquitetura de plantas de feijão no início de desenvolvimento. Acta Scientiarum Agronomy. 32(2): 325-332.

Streck EV, Kämpf N, Dalmolin RS, Klamt E, Nascimento PC do, Schneider P, Giasson É, Pinto LFS (2008) Solos do Rio Grande do Sul.2. Porto Alegre, Emater, 222 p.

Szareski VJ, Carvalho IR, Kehl K, Levien AM, Nardino M, Demari GH, Lautenchleger F, Souza VQ, Pedo T, Aumonde TZ (2017) Univariate, multivariate techniques and mixed models applied to the adaptability and stability of wheat in the Rio Grande do Sul state. Genetics and Molecular Research. 16(3): 1-13.

Terasawa JM, Panobianco M, Possamai E, Koehler HS (2009) Antecipação da colheita na qualidade fisiológica desementes de soja. Bragantia. 68(3): 765-773.

Torga PP, Melo PGSM, Pereira HS, Faria LC, Del Peloso MJ, Melo LC (2013) Decomposition of the interaction of common black bean group genotypes with the environment. Agricultural Sciences. 4(12): 683-688.

Zilio M, Coelho CMM, Souza CA, Santos JCP, Miquelluti DJ (2011) Contribuição dos componentes de rendimento na produtividade de genótipos crioulos de feijão (*Phaseolus vulgaris* L.). Revista Ciência Agronômica. 42(2):429-438