Agronomic performance in different segregating soybean progenies

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Abstract - The estimate of variance component and genetic parameters for soybean grain yield in the northwestern region of the state of Rio Grande do Sul is 17% due to genetic effects and 83% due to the environment, management, and practices used. Thus, we aimed to evaluate the performance of quantitative and qualitative agronomic characteristics of soybean progenies in segregating generations F1, F2, F3, F4, and F5, as well as the interrelationships of these variables and their benefits in soybean breeding. Field trials were conducted from 2012 to 2020 in Campos Borges, Rio Grande do Sul. The variables that showed the greatest fluctuations during the segregating generations were pod insertion, number of pods on the main stem, number of pods with two seeds, and number of pods with four seeds. Taller plants in the F1 and F3 segregating generations had a greater number of pods with one, two, and three seeds; thus, as the plant size increased, the number of pods increased. As the segregating generations progressed, there was a reduction in the cycle and an increase in the seed mass per plant, consequently tending to be more productive.

Index terms: *Glycine max*; genetic improvement program; interrelations.

Desempenho agronômico de diferentes progênies segregantes da soja

Resumo - A estimativa do componente de variância e parâmetros genéticos para rendimento de grãos de soja na região noroeste do estado do Rio Grande do Sul é de 17% devido a efeitos genéticos e 83% devido ao ambiente, manejo e práticas utilizadas. Assim, objetivou-se avaliar o desempenho de características agronômicas quantitativas e qualitativas de progênies de soja nas gerações segregantes F1, F2, F3, F4 e F5, bem como as inter-relações dessas variáveis e seus benefícios no melhoramento genético da soja. Os testes de campo foram realizados de 2012 a 2020 em Campos Borges, no estado do Rio Grande do Sul. As variáveis que apresentaram as maiores oscilações durante as gerações segregantes foram a inserção do primeiro legume, número de legumes na haste principal, número de legumes com duas sementes e número de legumes com quatro sementes. Plantas mais altas nas gerações segregantes F1 e F3 tiveram uma maior quantidade de legumes com uma, duas e três sementes, portanto, à medida que o tamanho da planta aumentava, o número de legumes era incrementado. Com o avançar das gerações segregantes, houve redução do ciclo e aumento da massa de sementes por planta, consequentemente tendendo a ser mais produtiva.

Termos de indexação*:* *Glycine max*; programa de melhoramento genético; inter-relações.

Introduction

Soybean (*Glycine max*) is an exotic species in Brazil, originally from China. The first studies in Southern Brazil were conducted at the *Estação Experimental de Pelotas* for adaptation of cultivars in Rio Grande do Sul. After the first hybridizations were carried out at the *Instituto de Pesquisas Agropecuárias do Sul* main objective was to obtain tolerance to pests and diseases (SEDIYAMA et al., 1999). Due to its global importance in human and animal nutrition, with its grains rich in proteins and macro and micronutrients (LORO et al., 2021), its development and expansion are in great ascendance. Brazil is the largest producer of soybeans worldwide; in the 2020/21 season, it reached a production of 135.9 million tons and a productivity of 3,529Kg ha^{-1} of grains (CONAB, 2021). While soybean stands out in the market and in the field, it still requires professionals to improve it.

At each harvest, growers look for better soybean yields. Hence, research on the breeding of the crop, advances in technologies, and efficient management to enhance the performance of genotypes are needed. The interaction between breeding, cultural practices and technology development is responsible for maintaining productivity, whose function is to solve the biotic and abiotic limitations that interfere with gene expression for productivity (SZARESKI et al., 2015). In research on soybean breeding, a broad capacity to adapt in relation to its cycle was sought to acclimate to different climatic conditions, different types of soil, and tolerance to diseases and insect attacks to maintain and raise

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productivity. Due to problems with cultivars losing tolerance to diseases and attack of insects, production ends up being economically unfeasible due to high control costs; therefore, it is necessary to develop genotypes with greater tolerance associated with biotechnological events (CARVALHO et al., 2017; CARVALHO et al., 2021).

The hybridizations increase the germplasm by genetic variability. The segregating generations are managed by autogamous plants, which can select the best plants presenting the desired characteristics for new cultivars. Thus, the genotypes resulting from the hybridization must be evaluated to determine if they are able to respond to the expected productivity, quality, and tolerance. Therefore, there is an interest in analyzing new soybean lines that are tolerant to these suppressions and in analyzing other agronomic aspects of each line so that they can indicate adequate management techniques for each one, such as spacing and sowing density (ALMEIDA et al., 1999; SEGATTO, et al., 2022).

Therefore, the possibility of evaluating genotypes, characterizing them aiming to identify regions of best adaptation and their main agronomic characteristics, has been studied. The yield potential of soybean genotypes is determined by their genetic potential and is thus dependent on the growing environment (BONATO et al., 2000). Understanding the linear relationships between soybean genotypes during segregating generations is fundamental for indirect selection, as well as defining selection strategies. Thus, this study aimed to evaluate the performance of agronomic traits of soybean progenies in the segregating generations F1, F2, F3, F4, and F5 and the linear relationships between the characteristics.

Material and methods

Field trials were conducted from 2012 to 2020 in Campos Borges, the State of Rio Grande do Sul. The municipality is located at geographic coordinates 28°53'10''South and 52°59'55''West, at 513 meters of altitude. The climate is characterized as subtropical (Köppen-Geiger climate characterization: Cfa). The soil is classified as a dark red Oxisol (SANTOS et al., 2018).

During 2012/2013, hybridizations were conducted and F1 seeds were obtained. In the following year, they were sown, obtaining in 2014/2015 a total of 134 experimental units. The F2 generation was conducted in the season 2015/2016, totaling 4077 experimental units. The F3 generation was conducted in 2016/2017, totaling 1425 experimental units. The F4 generation was conducted during 2017/2018, totaling 1131 experimental units. The F5 generation was conducted during 2018/2019 totaling 635 experimental units, reaching the F6 generation that was conducted during the 2019/20 season, finally obtaining a total of 5377 experimental units evaluated (Figure 1).

The methodology used to carry out the improvement was the genealogical method, which is the artificial selection

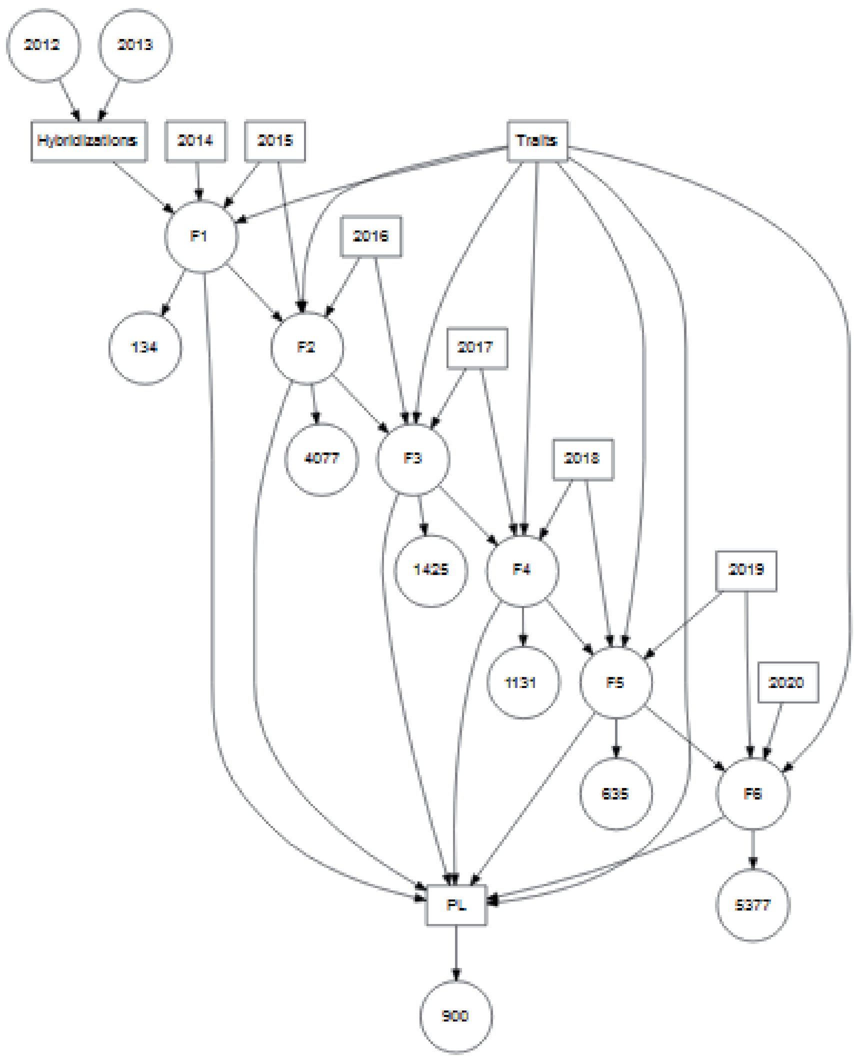

Figure 1. Dynamic schematic representation of the breeding process during all years of research, referring to the specific years that the hybridizations were carried out and in which year each segregating generation of F1, F2, F3, F4, F5, and F6 were conducted. Demonstration of the number of experimental units in each generation and the number of progeny testing performed. Campos Borges, state of Rio Grande do Sul, Brazil

Figura 1. Representação esquemática dinâmica do processo de melhoramento durante todos os anos de pesquisa, referindo-se aos anos específicos em que as hibridizações foram realizadas e em que ano cada geração segregante de F1, F2, F3, F4, F5 e F6 foi conduzida. Demonstração da quantidade de unidades experimentais em cada geração e a quantidade de testes de progênie realizados. Campos Borges, RS, Brasil of individual plants by the progeny test. This method involves crossing between parents, obtaining the F1 seed, which was carried out in a greenhouse. From the F1 seed, sowing has already been carried out under normal environmental conditions. In the F2 generation, a light pressure to select the best plants was started. Each selected plant was individualized, harvested, and placed in a separate bag, performing the progeny test. In F3, high selection pressure was performed and the selected individuals underwent a new progeny test. In F4, families were built and, within the line, the best plant was selected to advance generation. Finally, in F5, each line was harvested separately from the others. As this generation resulted in a small number of seeds, the advance of a generation was determined to obtain a greater quantity of seeds to have enough seeds to carry out the preliminary internal tests (CARVALHO et al., 2022). The experimental units consisted of a three-meter-long sowing row with a density of 15 plants per linear meter spaced 50 centimeters between rows. The sowing was conducted in a direct sowing system, seeking to be carried out on November 10th of each year, with a base fertilization of 250Kg ha^{-1} N-P-K in the 10-20-20 formulation.

The characters of agronomic interest were measured on the ten randomly collected plants using the measures of: first pod insertion height (FPI, cm); plant height (PH, cm); number of pods on the main stem (NPMS, units); number of pods on the branches (NPB, units); number of branches (NB, units); number of pods with one seed (NP1, units); number of pods with two seeds (NP2, units); number of pods with three seeds (NP3, units); number of pods with four seeds (NP4, units); seed mass per plant (SMP, grams), in which plants were subjected to individual husking and cleaning, and only seeds considered viable were subjected to mass measurement and placed at 13% moisture; cycle (CYCLE, days); segregating generation (GEN), consisting of five generations, F1, F2, F3, F4, F5, and F6; integument color (IC), determined in brown or yellow; Hilum color (HI), classified into perfect black, black, brown, and yellow; integument damage (ID); halo color (HA), comprising yellow, brown, and black; seed shape (SS), classified as oblong, spherical, and elliptical; green seeds (GS), meaning the presence or absence of green seeds in each sample; purple spot (PS), meaning the presence or absence of purple spot in each sample; presence of fungus (PF), meaning the presence or absence of fungi in each sample; physical damage level (PD, %), evaluated by visually observing the damage severity in the seed band and classified as high, medium, and low; stink bug damage (BD), classified by visually observing whether or not it was present; seed size (SI), identified between small and large; and moisture damage (MD), which identified the absence or presence of moisture damage (CARVALHO et al., 2022).

In all generations of this study, the families were designed in lines and intercalary controls. The data obtained in all segregating generations (F1, F2, F3, F4, F5, and F6) and in pure lines were subjected to a previous analysis to identify outliers. The arithmetic mean and the sampling variance of each characteristic in its respective segregating generation were calculated, which was called *a priori*. Due to the discrepant number of samples in each segregating generation, Bayesian inference was used with the Markov chain Monte Carlo method (MCMC) using a Gibbs sampler. First, *a priori* distributions of the phenotype value of each progeny in each segregating generation were constructed. These distributions were obtained by phenotypic information. The posterior distribution was obtained with 10000 observations. In order to understand the trend of association between quantitative and qualitative characteristics, linear correlation with significance based on 5% probability was used, as well as linear regressions and parent-offspring linear regressions.

Results and discussion

In the F1 segregating generation *a priori* (Table 1), an average first pod insertion (FPI) of 9 cm was obtained in relation to the soil surface. Follmann (2017) found in his research in northwestern Rio Grande do Sul that the smallest first pod insertion in varieties was 9cm, and the largest insertion was 20.15cm, and the average of 18 cultivars was 13.2cm. The plant height (PH) obtained in this study was 45cm, while Meira et al. (2015) obtained plant height oscillation between 30 and 40cm. The NPMS was 18cm, the NPB was 6.7 units, and the number of branches (NB) had an average of 0.97. The number of pods with one, two, three, and four seeds (NP1, NP2, NP3, and NP4) was 5.1, 11.0, 8.2, and 0.11 pods, respectively. Ferrari et al. (2014) found that the number of pods ranged from 45 to 49 pods, while the grain mass per plant (GMP) was 11.37 grams. For Ferrari, the grain mass per plant ranged from 10 to 12 grams; the same results were found by Souza et al. (2015). *A posteriori* information (Table 2) had FPI results: 9.8; PH: 44.9; NPMS: 18.7; NPB: 6.8; NB: 0.9; NP1: 5.1; NP2: 11.0; NP3: 8.2; NP4: 0.11; GMP: 11.3.

The first pod insertion had a positive variation of 1.7cm. Plant height had a positive variation of 34.48cm compared to the sample number. The number of pods on the main stem had a positive variation of 21.24cm. The number of pods in the branches had positive results of 12.38 units. The number of branches had a positive deviation of 1.78 units. The number of pods with one, two, three, and four seeds had positive variation with the sample number of 7.9, 15.9, 13.9, and 0.18 pods, respectively. Additionally, the grain mass per plant also had a positive variation and increased by 15.68 grams. No measured variable surpassed the pure lines. In their evaluation of cultivars

Table 1. Mean a priori results and variance obtained for first pod insertion (FPI); plant height (PH); number of pods on main stem (NPMS); number of pods on branches (NPB); number of branches (NB); number of pods containing one seed (NP1); number of pods containing two seeds (NP2); number of pods containing three seeds (NP3); number of pods containing four seeds (NP4); and seed mass per plant (SMP). Campos Borges - RS, 2012 to 2020 seasons. Campos Borges, state of Rio Grande do Sul, Brazil

Tabela 1. Resultados médios a priori e variância obtidos para a inserção da primeira vagem (FPI), altura da planta (PH), número de legumes no caule principal (NPMS), número de legumes nos ramos (NPB), número de ramos (NB), número de legumes contendo uma semente (NP1), número de legumes contendo duas sementes (NP2), número de legumes contendo três sementes (NP3), número de legumes contendo quatro sementes (NP4) e massa de sementes por planta (SMP). Campos Borges - RS, temporadas 2012 a 2020. Campos Borges, RS, Brasi

Homozygous Level	Heterozygous Level	*A priori* information										
		FPI (cm)			PH (cm)		NPMS (un)		NPB (un)		NB (un)	
		n	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.00%	100.00%	134	9.78	23.68	45.02	336.32	18.82	127.52	6.87	131.28	0.97	1.65
50.00%	50.00%	4077	18.69	40.94	78.63	304.33	32.39	75.80	33.65	1627.66	3.31	2.55
75.00%	25.00%	1425	13.43	48.95	71.73	605.25	29.98	160.91	32.85	1057.44	3.70	8.57
87.50%	12.50%	1131	17.25	91.95	71.76	303.88	24.02	185.57	14.14	555.90	1.74	4.00
93.75%	6.25%	635	21.44	43.11	84.85	235.53	20.33	55.60	18.63	314.62	3.05	3.63
96.87%	3.12%	5377	.	.	.	.	.	.	.	.	.	.
100.00%	0.00%	900	16.85	46.89	78.45	285.55	30.90	31.75	36.01	1943.67	4.37	16.08
Homozygous Level	**Heterozygous Level**	**NP1 (un)**			**NP2 (un)**		**NP3 (un)**		**NP4 (un)**		**SMP (grams)**	
		n	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.0 0%	100.00%	134	5.11	17.70	11.06	71.46	8.29	54.88	0.11	0.10	11.37	69.49
50.00%	50.00%	4077	11.96	56.56	31.23	664.03	23.57	402.42	0.26	0.14	25.45	410.77
75.00%	25.00%	1425	9.56	57.02	29.34	410.47	22.98	325.83	0.05	0.09	18.82	171.28
87.50%	12.50%	1131	5.43	39.13	14.98	183.25	13.42	228.35	0.20	0.40	13.12	169.21
93.75%	6.25%	635	5.61	18.87	20.73	97.10	12.79	84.44	0.08	0.11	10.05	21.66
96.87%	3.12%	5377	.	.	.	.	.	.	.	.	2.99	2.39
100.00%	0.00%	900	11.53	64.79	28.79	267.54	27.09	346.99	0.12	0.02	23.08	123.49

in off-season, Meier et al. (2019) found oscillations for plant height from 33 to 65cm, for first pod insertion from 9 to 16cm, and for the number of pods with two seeds from 7 to 11 units. The number of pods with three and four seeds varied from 7 to 14 units and from 0.08 to 0.66 respectively. The mass of seeds per plant ranged from 6 to 9 grams.

For all the characteristics, the lowest magnitudes are evident in the F1 generation, except for NP4 and SMP. The expression of the characteristics oscillate as the generations advance. The height of the pod insertion has greater magnitudes in the F5 generation. However, with 100% homozygosity, the value observed is closer to 16.85cm, which is the agronomic ideal. This value corroborates those found by Follmann et al. (2017) when studying commercial soybean genotypes. Furthermore, it is noteworthy that, as expected, the lowest variance of this characteristic is observed in the F1 generation, in which there is greater homogeneity since the genes did not recombine.

Some studies, such as that by Zuffo et al. (2018), showed a linear relationship between the height of the first pod insertion and plant height. This explains the same trends observed in

Table 2. Mean a posteriori results and variance obtained for first pod insertion (FPI, cm); plant height (PH, cm); number of pods on main stem (NPMS, un); number of pods on branches (NPB, un); number of branches (NB, un); number of pods with one seed (NP1, un); number of pods with two seeds (NP2, un); number of pods with three seeds (NP3, un); number of pods with four seeds (NP4, un); and seed mass per plant (SMP, un). Campos Borges - RS, 2012 to 2020 seasons. Campos Borges, state of Rio Grande do Sul, Brazil

Tabela 2. Resultados médios a posteriori e variância obtidos para a inserção da primeira vagem (FPI, cm), altura da planta (PH, cm), número de vagens no caule principal (NPMS, un), número de vagens nos ramos (NPB, un) , número de ramos (NB, un), número de vagens com uma semente (NP1, un), número de vagens com duas sementes (NP2, un), número de vagens com três sementes (NP3, un), número de vagens com quatro sementes (NP4, un) e massa de sementes por planta (SMP, un). Campos Borges - RS, temporadas 2012 a 2020. Campos Borges, RS, Brasil

Homozygous Level	Heterozygous Level	N	*A posteriori* information									
			FPI (cm)		PH (cm)		NPMS (un)		NPB (un)		NB (un)	
			Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.00%	100.00%	10000	9.84	16.39	44.98	1.19	18.79	0.45	6.84	0.46	0.96	0.005
50.00%	50.00%	10000	18.77	28.34	78.47	316.04	32.31	78.71	33.28	1690.29	3.29	2.65
75.00%	25.00%	10000	13.51	33.88	71.55	158.09	29.89	42.03	32.63	276.20	3.68	2.23
87.50%	12.50%	10000	17.36	63.65	71.66	0.80	23.94	0.49	14.01	1.47	1.73	0.01
93.75%	6.25%	10000	21.51	29.84	85.08	144.69	20.45	34.15	18.90	193.28	3.08	2.23
96.87%	3.12%	10000	.	.	.	.	.	.	.	.	.	.
100.00%	0.00%	10000	16.93	32.46	78.64	85.09	30.97	9.46	36.51	579.20	4.41	4.79
Homozygous Level	Heterozygous Level	N	NP1 (un)		NP2 (un)		NP3 (un)		NP4 (un)		SMP (grams)	
			Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.00%	100.00%	10000	5.10	0.06	11.04	0.25	8.27	0.19	0.11	0.0003	11.35	0.24
50.00%	50.00%	10000	11.89	58.74	30.99	689.58	23.39	417.91	0.26	0.15	25.26	426.58
75.00%	25.00%	10000	9.51	14.89	29.20	107.21	22.85	85.10	0.05	0.02	18.73	44.73
87.50%	12.50%	10000	5.40	0.10	14.91	0.48	13.34	0.60	0.20	0.001	13.05	0.44
93.75%	6.25%	10000	5.67	11.59	20.88	59.65	20.88	59.65	0.09	0.06	10.12	13.31
96.87%	3.12%	10000	.	.	.	.	.	.	.	.	3.01	0.71
100.00%	0.00%	10000	11.62	19.30	28.97	79.72	27.30	103.40	0.12	0.008	23.10	16.17

the expression of plant height. NPMS ranged from 18.82 to 32.39 in the F1 and F2 generations, respectively. However, with 100% homozygosity, the characteristic had an average of 30.9, indicating that it is already possible to see trends of this characteristic in the average of the F2 generation.

Similar trends are observed in the NPB and NB traits, with the highest magnitudes of both characteristics being observed when plants exhibited 100% homozygosity. Balbinot Junior et al. (2015) showed an average of 17.2 vegetables per branch. Zuffo et al. (2018) observed that the number of legumes is directly related to soybean grain yield. Thus, plants with 100% homozygosity have a high potential for number of legumes per branch and, consequently, tend to maximize grain yield and compensatory capacity.

The genotypes in the F1 segregating generation showed similar phenotypic trends in the expression of NP1, NP2, and NP3, as well as the lowest phenotypic variance. The highest magnitudes were observed in the F2 generation for NP1 and NP2, similar to the generation with 100% homozygosity. This indicates that it is possible to see plants with greater potential for phenotypic expression of these characteristics in the F2 generation. On the other hand, NP3 had its expression potentiated when plants were 100% homozygous.

The lowest variances within each segregating generation are observed for the NP4, which ranged from 0.09 to 0.4. This is evident since there is a lower expression of this characteristic among soybean genotypes. Thus, the smallest number of NP4 contributes to the lowest phenotypic variance. Due to this lower variance, the means of this characteristic do not exhibit large magnitudes, showing that the developed genotypes have low tendencies to express a high NP4.

The highest potential of SMP was evident in the F2 generation, although very similar to that expressed by plants when they were 100% homozygous. Thus, we may infer that it is possible to practice selection already in the F2 generation for this characteristic. Moreover, SMP has a strong correlation with grain yield (SMIDERLE et al., 2019), making it possible to carry out indirect selection.

The F1 segregating generation showed a large difference in PH compared to the pure lines, which were 45cm and 78.4cm, respectively. The characteristic surpassed the control in the F5 segregating generation (84.8cm), which may be linked to the variation in the growing environment. The ideal PH for good seed production and reduced losses from mechanized harvesting is 60 to 80cm (ALMEIDA et al., 2011). The PH has broad sense heritability (H^2; 0.95), demonstrating high genetic variation (CARVALHO et al., 2017).

NPMS was smaller in the F1 generation and increased abruptly in F2, presenting 32.3 units and surpassing the number of pure lines (30.9 units). The graph shows no variation between *a priori* and *a posteriori* information, only between generations. Oliveira et al. (2015) obtained an amount of 60 pods per plant in their study. Szareski et al. (2015) concluded that NPMS was positively correlated with NPB, NB, length of branches, NP1, NP2, NP3, and grain yield. The percentage of total carbohydrates was inversely proportional to NPMS. Since NPMS is a factor directly linked to productivity, its increase in genotypes that do not present branches becomes very important.

NPB, despite having a smaller number compared to NPMS, has a fundamental role in increasing the grain yield by increasing the number of pods per plant and consequently the grain yield. However, it is dependent on the characteristics of the genotype and the managements used. NPB has great environmental effect and low heritability, making it very difficult for breeders to manipulate it (CARVALHO et al., 2017). There were large variations between generations; as the level of homozygosity increased, the tendency was to approach the control. The segregating generation that stood out the was the F2 generation; however, none surpassed the control, which had 36.0 units.

Despite the variations in each segregating generation, none of them surpassed the average NB of the inbred lines (4.3 branches). NB is a reproductive structure that can be directly and indirectly associated with productivity. Directly, NB contributes to the production of pods and indirectly to the evolution of the leaf area index. This characteristic can be altered according to management, genotype characteristics, and sowing date. The contribution of branches to the LAI starts when the plant has four to six leaves on the main stem, that is, when the branches start to grow on the plant. The branches may have an increase in LAI by 16%, which may vary according to the genetic characteristic of each genotype and environmental variation (ZANON et al., 2018). A survey conducted in northwestern Rio Grande do Sul obtained 1.8 branches per plant from two soybean cultivars with indeterminate growth habit (SZARESKI et al., 2015).

For NP1, there was a linear growth of 11.9 until the F2 generation, surpassing the pure lines, which presented 11.5 pods with one seed. After the F2 generation, there was a persistent decrease until the F5 generation, which had a non-significant increase of 0.2 units. The number of pods present in each plant is characterized as a component of productivity and can be affected by the arrangement of plants. The number of pods formed depends on the number of flowers produced. The number of grains per pod is strongly influenced by genetics and the environment (ZANON et al., 2018).

As NP2 progressed, the segregating generations had an increase in the number of pods, surpassing the control in F3, decreasing in F4, and increasing in F5, tending to approach to pure lines in the next generations. There was a difference in the *a priori* and *a posteriori* information regarding NP3 when the number of experimental units was increased to 10000 in the F5 generation. No variance was observed in relation to the number of experimental units. In most generations, there was an overlap in NP4 in relation to the control mean. The F2 segregating generation had the greatest number of four-seeded pods, surpassing the control.

There was an increase and subsequent reduction in grain weight after the F2 generation until the F5 generation. The F2 segregating generation surpassed the control. Grain weight is determined by the genetic potential of soybean, which may be influenced by the environment and management used to express its genetic potential. A total of 190g (thousand seed mass) can enhance productivity (ZANON et al., 2018).

To recognize the trends of linear correlations for the evaluated characteristics and their associations with the F1, F2, F3, F4, and F5 segregating generations, 136 linear associations were performed for the characteristics PHF1, PHF3, P1F1, P1F3, P2F1, P2F3, P3F1, P3F3, P4F2, P4F4, PBF1, PBF3, NPF1, NPF3, NPF4, BF1, BF3.

Of these linear associations, 82 significant correlations were obtained, of which 76 had a positive coefficient and 6 had a negative coefficient. PHF1 had a positive influence on P1F1, P2F1, P3F1, PBF1, NPF1, and NBF1. Plants that had greater PHF1 provided a greater P1F1, P2F1, and P3F1 and, consequently, tended to have greater PBF1, NPF1, and BF1. Follmann et al. (2017) verified that there was a positive correlation between plant height and production; it is expected that larger genotypes present associations with higher yields.

PHF3 was positively correlated with P1F3, P2F3, and P3F3 and had a positive association for PBF3, NPF3, and NBF3. Therefore, plants that had greater PHF3 provided a greater P1F3, P2F3, and P3F3 and had an increase in PBF3, resulting in greater NPF3 and BF3. P1F1 had a positive association with P2F1 and P3F1, and consequently presented a greater PBF1, NPF1, and BF1. Thus, when P1F1 increases, P2F1 and P3F1 increase, in addition to being associated with an increase in PBF1, NPF1, and BF1.

P1F3 was positively correlated with P2F3 in the same generation and had a positive correlation with PBF3, NPF3, and BF3. Thus, as P1F3 increases, P2F3 and P3F3 increase in the same generation. Moreover, as P1F3 generation increases, the number of pods in the branches also increases, consequently increasing NPF3 and BF3. P2F1 showed a positive correlation with P3F1 in the same segregating generation and a positive correlation with PBF3, resulting in a positive correlation with NPF3 and BF1. Thus, as P2F1 increases, P3F1, PBF1, NPF1, and BF1 also increase.

P2F3 had a positive correlation with P3F3, NPBF3, NPF3, and BF3. Therefore, when increasing P2F3, there is an increase in P3F3 and NPB in the same generation. For P3F1, there was a positive correlation in the same generation for PBF1, NPF1, and BF1. Therefore, when increasing the number of P3F1 generation, there is an increase in PBF1, NPF1, and BF1 in the same segregating generation. For P3F3, there was a positive correlation for PBF3, NPF3, and BF3 in the same generation. This shows that when P3F3 increases, PBF3, NPF3, and BF3 increase.

P4F4 had a positive correlation with NPF4. Therefore, when P4F4 increase, NPF4 in the same generation increases. For the PBF1 generation, there was a positive correlation for NPF1 and BF1. However, when BF1 increases, the NPF1 generation increases. PBF3 had a positive correlation for NPF3 and BF3 in the same generation. As PBF3 increases, NPF3 and BF3 increase. PBF3 had a positive correlation with NPF3 and BF3. When BF3 increased, NPF3 and PBF3 consequently increased. NPF1 had a positive correlation with BF1. When NPF1 increased, BF1 increased as well. NPF3 showed a correlation with BF3. Therefore, when NPF3 increased, BF3 also increased in the same generation.

An evaluation of the specific quantitative correlation of F3, F4, and F6 generations was carried out in the 2019/20 season, corresponding to a homozygosity levels of 75%, 87.5%, and 96.87% respectively. We observed that when generation (GEN) increases, cycle (CYCLE) decreases and seed mass per plant (SMP) increases. Seed mass per plant had a negative correlation with cycle; thus, when cycle increases, seed mass per plant decreases.

A correlation of the qualitative attributes was performed. We found that the segregating generation had a positive correlation with greenish seeds (GS) and moisture damage (MD); when the generation increased, greenish seeds and moisture damage also increased. Integument color (IC) was negatively correlated with stink bug damage (BD). Hilum color (HI) was negatively correlated with purple spot (PS) and positively correlated with halo color (HA). Seed shape (SS) was negatively correlated with moisture damage (MU) and stink bug damage (BD), and positively correlated with presence of fungus (PF). Greenish seeds (GS) was negatively correlated with seed size (SI) and level of physical damage (PD). Level of physical damage (PD) had a positive correlation for moisture damage (MD), seed size (SI), and stink bug damage (BD).

A relation of the F3, F4, and F6 generations for seed mass per plant (SMP) and cycle (CYCLE) in days was performed. In F3, when plants had 75% homozygosity, seed mass per plant was lower when the cycle was increased. In F4, when plants were at a homozygous level of 87.5%, seed mass behavior was stable with a small increase in seed mass per plant when the cycle was increased. Seed mass per plant in F6 showed a decrease when the cycle was longer; the most productive lines had a cycle of 100 to 110 days, most lines had their cycle of 120 to 135 days and the less productive had their cycle of 145 to 165 days.

Plant breeding is based on management and selection methods, in addition to phenotype measurements that quantify characteristics of interest influenced by non-additive and additive genetic effects, and even by the environment. To verify genetic heritability, progeny regression was performed and showed that broad sense heritability had a high correlation for the characteristic first pod insertion compared to plant height; number of pods on the main stem; number of pods in branches; number of ramifications; number of pods with one, two, three, and four seeds; and grain mass per plant. Thus, the first pod insertion was highly influenced by environmental action. Follmann et al. (2017) report that late sowing when there is a reduction in the photoperiod can interact with phenotype expression, reducing first pod insertion, plant height, hundred grain mass and, consequently, productivity.

Regarding the evaluated characteristics, the F2 segregating generation showed the greatest oscillation, surpassing the pure lines for first pod insertion (FPI, cm); number of pods on the main stem (NPMS, un); number of pods with one seed (NP1, un); number of pods with two seeds (NP2, un); number of pods with four seeds (NP4, un); and seed mass per plant (SMP, g). Plant height (PH, cm) had lower mean fluctuations during the segregating generations and high correlations with productivity components: number of pods with one seed, number of pods with two seeds, and number of pods with three seeds. Seed shape (SS) was linked to the presence of storage fungi; the presence of green seeds increased as segregating generations progressed. Hilum color modification (HI) influenced the halo color (HA) but decreased the incidence of purple spot (PS). Integument color influenced the reduction of damage caused by bugs (BD). Longer cycle genotypes had lower seed mass per plant (SMP) in the F6 segregating generation.

Conclusions

Indirect selection of soybean genotypes for high grain mass per plant can be performed indirectly by cycle duration.

Plants with a higher number of pods can be selected indirectly by the number of pods with one, two, and three grains in the F3 generation.

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