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Correlation between productive components and grain yield of soybean cultivars sown in the northwest region of Rio Grande do Sul

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ABSTRACT

Considering the expressive number of commercial soybean cultivars available for cultivation in Brazil and the constant search for improvements in the production system, the objective was to evaluate the productive components and grain yield and to estimate the correlation between them in soybean cultivars sown in the northwest region of Rio Grande do Sul, during the 2019/20 harvest. Sixteen commercial soybean cultivars were sown under their respective plant density recommendations, in a randomized block design with three replications. At the end of the cultivation cycle, the following variables were evaluated: plant height; height of insertion of the first pod; number of nodes; number of pods with one, two, three and four grains; pods per plant; grains per plant; weight of thousand grains, and; grain yield. The cultivars BMX ZEUS IPRO, NS 5445 IPRO and NS 5700 IPRO presented the highest grain yields, mainly due to the high relationship between the number of pods and grains per plant and the weight of a thousand grains. The indirect selection of more productive genotypes can be carried out through the variables weight of thousand grains, number of pods, grains and nodes per plant, given the significant positive correlation between them.

Keywords: *Glycine max*; indirect selection; plant morphology.

INTRODUCTION

Soybean [*Glycine max* (L.) Merril] is the principal oilseed grown in the world, primarily due to the high socio-economic importance it performs in agroindustrial sectors. In Brazil, the production of the commodity has increased expressively during the last decades, so that the country has become the world's largest producer of the crop (USDA, 2023), with its production estimated at more than 153 million tons for the 2022/23 harvest (CONAB, 2023).

Among the improvements observed in the production system of the Southern Region of Brazil, we highlight the increase in the use of modern cultivars, characterized by indeterminate growth habit and early cycle (Richter *et al.*, 2014; Zanon *et al.*, 2015). As well as, the adoption of important management technologies related to phytosanitary control, adoption and maintenance of soil conservation practices, use of cultivars more adapted to the macro-regions of cultivation, efficient management of fertilizers and correctives, in addition to cultivation under adequate plant density and arrangement, with high quality seeds (Cruz *et al.*, 2016). From this perspective, it is evident that the joint adoption of appropriate management practices and the use of cultivars with high productive potential was decisive in making Brazil an international power in soybean production.

However, due to the increase in crop production costs over the last few years, it has become common to look

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for cultivars with high production potential and adapted no longer to macro-regions of cultivation, but to micro-regions, in order to optimize the crop production system and increase profitability per unit area. Thus, given the large number of cultivars available for cultivation in each of the macro-regions and the annual launch of new genotypes, which tend to be more productive and resistant to biotic and abiotic stresses, it is interesting to carry out studies on the adaptability and productivity of new soybean cultivars in micro-regions to define the best option for farmers (Gaviraghi *et al.*, 2018).

The selection of superior soybean genotypes is indeed a complex process, and most of the characters are quantitative and correlated with each other (Leite *et al.*, 2018). To select the best genotypes, it is necessary to analyze the characters simultaneously during the selection process. Genetic parameters and correlations are useful tools in breeding programs, helping to make decisions about the most efficient method of selecting soybean progenies (Gastl Filho *et al.*, 2022).

In this perspective, strategies such as the evaluation of productive components and the correlation between them have been carried out to serve as a basis for the indirect selection of genotypes based on the agronomic ideotype, as well as to recommend cultivars for cultivation under certain edaphoclimatic conditions (Almeida *et al.*, 2010; Nogueira *et al.*, 2012; Rigon *et al.*, 2012; Leite *et al.*, 2015; Follmann *et al.*, 2017; Ferreira *et al.*, 2022; Souza *et al.*, 2023).

Various studies reported the dependence of grain yield on the performance of the crop's productive components (Ciampitti & Vyn, 2012; Dutamo *et al.*, 2015; Cao *et al.*, 2020; Xavier & Rainey, 2020; Yoosefzadeh-Najafabadi *et al.*, 2021). In soybeans, characteristics such as the number of nodes per plant, number of pods per plant, number of grains per pod, number of grains per plant and weight of 100 grains have been considered to be the main contributors to grain yield, most of the time, showing strong positive correlations with each other (Cui & Yu, 2005; Egli, 2005; Kahlon & Board, 2012; Egli, 2013; Baraskar *et al.*, 2014; Rincker *et al.*, 2014; Islam *et al.*, 2015; Ghiday *et al.*, 2017; Xavier & Rainey, 2020; Yoosefzadeh-Najafabadi *et al.*, 2021; Ferreira *et al.*, 2022; Souza *et al.*, 2023).

The objective was to evaluate the productive components and grain yield and to estimate the correlation between them in soybean cultivars sown in the northwestern region of Rio Grande do Sul, during the 2019/20 harvest, in order to suggest cultivars with characteristics capable of conferring higher grain yields in this growing micro-region.

MATERIAL AND METHODS

The study was conducted in an experimental area located in Santo Augusto, Rio Grande do Sul, Brazil (27º52'28" S latitude, 53º49'57" W longitude and 492 m of altitude), during the 2019/20 harvest. The region is characterized by a humid subtropical climate (Cfa) (Alvares *et al.*, 2014) and the presence of soils characterized as Latossolic Dystrophic Red Nitosol (Cunha *et al.*, 2004). The chemical characteristics of the soil in the experimental area are presented in Table 1. The rainfall recorded during the experimental period (November 20th, 2019 to March 21st, 2020) was approximately 470 mm (Figure 1).

Sixteen commercial soybean cultivars were used for the experiment (Table 2), each of which was sown according

Table 1: Chemical analysis of the soil in the experimental area at a depth of 0-20 cm

pH water	Ca	Mg	Relation Ca/Mg	Al	H + Al	CTC effective	Saturation (%)		Index SMP
	Cmolc dm^{-3}			Cmolc dm^{-3}			Al	Bases	
5.66	9.5	3.7	2.6	0.0	4.0	14.1	0.0	77.7	6.08

Diagnosis for soil acidity and liming: pH in water 1:1; Ca, Mg, Al and Mn exchangeable extracted with KCl 1M and CTC apH 7.0 (Tedesco *et al.*, 1995); Index SMP (Toledo *et al.*, 2012).

% MO	% Clay	S	P-Mehlich	K	CTC pH 7.0	K
m/v		mg dm^{-3}		Cmolc dm^{-3}		mg dm^{-3}
6.8	60.0	13.9	14.9	0.857	18.1	335.1

Diagnosis for macronutrients and recommendation of fertilization NPK-S: Clay determined by the densimeter method; Mo by humid digestion; $S-SO_4$ extracted with $CaHPO_4$ 500 mg L^{-1} of P and P, K and Na determined by the method Mehlich I (Tedesco *et al.*, 1995).

Cu	Zn	Molar relations			
mg dm^{-3}		K/CTC	Ca/CTC	Mg/CTC	(Ca + Mg)/K
8.8	1.4	4.735	52.5	20.4	15.4

Diagnosis for micronutrients and molar relations: Cu and Zn extracted using the method Mehlich I (Embrapa, 2009).

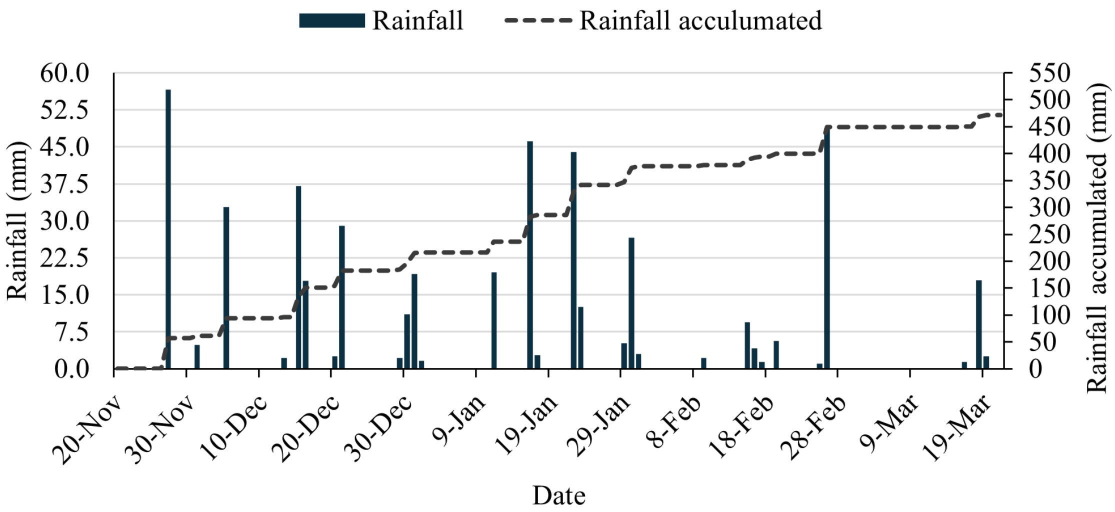

Figure 1: Rainfall regime recorded during the experimental period (November 20th, 2019 – March 21st, 2020) in Santo Augusto, Rio Grande do Sul, Brazil.

to the plant density recommended for the region (Table 3). The experimental design used was randomized block with three repetitions. The seeds of all cultivars received the industrial seed treatment Fortenza® Duo (Fortenza 600 FS® + Cruiser® 600 FS + Maxim Advanced®) and, subsequently, at the time of sowing, the seeds were inoculated with *Bradyrhizobium japonicum* and co-inoculated with *Azospirillum brasilense* strains AbV5 and AbV6.

Sowing was carried out on November 20th, 2019 in a mechanized way under the no-tillage system, with a seeding speed of ± 6 km h^{-1}, seeding depth of ± 4 cm and row spacing of 45 cm. We used 270 kg ha^{-1} of fertilizer with formulation 2-23-23 (N-P_2O_5-K_2O) in the line of sowing and, later, 20 days after emergence, we applied 120 kg ha^{-1} of KCl (60% K_2O). The size of the plots was 3.15 × 10 meters. The cultural management was carried out with the use of fungicides and insecticides recommended for the crop, when necessary.

The harvest of the plots was performed on March 21st, 2020 (phenological stage R8), by manually uprooting the plants present in 0.90 m^2 of the central area of the plots. The evaluation of the productive components was carried out individually on the harvested plants, being evaluated: Plant height, in cm (PH); Insertion height of the first pod, in cm (IHFP); Number of nodes, in units (NN); Pods with one grain, in units per plant (P1G); Pods with two grains, in units per plant (P2G); Pods with three grains, in units per plant (P3G); Pods with four grains, in units per plant (P4G); Pods per plant, in units (PP); Grains per plant, in units (GP); Weight of thousand grains, in grams (WTG), and; Grain yield, in kg ha^{-1} (GY). The humidity content (%) of the grains was measured with the aid of an Agrologic portable grain humidity measuring device (model AL-102 ECO), with an accuracy of 0.1%. Thus, at the time of the statistical analysis, the WTG and GY variables had their values standardized at 13% of humidity.

For each variable, the components of variance were estimated using the mathematical model of the randomized block design, given by:

$$Yij = \mu + Ci + \beta j + \varepsilon ij$$

Where Y_{ij} is the mean observed value for the response variable in plot *ij*, μ is the overall mean, C_i is the effect of cultivar *i* (*i* = BMX LANÇA IPRO, BMX ZEUS IPRO, BRS 5601 RR, DM 53I54 RSF IPRO, FPS 1859 RR, M5838 IPRO, NEO 610 IPRO, NEO 660 IPRO, NA 5909 RG, NS 5258 RR, NS 5445 IPRO, NS 5700 IPRO, NS 6010 IPRO, NS 6601 IPRO, NS 6909 IPRO, P95Y52 RR), β_j is the effect of block *j* (*j* = 1, 2, 3), ε_{ij} is the effect of experimental error (Storck *et al.*, 2016). From the significance of the factor under study, the grouping of means was performed using the Scott-Knott test at 5% probability for cultivars. Finally, we calculated the coefficient of Pearson's linear correlation between the productive components (PH, IHFP, NN, P1G, P2G, P3G, P4G, PP, GP and WTG) and

Table 2: Description of the agronomic characteristics of the cultivars used

Cultivar	Relative Maturity Group	Requirement to fertility	Technology[(1)]
BMX LANÇA IPRO	5.8	High	IPRO
BMX ZEUS IPRO	5.5	High	IPRO
BRS 5601 RR	5.6	High	RR
DM 53I54 RSF IPRO	5.4	High	IPRO
FPS 1859 RR	5.9	Medium/High	RR
M5838 IPRO	5.8	High	IPRO
NEO 610 IPRO	6.1	High	IPRO
NEO 660 IPRO	6.6	Medium	IPRO
NA 5909 RG	6.2	Medium/High	RG
NS 5258 RR	5.6	Medium/High	RR
NS 5445 IPRO	5.4	High	IPRO
NS 5700 IPRO	5.7	High	IPRO
NS 6010 IPRO	6.0	Medium/High	IPRO
NS 6601 IPRO	6.6	Medium/High	IPRO
NS 6909 IPRO	6.3	Medium/High	IPRO
P95Y52 RR	5.3	High	RR

(1) IPRO: Technology with addition of *Bt* protein (*Cry1Ac*) that provides resistance to *Anticarsia gemmatalis*, *Chrysodeixis includens*, *Crocidosema aporema* and *Chloridea virescens*; RR and RG: Technology that provides resistance to herbicides of the 5-enolpyruvylshikimate-3-phosphate synthase group (EPSPs), also known as Glyphosate. Source: Brasmax®, Embrapa®, DonMario®, Fundação Pró-Sementes®, Monsoy®, Neogen®, Nidera® and Pioneer®.

grain yield (GY) and performed a paired hypothesis test for each of the correlations under study at 5% probability. All analyses were performed with the use of the software Microsoft Office Excel and R (R Development Core Team, 2022).

RESULTS AND DISCUSSION

The experimental precision ranged from high to very low (4.17% ≤ CV ≤ 57.32%), according to the classification of Pimentel-Gomes (2009), depending on the variable evaluated (Table 4).

The use of cultivars suitable for the cultivation environment is fundamental for the maximization of grain yield. Thus, during the choice of a cultivar, both its morphological and productive characteristics, as well as its history in the growing environment, should be taken into account (Cruz *et al.*, 2010). Factors such as sowing time, population density and soil and climatic conditions can promote changes in plant characteristics and, consequently, in grain yield (Rocha *et al.*, 2012).

Thus, the use of cultivars with plant height between 50 and 90 cm has been suggested when aiming for high grain yield (Sediyama *et al.*, 2015). In addition, this characteristic facilitates weed control through the greater interspecific competition provided by the height of the crop in relation to weeds, being also favorable for the reduction of lodging and losses during mechanized harvesting (Pires *et al.*, 2012). In general, the average plant height observed was 97.79 cm, with the highest plant heights observed in the cultivars NEO660 IPRO and NS 5258 RR (113.99 and 111.19 cm, respectively) and the lowest in the cultivars FPS 1859 RR, M5838 IPRO, NEO610 IPRO and NS5445 IPRO (89.07, 89.52, 90.63 and 91.51 cm, respectively) (Table 3).

According to Aquino *et al.* (2011), the insertion height of the first pod is associated with losses during harvest, so that when it is less than 10 cm there is potentiation of the loss rate. Thus, the selection of plants with insertion height of the first pod ranging from 10 to 15 cm has been recommended by breeding programs to help reduce losses during harvest (Sediyama *et al.*, 2015; Cruz *et al.*, 2016). However, as the expression of the phenotype occurs as a function of the interaction genotype × environment, variations are generally observed due to the edaphoclimatic conditions of the micro-region and cultural practices used (Torres *et al.*, 2015). Thus, the average insertion height of the first pod was 13.37 cm, with only the cultivars NEO 610 IPRO, P95Y52 RR, BMX LANÇA IPRO, NS 5700 IPRO, BMX ZEUS IPRO and NA 5909 RG falling within the ideal range suggested by Sediyama *et al.* (2015) and Cruz *et al.* (2016) (Table 4).

Table 3: Recommended, sown and emerged density (in thousand plants ha^{-1}) for soybean cultivars sown during the 2019/20 harvest in Santo Augusto, Rio Grande do Sul, Brazil

Cultivar	Recommended density (in 1000 plants ha^{-1}) (1)	Sown density (in 1000 plants ha^{-1})	Emerged density (in 1000 plants ha^{-1})
BMX LANÇA IPRO	200 – 250	± 330	± 257
BMX ZEUS IPRO	250 – 300	± 330	± 259
BRS 5601 RR	200 – 300	± 348	± 258
DM 53I54 RSF IPRO	220 – 300	± 330	± 223
FPS 1859 RR	240 – 280	± 348	± 268
M5838 IPRO	240 – 280	± 330	± 246
NEO 610 IPRO	220 – 300	± 271	± 223
NEO 660 IPRO	180 – 250	± 271	± 206
NA 5909 RG	200 – 320	± 331	± 270
NS 5258 RR	240 – 300	± 303	± 250
NS 5445 IPRO	260 – 320	± 331	± 230
NS 5700 IPRO	240 – 280	± 331	± 263
NS 6010 IPRO	220 – 260	± 331	± 281
NS 6601 IPRO	200 – 240	± 271	± 225
NS 6909 IPRO	220 – 300	± 348	± 261
P95Y52 RR	320 – 380	± 396	± 225

(1) Density of plants recommended for the Soybean Macro-region 103. Source: Brasmax®, Embrapa®, DonMario®, Fundação Pró-Sementes®, Monsoy®, Neogen®, Nidera® and Pioneer®.

Given that the number of nodes per plant is defined by intrinsic factors of the cultivar, management system and edaphoclimatic conditions of the growing environment (Egli, 2013), the higher number of nodes observed in the cultivars NS6601 IPRO, NEO660 IPRO, NEO610 IPRO and NS 6601 IPRO can be attributed to their long cycle, which allowed the vegetative growth period to be longer than that of early cultivars (Tables 2 and 4). The high number of nodes observed in the cultivars M5838 IPRO, FPS 1859 RR, DM53I54 RSF IPRO, NS5700 IPRO and P95Y52 RR is associated with the regularity of rainfall during the vegetative growth period and the genetic characteristics of the cultivars (Figure 1, Tables 2 and 4).

The yield of pods with one grain was low in all cultivars, however, cultivars NA 5909 RG, NEO 610 IPRO, DM 53I54 RSF IPRO and BMX LANÇA IPRO stood out from the others. The number of pods with two grains ranged between 5.50 and 20.80 pods per plant (BMX ZEUS IPRO and NEO610 IPRO, respectively), with the cultivars NS 610 IPRO, FPS 1859 RR, M5838 IPRO and BMX LANÇA IPRO presenting the highest productions of these. The production of pods with three grains ranged from 24.70 to 52.55 pods per plant (BRS 5601 RR and NS 5700 IPRO, respectively), with the cultivars NS 5700 IPRO, NEO 660 IPRO, NS 5445 IPRO, NS 6601 IPRO, DM 53I54 RSF IPRO and BMX ZEUS IPRO standing out from the others. The production of pods with four grains was low, however, the cultivars BMX ZEUS IPRO and NEO660 IPRO showed significantly higher values (1.42 and 1.27 pods per plant, respectively) (Table 4).

The number of pods per plant ranged from 41.89 to 66.26 (BRS 5601 RR and NEO 660 IPRO, respectively), with the cultivars NEO 660 IPRO, NS 5700 IPRO, DM 53I54 RSF IPRO, NS 6601 IPRO, M5838 IPRO, NEO 610 IPRO and NS 5445 IPRO standing out from the rest (Table 4). Since most of these cultivars also stood out in the number of nodes, it is plausible to state that the number of pods is limited by the number of nodes. Once the critical number of nodes is reached, pod production (drains) is limited by the supply of photoassimilates (sources) during flowering and pod formation (Andrade *et al.*, 2005; Egli, 2013; Ramos Junior *et al.*, 2019). In addition, as the number of pods per plant is related to the number of grains per plant and, consequently, grain yield, the selection of this variable occurs intensively in breeding programs, thus explaining the small numerical distinctions observed among cultivars (Rigon *et al.*, 2012; Torres *et al.*, 2015).

The number of grains per plant ranged between 93.21 and 174.75 (BRS 5601 RR and NEO 660 IPRO, respectively). The production of grains per plant was directly propor-

Table 4: Abstract of the analysis of variance with the sources of variation (SV), degrees of freedom (DF) and the mean squares of the analysis of variance with the respective significance, coefficient of experimental variation (CV_{exp}, in %) and the means of the variables evaluated in soybean cultivars sown during the 2019/20 harvest in Santo Augusto, Rio Grande do Sul, Brazil

SV	DF	PH[(1)]	IHFP	NN	P1G	P2G	P3G
		Mean Square					
Block	2	1.507^{ns}	43.325*	8.486*	0.064^{ns}	17.498*	129.968^{ns}
Cultivar	15	155.430*	33.176*	4.632*	0.371*	69.189*	210.708*
Error	30	16.612	10.697	1.045	0.092	4.136	42.062
CV_{exp}	(%)	4.17	24.76	5.45	40.89	14.75	17.56
Cultivar		Mean					
BMX LANÇA IPRO		94.00 c	11.68 b	18.35 b	1.01 a	18.81 a	30.09 b
BMX ZEUS IPRO		98.78 c	10.74 b	16.81 b	0.24 b	5.50 d	40.17 a
BRS 5601 RR		95.27 c	17.34 a	17.71 b	0.65 b	16.28 b	24.70 b
DM 53I54 RSF IPRO		98.07 c	8.46 b	19.40 a	1.27 a	14.10 b	41.87 a
FPS 1859 RR		89.07 d	17.79 a	20.31 a	0.50 b	19.81 a	30.36 b
M5838 IPRO		89.52 d	16.46 a	20.08 a	0.83 b	19.26 a	36.80 b
NEO 610 IPRO		90.63 d	13.26 b	19.40 a	1.30 a	20.80 a	34.50 b
NEO 660 IPRO		113.99 a	17.77 a	20.14 a	0.75 b	14.43 b	49.80 a
NA 5909 RG		96.87 c	10.55 b	16.61 b	1.41 a	16.38 b	29.38 b
NS 5258 RR		111.19 a	9.10 b	17.60 b	0.85 b	17.31 b	26.51 b
NS 5445 IPRO		91.51 d	9.58 b	17.49 b	0.35 b	8.01 d	46.03 a
NS 5700 IPRO		94.64 c	10.76 b	19.18 a	0.55 b	11.39 c	52.55 a
NS 6010 IPRO		101.91 b	16.32 a	18.11 b	0.40 b	9.72 c	37.56 b
NS 6601 IPRO		104.76 b	15.88 a	20.30 a	0.73 b	10.17 c	45.60 a
NS 6909 IPRO		96.78 c	15.60 a	19.58 a	0.61 b	10.47 c	31.67 b
P95Y52 RR		97.59 c	12.68 b	18.73 a	0.43 b	8.20 d	33.50 b
Overall Mean		97.79	13.37	18.74	0.74	13.79	36.94

SV	DF	P4G	PP	GP	WTG	GY
		Mean Square				
Block	2	0.065^{ns}	255.614*	1729.223*	134.517^{ns}	664631.1^{ns}
Cultivar	15	0.592*	175.802*	1444.471*	1166.488*	690432.9^{ns}
Error	30	0.064	61.530	395.936	530.124	394552.9
CV_{exp}	(%)	57.32	15.11	15.82	15.72	14.76
Cultivar		Mean				
BMX LANÇA IPRO		0.12 d	50.02 b	119.27 b	152.98 a	4715.23 a
BMX ZEUS IPRO		1.42 a	47.33 b	113.41 b	178.20 a	5080.81 a
BRS 5601 RR		0.26 d	41.89 b	93.21 b	152.70 a	3992.08 a
DM 53I54 RSF IPRO		0.60 c	57.83 a	134.20 a	141.97 a	4200.93 a
FPS 1859 RR		0.81 b	51.47 b	121.92 b	145.01 a	4664.09 a
M5838 IPRO		0.00 d	56.88 a	131.26 a	137.93 a	4575.19 a
NEO 610 IPRO		0.17 d	56.77 a	137.63 a	122.99 a	3759.19 a
NEO 660 IPRO		1.27 a	66.26 a	174.75 a	95.36 a	3297.24 a
NA 5909 RG		0.05 d	47.22 b	110.65 b	136.56 a	4094.98 a
NS 5258 RR		0.53 c	45.20 b	101.61 b	153.27 a	3927.55 a
NS 5445 IPRO		0.48 c	54.88 a	134.87 a	164.74 a	5080.81 a
NS 5700 IPRO		0.26 d	64.76 a	156.68 a	142.75 a	4978.55 a
NS 6010 IPRO		0.15 d	47.84 b	116.69 b	156.08 a	4318.10 a
NS 6601 IPRO		0.83 b	57.33 a	152.10 a	135.76 a	4543.91 a
NS 6909 IPRO		0.11 d	42.86 b	109.53 b	153.82 a	4488.54 a
P95Y52 RR		0.00 d	42.13 b	105.27 b	173.53 a	3927.55 a
Overall Mean		0.44	51.92	125.82	146.48	4352.79

[(1)] PH – Plant height, in cm; IHFP – Insertion height of the first pod, in cm; NN – Number of nodes, in units; P1G – Pods with one grain, in units per plant; P2G – Pods with two grains, in units per plant; P3G – Pods with three grains, in units per plant; P4G – Pods with four grains, in units per plant; PP – Pods per plant, in units; GP – Grains per plant, in units; WTG – Weight of thousand grains, in grams; GY – Grain yield, in kg ha^{-1}. * Indicate significant effect by F test at 5% probability. ^{ns} Indicates non-significant effect. Averages of cultivars not followed by the same lower case letter in the column differed by the Scott-Knott test at 5% probability.

tional to the number of pods per plant observed, since the cultivars NEO 660 IPRO, NS 5700 IPRO, DM 53I54 RSF IPRO, NS 6601 IPRO, M5838 IPRO, NEO 610 IPRO and NS 5445 IPRO resulted in the highest numbers of grains per plant (Table 4). According to the literature, the number of grains per plant is considered a determining factor for the selection of cultivars with high productive potential in breeding programs, in the same way as the number of pods per plant (Cui & Yu, 2005; Kahlon & Board, 2012; Perini *et al.*, 2012; Rincker *et al.*, 2014; Ghiday *et al.*, 2017; Yoosefzadeh-Najafabadi *et al.*, 2021; Ferreira *et al.*, 2022; Souza *et al.*, 2023).

The weight of thousand grains ranged between 95.36 and 178.20 grams (NEO 660 IPRO and BMX ZEUS IPRO, respectively), however, there was no significant difference between cultivars (Table 4). According to Ribeiro *et al.* (2016), the weight of thousand grains is determined genetically, but it can be influenced expressively by the edaphoclimatic conditions of the cultivation environment. However, among the productive components, it is the variable that presents the lowest percentage variation in the face of environmental changes (Ramos Junior *et al.*, 2019). Also, Perini *et al.* (2012) points out that inversely proportional relationships between the weight of thousand grains and the number of grains per plant have been frequently observed in brazilian soybean cultivars.

The grain yield ranged between 3297.24 and 5080.81 kg ha^{-1} (NEO 660 IPRO and BMX ZEUS IPRO, respectively), but there was no significant difference among the cultivars. On the other hand, numerically, the cultivars BMX ZEUS IPRO, NS 5445 IPRO and NS 5700 IPRO showed the highest grain yields (5080.81, 5080.00 and 4978.55 kg ha^{-1}, respectively) due to their high number of grains per plant and weight of thousand grains. In contrast, the low productivity of cultivar NEO 660 IPRO was due to its low weight of thousand grains (95.36 grams), which was the lowest among the cultivars (Table 4). The significant variation in grain yield observed between the cultivars evaluated ($\cong$ 1780 kg ha^{-1}) shows the existence of different levels of adaptability of commercial soybean genotypes to the environmental conditions of the micro-region under study, which reinforces the importance of conducting comparative studies between cultivars in order to promote the adequate positioning of genotypes in specific environments (Ferreira *et al.*, 2022).

The evaluation of productive components and agronomic characteristics has been used over the years in soybean breeding programs to guide the selection of genotypes and assist in the definition of commercial cultivars. In general, the central objective of crop genetic improvement focuses on the selection of genotypes that are more resistant to biotic and abiotic stresses and with high potential productive. It is known that grain yield is the result of the sum of the productive components of the plant (Yoosefzadeh-Najafabadi *et al.*, 2021). Thus, the knowledge of the correlation between the productive components and grain yield is fundamental for the selection of more productive genotypes. In general, characteristics such as the plant height, number of nodes per plant, number of pods per plant, number of grains per pod, number of grains per plant and weight of thousand grains have positive effects on grain yield, that way the selecting plants with a high expression of these characteristics favors obtaining of genotypes with a high grain yield (Specht *et al.*, 1999; Baraskar *et al.*, 2014; Islam *et al.*, 2015; Ghiday *et al.*, 2017; Yoosefzadeh-Najafabadi *et al.*, 2021; Ferreira *et al.*, 2022).

In view of this, the use of Pearson's linear correlation to estimate the direction and degree of linear association between two random characteristics makes it possible to verify the degree of interference of one characteristic on another of economic interest, in order to assist in the indirect selection of genotypes (Olivoto *et al.*, 2016; Ferreira *et al.*, 2022). In addition, makes it possible to identify and quantify the associations of morphological and productive characters with crop performance (Carvalho *et al.*, 2015). The interpretation of the coefficients occurs through the sign of the correlation (i.e.: Negative = Inversely proportional; Positive = Directly proportional), and the intensity of this is represented numerically between values ranging from -1 to 1 (Cargnelutti Filho *et al.*, 2010).

Among the correlations with inversely proportional effect, the following stand out in terms of intensity and significance: WTG×PP (r = -0.56), WTG×GP (r = -0.56), GY×IHFP (r = -0.43) and WTG×NN (r = -0.38) (Figure 2). In this perspective, the correlations between the weight of thousand grains and the number of nodes, pods per plant and grains per plant, reinforce the results observed previously, which indicated the tendency of reduction of the weight of thousand grains as the number of nodes, pods per plant and grains per plant increased (Table 3). The inversely proportional effect of the correlation between grain yield and insertion height of the first pod is contrasting to that observed by Almeida *et al.* (2010), indicating that the selection of more productive genotypes is dependent on the growing environment (Follmann *et al.*, 2017) and not only on the characteristics of the productive component. The expression of the phenotype is highly dependent on the interaction between the genotype and the environment (Ramalho *et al.*, 2012).

Among the directly proportional or positive correlations, the following stand out for the intensity and significance of the correlation coefficient: PP×GP (r = 0.97), P3G×GP (r = 0.89), P3G×PP (r = 0.87), NN×GP (r = 0.63), NN×PP (r = 0.60), P1G×P2G (r = 0.59), WTG×GY (r = 0.56), WTG×GP (r = 0.56), P3G×P4G (r = 0.46) and NN×P3G (r = 0.43). Thus, it is noted that the number of nodes has a direct influence on the number of pods per plant and grains per plant, variables that present a high correlation between them (r = 0.97). Likewise, it is observed that the number of pods per plant is positively correlated and influenced by P1G (r = 0.25), P2G (r = 0.27), P3G (r = 0.87) and P4G (r = 0.40). The number of grains per plant has a high correlation with PP (r = 0.97) and P3G (r = 0.89). Thus, it is understood that among all the productive components evaluated, those that are most closely linked are NN, PP and GP (Figure 2). The direct impact of the number of pods per plant on the number of grains per plant and, consequently, on soybean grain yield was also reported by Bastidas *et al.* (2008) and Yoosefzadeh-Najafabadi *et al.* (2021).

The grain yield was directly proportional to the weight of thousand grains, having presented a positive correlation coefficient (r = 0.56). However, the grain yield is a complex variable to be explained, having been positively influenced by NN, GP, PP and P3G, with which it presents positive correlations of less intensity (Figure 2). Therefore, it is plausible to understand that grain yield is the result of the balance between NN, GP, PP and of P3G with WTG. Since grain yield was shown to be the result of the sum of the effects of the above-mentioned productive components, all of them are important in efforts to achieve new levels of productivity in soybeans, so that selecting these characters can result in higher grain yields (Ghiday *et al.*, 2017).

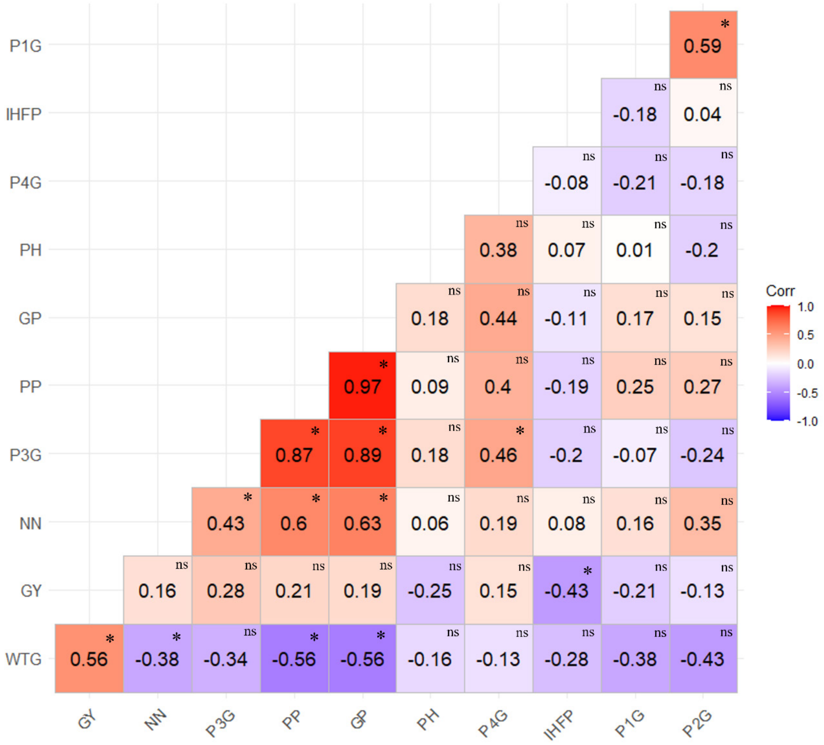

Figure 2: Pearson correlation matrix between the productive components [Plant height (PH); Insertion height of the first pod (IHFP); Number of nodes (NN); Pods with one grain (P1G); Pods with two grains (P2G); Pods with three grains (P3G); Pods with four grains (P4G); Pods per plant (PP); Grains per plant (GP); Weight of thousand grains (WTG), and; Grain yield (GY)] of sixteen soybean cultivars sown in Santo Augusto, RS, Brazil during the 2019/20 harvest. * Indicate significant effect by F test at 5% probability. ns Indicates non-significant effect by F test at 5% probability.

In the literature, some studies on linear relationships in soybean suggest that plant height can be used to indirectly select more productive cultivars, because tall plants generally stand out for their ability to support seed growth due to the highter mobilization of stem reserves (Mohsen *et al.*, 2013; Leite *et al.*, 2015; Teodoro *et al.*, 2015; Follmann *et al.*, 2017), however, this is not very clear for the group of cultivars used, since the correlation coefficient between GY×PH was negative (r = -0.16). On the other hand, the positive effects observed by Kavalco *et al.* (2014) and Souza *et al.* (2015) between the weight of thousand grains and grain yield are reinforced by the present study (r = 0.56) (Figure 2). Thus, based on both the similar and divergent results, it is plausible to say that the soil and climatic conditions of the growing environment exert a strong influence on the grain yield of the genotypes, regardless of their productive potential (Follmann *et al.*, 2017), since the expression of the phenotype is determined by the interaction between the genotype and the environment, genetic constitution of the cultivar and of the environmental conditions of the micro-region of cultivation (Ramalho *et al.*, 2012; Ferrari *et al.*, 2016).

CONCLUSIONS

The cultivars BMX ZEUS IPRO, NS 5445 IPRO and NS 5700 IPRO presented the highest grain yields, mainly due to the high relationship between the number of pods and grains per plant and the weight of thousand grains.

Indirect selection of more productive genotypes can be performed through the characteristics weight of thousand grains, number of pods, grains and nodes per plant, given the significant positive correlation between them.

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REFERENCES

Almeida RD, Peluzio JM & Afferri FS (2010) Correlações fenotípicas, genotípicas e ambientais em soja cultivada sob condições várzea irrigada, sul do Tocantins. Bioscience Journal, 26:95-99.

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM & Sparovek G (2014) Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, 22:711-728.

Andrade FH, Sadras VO, Veja CRC & Echarte L (2005) Physiological determinants of crop growth and yield in maize, sunflower, and soybean. Journal of Crop Improvement, 14:51-101.

Aquino LA, Silva TC, Aquino RFBA, Batista CH & Silva HRF (2011) Avaliação agronômica de cultivares de soja sob irrigação no semiárido mineiro. Revista Brasileira de Agricultura Irrigada, 5:165-172.

Baraskar VV, Kachhadia VH, Vachhanl JH, Barad HR, Patel MB & Darwankar MS (2014) Genetic variability, heritability and genetic advance in soybean [*Glycine max* (L.) Merrill]. Electronic Journal of Plant Breeding, 5:802-806.

Bastidas AM, Setiyono TD, Dobermann A, Cassman KG, Elmore RW, Graef GL & Specht JE (2008) Soybean sowing date: The vegetative, reproductive, and agronomic impacts. Crop Science, 48:727-740.

Cao S, Xu D, Hanif M, Xia X & He Z (2020) Genetic architecture underpinning yield component traits in wheat. Theoretical and Applied Genetics, 133:1811-1823.

Cargnelutti Filho A, Toebe M, Burin C, Silveira TR & Casarotto G (2010) Tamanho de amostra para estimação do coeficiente de correlação linear de Pearson entre caracteres de milho. Pesquisa Agropecuária Brasileira, 45:1363-1371.

Carvalho IR, Souza VQ, Nardino M, Follmann DN, Schmidt D & Baretta D (2015) Correlações canônicas entre caracteres morfológicos e componentes de produção em trigo de duplo propósito. Pesquisa Agropecuaria Brasileira, 50:690-697.

Ciampitti IA & Vyn TJ (2012) Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. Field Crops Research, 133:48-67.

CONAB – Companhia Nacional de Abastecimento (2023) Safra – Série Histórica dos Grãos. Available at: <https://portaldeinformacoes.conab.gov.br/safra-serie-historica-graos.html>. Accessed on: January 02nd, 2023.

Cruz CD, Peixoto CP, Martins MC & Peixoto MFSP (2010) Componentes de produção de soja em diferentes épocas de semeadura, no oeste da Bahia. Bioscience Journal, 26:709-716.

Cruz SCS, Sena Junior DG, Santos DMA, Lunezzo LO & Machado CG (2016) Cultivo de soja sob diferentes densidades de semeadura e arranjos espaciais. Revista de Agricultura Neotropical, 3:01-06.

Cui SY & Yu DY (2005) Estimates of relative contribution of biomass, harvest index and yield components to soybean yield improvements in China. Plant Breeding, 124:473-476.

Cunha NG, Silveira RJC & Severo CRS (2004) Estudo de Solos do Município de Santo Augusto – RS. Pelotas, Embrapa Clima Temperado. 64p. (Circular, 39).

Dutamo D, Alamerew S, Eticha F & Assefa E (2015) Genetic variability in bread wheat (*Triticum aestivum* L.) germplasm for yield and yield component traits. Journal of Biology, Agriculture and Healthcare, 5:140-147.

Egli D (2005) Flowering, pod set and reproductive success in soya bean. Journal of Agronomy and crop science, 191:283-291.

Egli DB (2013) The Relationship between the number of nodes and pods in soybean communities. Crop Science, 53:1668-1676.

Embrapa – Empresa Brasileira de Pesquisa Agropecuária (2009) Manual de análises químicas de solos, plantas e fertilizantes. 2ª ed. Brasília, Embrapa. 627p.

Ferrari M, Pelegrin AJ, Nardino M, Carvalho IR, Szareski VJ, Olivoto T, Belle R, Oliveira AC, Maia LC & Souza VQ (2016) Evaluation off soybeans genotypes in field environments of Rio Grande do Sul state, Brazil. International Journal of Current Research, 8:38383-38392.

Ferreira LL, Silva JÂ, Carvalho IR, Fernandes MS, Lautenchleger F & Loro MV (2022) Correlations and canonical variables applied to the distinction of soybean cultivars in a tropical enviroment. Agronomy Science and Biotechnology, 8:01-12.

Follmann DN, Cargnelutti Filho A, Souza VQ, Nardino M, Carvalho IR, Demari GH, Ferrari M, Pellegrin AJ & Szareski VJ (2017) Relações lineares entre caracteres de soja safrinha. Revista de Ciências Agrárias, 40:213-221.

Gastl Filho J, Hamawaki OT, Nogueira APO, Silva CO, Hamawaki RL & Hamawaki CDL (2022) Genetic parameters and selection strategies for soybean progenies aiming at precocity and grain productivity. Ciência e Agrotecnologia, 46:e004322.

Gaviraghi L, Pellegrin J, Werner A, Bellé EP & Basso CJ (2018) Adaptabilidade de cultivares de soja (*Glycine max*) no município de Frederico Westphalen. Revista Brasileira de Iniciação Científica, 5:04-14.

Ghiday T, Amogne A, Tefera G & Malede M (2017) Heriditability, Genetic Advance and Path Coefficient Analysis for Grain Yield and its Component Characters in Soybean (*Glycine max* L. Merrill). International Journal of Research Studies in Agricultural Sciences, 3:01-11.

Islam MA, Raffi SA, Hossain MA & Hasan AK (2015) Analysis of genetic variability, heritability and genetic advance for yield and yield associated traits in some promising advanced lines of rice. Progressive Agriculture, 26:26-31.

Kahlon CS & Board JE (2012) Growth dynamic factors explaining yield improvement in new versus old soybean cultivars. Journal of crop improvement, 26:282-299.

Kavalco SAF, Souza VQ, Follmann DN, Carvalho IR, Nardino M & Demari GH (2014) Desenvolvimento da soja com aplicações de hormônios em diferentes densidades de cultivo. Revista Brasileira de Agropecuária Sustentável, 4:112-120.

Leite WS, Pavan BE, Matos Filho CHA, Feitosa FS & Oliveira CB (2015) Estimativas de parâmetros genéticos e correlações entre caracteres agronômicos em genótipos de soja. Nativa, 3:241-245.

Leite WS, Unêda-Trevisoli SH, Silva FM, Silva AJ & Mauro AOD (2018) Identification of superior genotypes and soybean traits by multivariate analysis and selection index. Revista Ciência Agronômica, 49:491-500.

Mohsen AE, Ashraf A, Mahmoud GO & Safina SA (2013) Agronomical evaluation of six soybean cultivars using correlation and regression analysis under different irrigation regime conditions. Journal of Plant Breeding and Crop Science, 5:91-102.

Nogueira APO, Sediyama T, Sousa LB, Hamawaki OT, Cruz CD, Pereira DG & Matsuo E (2012) Análise de trilha e correlações entre caracteres em soja cultivada em duas épocas de semeadura. Bioscience Journal, 28:877-888.

Olivoto T, Nardino M, Carvalho IRC, Follmann DN, Szareski VJ, Ferrari M, Pelegrin AJ & Souza VQ (2016) Pearson correlation coefficient and accuracy of path analysis used in maize breeding: a critical review. International Journal of Current Research, 8:37787-37795.

Perini LJ, Fonseca Júnior NS, Destro D & Prete CEC (2012) Componentes da produção em cultivares de soja com crescimento determinado e indeterminado. Semina: Ciências Agrárias, 33:2531-2543.

Pimentel-Gomes F (2009) Curso de estatística experimental. 15ª ed. Piracicaba, FEALQ. 451p.

Pires LPM, Peluzio JM, Cancellier LL, Ribeiro GR, Colombo GA & Afférri FS (2012) Desempenho de genótipos de soja, cultivados na região centro-sul do estado do Tocantins, safra 2009/2010. Bioscience Journal, 28:214-223.

R Development Core Team (2022) R: A language and environment for statistical computing. Available at: <http://www.r-project.org>. Accessed on: January 02nd, 2023.

Ramalho MAP, Santos JB, Pinto CABP, Souza EA, Gonçalvez FMA & Souza JC (2012) Genética na agropecuária. 5ª ed. Lavras, UFLA. 566p.

Ramos Junior EU, Ramos EM & Cerezo CB (2019) Densidade de plantas nos componentes produtivos e produtividade de cultivares de soja. Revista de Ciências Agroambientais, 17:51-56.

Ribeiro FC, Colombo GA, Silva POS, Silva JIC, Erasmo EAL & Peluzio JM (2016) Desempenho agronômico de cultivares de soja na região central do Estado do Tocantins, safra 2014/2015. Scientia Plena, 12:01-07.

Richter GL, Zanon Júnior A, Streck NA, Guedes JVC, Kraulich B, Rocha TSM, Winck JEM & Cera JC (2014) Estimating leaf area of modern soybean cultivars by a non-destructive method. Bragantia, 73:416-425.

Rigon JPG, Capuani S, Brito Neto JS, Rosa GM, Wastowski AD & Rigon CA (2012) Dissimilaridade genética e análise de trilha de cultivares de soja avaliada por meio de descritores quantitativos. Revista Ceres, 59:233-240.

Rincker K, Nelson R, Specht J, Sleper D, Cary T, Cianzio SR, Casteel S, Conley S, Chen P, Davis V, Fox C, Graef G, Godsey C, Holshouser D, Jiang GL, Kantartzi SK, Kenworthy W, Lee C, Mian R, McHale L, Naeve S, Orf J, Poysa V, Schapaugh W, Shannon G, Uniatowski R, Wang D & Diers B (2014) Genetic improvement of US soybean in maturity groups II, III, and IV. Crop Science, 54:1419-1432.

Rocha RS, Silva JAL, Neves JA, Sediyama T & Teixeira RC (2012) Desempenho agronômico de variedades e linhagens de soja em condições de baixa latitude em Teresina-PI. Revista Ciência Agronômica, 43:154-162.

Sediyama T, Matsuo E, Oliveira RCT & Glasenapp JS (2015) Características agronômicas de cultivares. In: Sediyama Tuneo (Ed.) Melhoramento genético da soja. Londrina, Mecenas. p.73-82.

Souza RR, Toebe M, Marchioro VS, Cargnelutti Filho A, Bittencourt KC, Mello AC & Paraginski JA (2023) Sample size and modeling of plant variability using precision statistics in soybean counting traits. Field Crops Research, 291:108789.

Souza VQ, Bellé R, Ferrari M, Pelegrin AJ, Caron BO, Nardino M, Follmann DN & Carvalho IR (2015) Componentes de rendimento em combinações de fungicidas e inseticidas e análise de trilha em soja. Global Science and Technology, 8:167-176.

Specht JE, Hume DJ & Kumudini SV (1999) Soybean Yield Potential – A Genetic and Physiological Perspective. Crop Science, 39:1560-1570.

Storck L, Garcia DC, Lopes SJ & Stefanel V (2016) Experimentação vegetal. 3ª ed. Santa Maria, UFSM. 198p.

Tedesco JA, Gianello C, Bissani CA, Bohnen H & Volkweiss SJ (1995) Análise de solo, plantas e outros materiais. Porto Alegre, UFRGS. 174p. (Boletim Técnico, 5).

Teodoro PE, Ribeiro LP, Corrêa CCG, Luz Júnior RAA, Zanuncio AS, Capristo DP & Torres FE (2015) Path analysis in soybean genotypes as function of growth habit. Bioscience Journal, 31:794-799.

Toledo JA, Kaminski J, Santana MA & Santos DR (2012) Tampão Santa Maria (TSM) como alternativa ao tampão SMP para medição da acidez potencial de solos ácidos. Revista Brasileira de Ciência do Solo, 36:427-435.

Torres FE, David GV, Teodoro PE, Ribeiro LP, Correa CG & Luz Júnior RA (2015) Desempenho agronómico e dissimilaridade genética entre genótipos de soja. Revista de Ciências Agrárias, 38:111-117.

USDA – United States Department of Agricullture (2023) PSED – Production, Supply and Distribution. Avaliable at: <https://apps.fas.usda.gov/psdonline/app/index.html#/app/topCountriesByCommodity>. Accessed on: January 02nd, 2023.

Xavier A & Rainey KM (2020) Quantitative Genomic Dissection of Soybean Yield Components. G3: Genes, Genomes, Genetics, 10:665-675.

Yoosefzadeh-Najafabadi M, Tulpan D & Eskandari M (2021) Application of machine learning and genetic optimization algorithms for modeling and optimizing soybean yield using its component traits. Plos one, 16:01-18.

Zanon AJ, Streck NA, Richter GL, Becker CC, Rocha TSM, Cera JC, Winck JEM, Cardoso AP, Tagliapietra EL & Weber PS (2015) Branches contribution and leaf area index evolution in modern cultivars of soybean. Bragantia, 74:279-290.