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Research Article

Grain yield predictor model using agronomic aspects and vegetative indices of soybean

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Abstract

The objective of this work was to evaluate, through a predictive model, which factors influence soybean yield, using agronomic aspects and vegetative indices, in addition to identifying the best soybean cultivar for the northwest of Rio Grande do Sul. The experimental design used was strips with randomized blocks, consisting of 10 cultivars and five blocks. Analyzing the quantitative characters, the positive contributions to yield came from the grain weight of vegetables with two grains, and the grain weight of the plant, having a strong influence on the average grain yield. The vegetable grain weight with three grains contributed negatively to the yield, as the average grain weight was lower than expected, lowering the average grain yield. For the vegetation indices that contributed positively, the GRAY, IGB and RGRI index stand out, while the BGI, GLI2, GRAY2, IGR, IRB, NRBDI and NG indices had negative contributions to the average grain yield. The NEO 581 E cultivar showed better yield performance, reaching 5780 kg ha^{-1}, followed by the SOYTECH 541 I2X cultivar, which reached a yield of 5356 kg ha^{-1}. The predictive model identified the main variables that influenced final yield, with *Cercospora sojina* and *Corynespora casiicola*, grain weight in three-grain legumes, plant grain weight, GRAY index, IGB, NGBDI and RGRI, the variables that contributed positively to grain yield.

Keywords: *Glycine max*; genotype recommendation; phenomics; sustainable management; maturity groups; sowing time.

Introduction

Soybean (*Glycine max* L.) is a plant originating in China, which is part of the Fabaceae family. This oilseed has a grain rich in proteins and oil, used mainly for human and animal consumption, and in the production of biofuels and vegetable oil, being strongly active in the production sector, demanding more product each year and consequently increasing its cultivation area and yield (Lenhardt et al., 2023).

According to the National Supply Company (CONAB), the 2023/2024 harvest reached a total production of 147.3 million tons, with a cultivated area of 45.9 million hectares, with Mato Grosso as the largest producer. In Rio Grande do Sul these numbers are around 20.19 million tons, with a sown area of 6.76 million hectares (Companhia Nacional de Abastecimento [CONAB], 2024).

Due to the great demand and high production numbers, it is important that the genetic changes carried out in the plants of new cultivars are observed, especially when it comes to soybeans. In view of this, it becomes possible to see that technological advances are increasingly being introduced into the field, making the work constantly updated so that efficient and sustainable management of cultivars within cultivation systems can be achieved.

Therefore, it is important to highlight that there are different biotechnologies imposed on cultivars, which can be classified into large groups, such as Intacta I2x soybeans, a type of transgenic soybean tolerant to the herbicides glyphosate and dicamba, in addition to having technologies that allow the control of the main soybean caterpillars (Ribeiro, Rocha, Erasmo, Matos, & Costa, 2016). RR soybean cultivars, which are produced with Roundup Ready technology, make the plant tolerant to herbicide application due to resistance to glyphosate (Castro et al., 2017).

Furthermore, represented by the acronym GMR, there are soybean relative maturity groups that are divided into: classification less than 6.0: super-early; rating between 6.0 and 6.5: precocious; classification with a number greater than 7 or equal to 10: late. In this sense, it is worth highlighting that soybean cultivars can present three types of growth: indeterminate (without terminal raceme), determinate (with terminal raceme) or semi-determinate (intermediate) (Zanon et al., 2016).

The difference in grain yield from different crops is directly linked to the level of technology adopted and the climate variability that exists in each location and that occurs in each harvest (Degani, Leitner, Baggenstoss, Torkomian, & Alves Filho, 2021). Therefore, when analyzing the best soybean cultivar for sowing in the northwest region of the state of Rio Grande do Sul, several factors must be taken into consideration, such as checking the correct sowing time, best form of fertilization and soil management.

According to Balest et al. (2022), the adaptation of a cultivar can be described as the ability of a genotype to respond advantageously to its environment, with soybean cultivars differing from one to another in terms of adaptability and stability. According to the authors, saying that a cultivar has high adaptability refers to its responsiveness to improvements in the environment and management, adapting to the circumstances to which it is exposed.

The adaptability of soybean cultivars refers to the ability to reach their maximum production potential in favorable environments, while stability is related to the consistency of the cultivar's performance, presenting less variation in yield in unfavorable conditions (Vasconcelos, Reis, Sediyama, & Cruz,2015). For Teixeira, Battisti, Sentelhas, Moraes and Oliveira Junior (2019), the choice of the ideal soybean cultivar for a specific region must consider the complex interaction between genotype, environment, agronomic management and producer characteristics, emphasizing the importance of reliable data obtained through research and practical experimentation in the field.

New alternatives for identifying the best genotypes and the characteristics that most influence soybean grain yield are welcome (Deshmukh et al., 2014) and the use of tools for the phenotypic evaluation of plants, through aerial images, have already been used, as by Bruce, Rajcan and Sulik (2021), for classifying soybean pubescence, and for selecting lines in breeding programs (Parmley, Nagasubramanian, Sarkar, Ganapathysubramanian, & Singh, 2019).

In this sense, the objective of this work was to evaluate, through a predictive model, which factors influence soybean yield, using agronomic aspects and vegetative indices, in addition to identifying the best soybean cultivar for the northwest of Rio Grande do Sul.

Materials and Methods

The study was carried out in the 23/24 harvest, at the Escola Fazenda of the Universidade Regional do Noroeste of the State of Rio Grande do Sul, located in the municipality of Augusto Pestana-RS (28° 26' 30" S latitude and 54° 00 ' 58" W longitude and altitude of 301 meters). The soil in the area can be classified as a typical dystroferric Oxisol (U.M. Santo Ângelo), well drained, with a deep profile, and dark red color, with high clay content and a predominance of 1:1 clay minerals and iron and aluminum oxy hydroxides. According to Köeppen, the region's climate classification fits the description of Cfa, with hot summers and no prolonged droughts (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2014),

The experimental design used was strips with randomized blocks, consisting of 10 cultivars and five blocks. Before sowing and beginning of management, a physical-chemical soil analysis was carried out in the area, to diagnose its fertility and identify the type of soil present in the area. Each experimental unit was composed of seven rows 15 meters long, spaced 0.5 meters apart (Table 1).

Table 1. Characteristic description of the cultivars.

Cultivar	Flower color	Growth Habit	GMR	PMS (g)	Pubescence	Hilo
NEO581 E	Purple	Undetermined	5.8	183	Gray	Imperfect black
NEO 580 IPRO	Purple	Undetermined	5.8	180	Gray	Imperfect black
NEO 560 IPRO	Purple	Undetermined	5.6	196	Gray	Imperfect black
NEO531 I2X	Purple	Undetermined	5.3	187	Gray	Imperfect black
NEO 510 IPRO	Purple	Undetermined	5.1	195	Gray	Imperfect black
SOYTECH 580 I2X	Purple	Undetermined	5.8	210	Gray	Imperfect black
SOYTECH 535 I2X	Purple	Undetermined	5.3	173	Gray	Imperfect black
SOYTECH 541 I2X	Purple	Undetermined	5.4	205	Gray	Imperfect black
SOYTECH 622 IPRO	Purple	Undetermined	6.2	173	Gray	Imperfect black
SOYTECH 611 IPRO	Purple	Undetermined	6.1	185	Gray	Imperfect black

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Sowing was carried out in the first fortnight of November 2023 using a seeder-fertilizer, with a density of 14 seeds per linear meter. The harvest took place on March 25, 2024. Phytosanitary management was carried out to minimize biotic effects on the results of the experiments and is shown in Table 2.

Table 2. Phytosanitary management carried out during the cycle of soybean cultivars.

Time of Application	Herbicides	Insecticides	Fungicides	Mineral oil and reducer pH
Pre-sowing - 30 days before	Glyphosate (2L ha $^{-1}$); 2,4D (1.5 L ha $^{-1}$); Clethodim (0,6 L ha $^{-1}$)	-	-	0.25L ha $^{-1}$ + 50 ml ha $^{-1}$
2 days before sowing	Diquat (2.5 L ha $^{-1}$)	-	-	0.25L ha $^{-1}$ + 50 ml ha $^{-1}$
V4	-	Acetamiprid + Bifenthrin (200 g ha^{-1}); Diflubenzuron (60 g ha $^{-1}$)	Difeconazole (250 ml ha $^{-1}$)	0.25L ha $^{-1}$ + 50 ml ha $^{-1}$
R1	-	Thiamethoxam + Lambda-cyhalothrin (250 ml ha $^{-1}$)	Benzovindiflupir + Ciproconazole + Difenoconazole (0.5 L ha^{-1})	0.25L ha $^{-1}$ + 50 ml ha $^{-1}$
R3	-	Acetamiprid + Bifenthrin (200 g ha^{-1})	Benzovindiflupir + Prothioconazole (0.5 L ha^{-1})	0.25L ha $^{-1}$ + 50 ml ha $^{-1}$
R5	-	Acetamiprid + Bifenthrin (200 g ha^{-1})	Azoxystrobin + Mancozeb + Prothioconazole (2.0 kg ha^{-1})	0.25L ha $^{-1}$ + 50 ml ha $^{-1}$

The variables analyzed were: number of plants per final linear meter (NPLM_F, units); plant height (PH, cm); height of the productive zone (HPZ, cm); insertion height of the 1st vegetable (IHFV, cm); number of total nodes on the main stem (NTNMS, units); number of total nodes in the branches (NTN_B, units); number of vegetables on the main stem (NVMS, units); number of vegetables on branches (NVB, units); number of branches (NB, units); branch length (BL, cm); root length (ROOT_L, cm); number of vegetables with 1 grain (NV1, units); number of vegetables with 2 grains (NV2, units); number of vegetables with 3 grains (NV3, units); number of vegetables with 4 grains (NV4, units); number of vegetables with 0 grains (NV0, units); percentage of disease incidence (%); percentage of incidence of pest insects (%); percentage of incidence of invasive plants (%); main stem internode length (INTER_MS, cm); branching internode length (INTER_B, cm).

At the time of harvest, the following variables were analyzed: grain weight with one-grain vegetable (GWV1, g); grain weight with two-grain vegetable (GWV2, g); grain weight with three-grain vegetable (GWV3, g); grain weight with four-grain vegetable (GWV4, g); grain weight per plant (GWP, g); grain yield (kg ha^{-1}). The meteorological attributes were obtained through the NASA Power platform (NASA POWER, 2022) and were as follows: mean air temperature (Tmean, °C), minimum air temperature (Tmin, °C), maximum air temperature (Tmax, C), precipitation (PREC, mm).

To obtain vegetative indices, five flights were carried out with a specialized drone, equipped with a 20 MP resolution camera and standard height (80 m), throughout the soybean cycle in the study. Image processing took place through a computer center immediately after image capture was completed; these were selected based on their quality and composed the orthomosaic.

Using orthomasaic, the vegetation indices were estimated: GRAY, IGB (green-blue ratio), RGRI, BGI (blue-green pigment), GLI2 (green leaf index 2), GRAY2, IGR (green-red ratio), IRB (red-blue ratio), NRBDI (normalized red-blue difference index) and NG (normalized green), according to Pradebon et al. (2024).

Descriptive analyzes were used in order to understand the contribution of each variable in the study. The data obtained were subjected to normality and homogeneity of variance tests, using the Shapiro-Wilk and Bartlett tests. Furthermore, analysis of variance was carried out in order to determine the effect of cultivars on the agronomic traits evaluated, at 5% probability. In the variables that had a significant effect on the factors tested, a mean comparison test was carried out by Tukey at 5% probability

The multiple linear regression predictive model was developed using StepWise in order to understand the contribution of some variables to grain yield, using the statistical packages *metan* and *AgroR* (R Core Team, 2023).

Results and Discussion

In the meteorological data evidenced during the average cycle of 125 days for the cultivars, the mean air temperature remained at 24ºC, peaking at 30ºC around 40 days. The maximum temperature averaged 30ºC, with its highest temperature between days 40 and 45, reaching 35ºC. For the minimum temperature, the average remained at 19ºC, recording the lowest temperature during the 15 days, with approximately 11ºC. Precipitation during the cycle had an average of 10mm, with the highest rate at 100 days, being 90mm. It is known that the optimal conditions for the development of the crop is 25ºC, and it can complete its cycle with 700mm of rain, however the large fluctuation in rainfall that occurs in Rio Grande do Sul is considered as the main meteorological variable determining fluctuations in soybean grain yield in the state (Figure 1) (Oliveira, Knies, Rodrigues, Schmidt, & Kury, 2021).

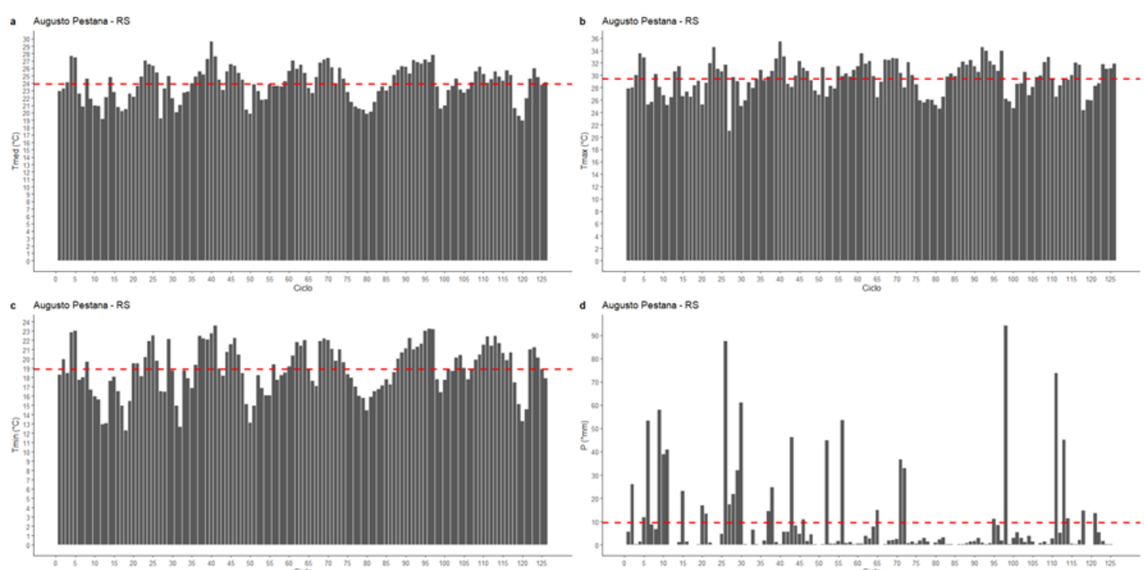

Figure 1. Meteorological data from the city of Augusto Pestana – RS, during the soybean cultivar cycle.

In order to understand the behavior of the data, a descriptive analysis was carried out (Table 4), where it was observed that for the variable number of vegetables in the branch, the cultivar ST535 I2X was superior, with an average of 46.4 vegetables, while NEO510 IPRO obtained the worst average, of 14 vegetables. For the variable number of vegetables with zero grains, the cultivar NEO580 IPRO, with an average of 4 vegetables, was superior, while the cultivar ST 535 I2X was inferior, with an average of 0.25 vegetables.

For the variable number of vegetables with 1 grain, the ST541 I2X cultivar was superior to the others, with an average of 12.8 vegetables, while the NEO531 I2X cultivar was inferior, with an average of 1.8 vegetables. The variable number of vegetables with 2 grains showed the ST535 I2X cultivar to be superior, with an average of 34 vegetables, while the NEO580 IPRO cultivar was inferior, with an average of 17 vegetables.

For the variable number of vegetables with 4 grains, the ST580 I2X cultivar demonstrated superiority, with an average of 0.8 vegetables, while the NEO581 E and NEO560 IPRO cultivars demonstrated inferiority, with an average of zero legumes. In the variable of the main stem internode length, the NEO510 IPRO cultivar showed the highest value, with an average of 4.5cm, while the ST622 IPRO cultivar showed the lowest value, with an average of 2.03cm. Finally, for the variable branching internode length, the cultivar that showed the highest value was NEO531 I2X, with an average of 3.7cm, while the cultivar NEO580 IPRO showed the lowest value with an average of 1.14cm. For Porta et al. (2024), the increase in grain yield is influenced by the shorter internodes length, characteristic of cultivars with indeterminate growth.

Observing the descriptive analysis for diseases (Table 5), a high incidence of Asian rust (*Phakpsora pachrizi*) was evident in all cultivars, which can lead to losses of over 80% in soybean grain yield, when not controlled. (Lana, Ziegelmann, Maia, Godoy, & Ponte, 2015). The cultivars NEO581 E, NEO510 IPRO and ST622 IPRO showed 20% presence of anthracnose (*Colletotrichum truncatum*); cultivar NEO531 I2X had a 40% incidence of the pathogen; the NEO560 IPRO cultivar found a 60% incidence of the disease; the other cultivars had no incidence of anthracnose. Observing bacterial blight (*Pseudomonas savastanoi pv. Glycinea*), in the cultivars NEO510 IPRO, ST622 IPRO and ST611 IPRO, there was a 20% incidence, while in the cultivar ST580 I2X, the incidence was 40%. In the other cultivars, the presence of the pathogen was not recorded.

For red root rot (*Fusarium brasiliense*), it was observed that the ST535 I2X and ST611 IPRO cultivars had a 20% incidence, while the others did not show the presence of the disease. For charcoal rot (*Macrophomina phaseolina*), the cultivars NEO560 IPRO, NEO 531 I2X, NEO510 IPRO, ST580 I2X and ST535 I2X, showed 20% presence of the pathogen, while the cultivar ST541 I2X had 40% incidence, while the others genotypes did not present the disease. The use of cultivars with tolerance to the pathogen is one of the most efficient alternatives for reducing the incidence in plants (Ishikawa, Ribeiro, Oliveira, Almeida, & Balbi-Peña, 2018; Mengistu et al., 2013). For mildew (*Peronospora manshurica*), the NEO580 IPRO cultivar showed 20% presence of the pathogen, while the others had no presence of the disease.

For frog's eye spot (*Cercospora sojina*), it was observed that the cultivars NEO531 I2X and NEO510 IPRO showed a 20% incidence of the disease; cultivars NEO560 IPRO, ST580 I2X, ST535 I2X, ST541 I2X, ST622 IPRO, ST611 IPRO showed 40% presence of the pathogen; cultivar NEO581 E had 60% presence of the spot and cultivar NEO580 showed 100% presence of the pathogen. For target spot (*Corynespora cassiicola*), the cultivars NEO560 IPRO, ST535 I2X, ST541 I2X, ST622 IPRO and ST611 IPRO showed 40% presence of the pathogen, while the cultivars NEO581 E, NEO580 IPRO, NEO531 I2X, NEO510 IPRO, ST580 I2X had 60% of the disease.

The descriptive analysis for insect pests (Table 6) showed that there was a 20% presence of cucurbit beetle (*Diabrotica speciosa*) in the cultivars ST580 I2X, ST535 I2X, the other cultivars did not show the presence of the pest. For the green belly stink bug, the NEO560 IPRO cultivar showed 20% presence of the pest, while the others showed no incidence of the insect pest. For the brown soybean bug (*Euschistus heros*), all cultivars showed 20% of the presence of the insect pest. Furthermore, all cultivars had 100% presence of thrips (*Thysanoptera*).

The incidence of invasive plants occurred in the plots, but is not related to the cultivars analyzed. The descriptive analysis for the incidence of invasive plants (Table 7) showed a 100% incidence of horseweed (*Conyza bonarienses*) and pigweed (*Amaranthus viridis*). For cobblers pegs (*Bidens pilosa*), the incidence was lower, reaching 40% in the area of the NEO581 E and ST541 I2X cultivars. The incidence of guanxuma (*Sida rhombifolia*) was absent in most cultivars, except for NEO560 IPRO and NEO531 I2X, where it was 20%. The incidence of viola string (*Ipomea acuminata*) was 20% in the area of cultivars NEO581 E and NEO531 I2X, and 40% in the area of cultivars NEO580 IPRO, NEO560 IPRO, NEO510IPRO and ST622 IPRO. When not managed efficiently, invasive plants compete for light, water and nutrients with the crop, influencing grain yield (Siqueira, Oliveira, Peixoto, & Amaral, 2021).

The analysis of variance (Table 3) highlighted the variables plant height, insertion height of the first legume, number of branches, number of legume on the main stem, number of total nodes on the branch, plant per linear meter, grain weight in legumes with 1 grain, grain weight in vegetables with 3 grains, plant grain weight, grain yield, height of the productive zone, number of total nodes on the main stem were significant for the treatment, while the variables branch length, length of root and number of 3-grain vegetables the treatment effect was not significant.

Table 3. Summary of the analysis of variance for the effect of cultivars on soybean agronomic traits.

SV	DF	PH	IHFV	NB	NVMS	NTN _B	PLM
		Pr>Fc					
CULTIVARS	9	0,0001*	0,00004*	0,00001*	0.016	0,00004*	0.00001*
BLOCKS	4	0.612	0.701	0.629	0.746	7.772	0.855
RESIDUAL	36						
CV%		8.06	19.21	33.8	28.73	34.14	16.85
SV	**DF**	**GWV1**	**GWV3**	**GWP**	**GY_KG**	**HPZ**	**NTN_MS**
		Pr>Fc					
CULTIVARS	9	0.0001*	0.0001*	0.0016*	0.0001*	0.00009*	0.003*
BLOCKS	4	0.432	0.333	0.447	0.422	0.588	0.339
RESIDUAL	36						
CV%		24.21	22.55	23.2	22.08	17.04	18.19
SV	**DF**	**BL**	**ROOTL**	**NV3**			
		Pr>Fc					
CULTIVARS	9	0,527	0,14	0,054			
BLOCKS	4	0,49	0,595	0,155			
RESIDUAL	36						
CV%		31,3	20,64	31,06			

Observing Tukey's multiple comparison test of means (Table 4), for the variable height, the cultivar ST611 IPRO was statistically superior, with an average of 112.4 cm, while the cultivars ST541 I2X and NEO560 IPRO showed lower averages, being 72.8 cm and 81.4 cm, respectively. For the variable number of total nodes on the branch, the cultivar ST541 I2X was statistically superior, with an average of 46.8 cm, while the cultivars NEO560 IPRO, NEO531 I2X, NEO510 IPRO, were inferior, with 16.4 cm, 19.6 cm and 15.4 cm respectively. The variable height of insertion of the first vegetable showed that the cultivars ST580 I2X and ST611 IPRO were statistically superior, with 28.4 cm and 27.6 cm respectively, while the cultivar NEO560 IPRO demonstrated statistical inferiority, with 13.8 cm.

The ST541 I2X cultivar was statistically superior for the variable number of branches, with 6.4 branches, while the NEO510 IPRO cultivar was inferior, with 1.6 branches, that is, soybean plants that have more branches have a greater capacity to increase their grain yield, which is an ideotype that is sought in soybean cultivars. For the variable number of vegetables on the main stem, the cultivars NEO581 E and NEO560 IPRO were superior, with 38.8 and 29.4 vegetables respectively, while the cultivar ST622 IPRO was inferior, with 18.6 vegetables.

Table 4. Multiple comparison test of means.

CULTIVARS	PH	NTN_B	IHFV	NB	NVMS	PLM
ST 541 I2X	72.8 d	46.8 a	18 bc	6.4 a	27.8 ab	6.93 b
ST 622 IPRO	80.2 cd	41.6 ab	25.8 ab	4.4 abc	18.6 b	5.46 c
ST 580 I2X	93.4 bc	33.4 abc	28.4 a	5.2 ab	33 ab	5.6 c
ST 535 I2X	83.2 cd	32.2 abc	18.4 bc	5 ab	34.6 ab	7.42 b
ST 611 IPRO	112.4 a	29.2 abc	27.6 a	4.8 ab	30 ab	6.2 c
NEO 581 E	100.6 ab	23.8 bc	21.6 abc	3.4 bcd	38.8 a	7.99 a
NEO 560 IPRO	81.4 d	16.4 c	13.8 c	3 cd	42.8 a	6.94 b
NEO 580 IPRO	81.2 cd	22.6 bc	20.4 abc	3 bcd	29.4 ab	9.03 a
NEO 531 I2X	76.2 cd	19.6 c	20.8 abc	2 bcd	30.2 ab	6.13 c
NEO 510 IPRO	93 bc	15.4 c	20.6 abc	1.6 d	27.8 ab	4.62 c
CV	8.06	34.14	19.21	33.8	28.73	
CULTIVARS	**GWV1**	**GWV3**	**GWP**	**GY_KG**	**HPZ**	**NTN_MS**
ST 541 I2X	1.5 a	10.7 bcd	20.8 a	5356 ab	55.4 cd	20.8 a
ST 622 IPRO	0.6 c	18.7 a	21.6 a	4375 ab	45.2 d	21.4 a
ST 580 I2X	1 bc	12.2 bc	21.4 a	4455 ab	67.2 abcd	20.2 ab
ST 535 I2X	1.2 ab	7.9 cd	17.2 ab	4738 ab	66.6 abcd	21.8 a
ST 611 IPRO	0.6 c	13.7 ab	19.4 a	4472 ab	86.6 a	21.4 a
NEO 581 E	0.9 bc	10.9 bcd	19.5 a	5780 a	80.4 ab	20 ab
NEO 560 IPRO	0.9 bc	10.4 bcd	19 ab	4896 ab	63.6 abcd	18.6 ab
NEO 580 IPRO	0.8 bc	6.8 d	13.3 ab	4455 ab	64.4 abcd	15.4 ab
NEO 531 I2X	0.7 c	10.5 bcd	16.2 ab	3687 bc	61.6 bcd	13.4 b
NEO 510 IPRO	0.6 c	6.4 d	10.5 b	1804 c	75.2 abc	16.8 ab
CV	24.21	22.55	23.2	22.08	17.04	18.19
CULTIVARS	**BL**	**ROOTL**	**NV3**			
ST 541 I2X	56.4 a	17 a	22.2 a			
ST 622 IPRO	63.2 a	18.8 a	34.2 a			
ST 580 I2X	55.4 a	13.4 a	25 a			
ST 535 I2X	52.8 a	18 a	28.8 a			
ST 611 IPRO	67.8 a	14.8 a	31.4 a			
NEO 581 E	49.6 a	18.2 a	32.6 a			
NEO 560 IPRO	50.6 a	20.2 a	30 a			
NEO 580 IPRO	53 a	17.4 a	25.2 a			
NEO 531 I2X	43.6 a	15.4 a	19.8 a			
NEO 510 IPRO	47.4 a	17 a	18.8 a			
CV	31.3	20.64	31.06			

Superiority was observed in the NEO581 E and NEO580 IPRO cultivars in plants per linear meter, with 7.99 and 9.03 plants, while the ST622 IPRO, ST580 I2X, ST611 IPRO, NEO531 I2X and NEO510 IPRO cultivars were inferior and did not differ statistically, with 5.46, 5.6, 6.2, 6.13 and 4.62 plants per linear meter, respectively. For the grain weight variable in vegetables with one grain, the cultivar ST541 I2X was superior, with 1.5 g, while the cultivars ST622 IPRO, ST611 IPRO, NEO531 I2X and NEO510 IPRO were statistically inferior, with 0.6. 0.6, 0.7 and 0.6 g, respectively. For the grain weight variable in three-grain vegetables, the cultivar ST622 IPRO was superior, with an average of 18.7 g, while the cultivars NEO580 IPRO and NEO510 IPRO were inferior, with averages of 6.8 and 6.4 g, respectively.

In the primary yield component of grain weight in the plant, the cultivar ST622 IPRO was superior with 21.6 g, not statistically different from the cultivars ST 541 I2X ST580 I2X, ST611 IPRO, NEO581 E, while the cultivar NEO510 IPRO was inferior to too much. For the grain yield variable in kg ha^{-1}, the NEO581 E cultivar was superior, with 5780 kg ha^{-1}, while the NEO510 IPRO cultivar was inferior, with 1804 kg ha^{-1}. For the variable height of the production zone, the ST611 IPRO cultivar was superior, with 86.4 cm, while the ST622 IPRO cultivar was inferior, with an average of 45.2 cm.

For the variable number of total nodes on the main stem, the cultivar ST535 I2X was superior with 21.8 nodes, not statistically different from the cultivars ST541 I2X, ST622 IPRO, and ST611 IPRO, while the cultivar NEO531 I2X was inferior. The variables branch length, root length and number of legumes with three grains did not show any significant difference between them.

In the table 5 of the predictive model, it was observed that the grain yield had an average of 4463.5 kg for the ten cultivars, and that some variables contributed positively and some negatively. Observing the group of diseases, it was evident that the pathogens *Cercospora sojina* and *Corynespora casiicola* had a positive contribution to yield, that is, even with the presence of the pathogen in plants, grain yield was not compromised. The pathogens *Macrophomina phaseolina*, *Colletotrichum truncatum*, *Crestamento* and *Perenospora manshurica* contributed negatively, that is, with the presence of the pathogen in the plants, yield was reduced on average across the cultivars. The same negative contribution was observed for the insect pests *Bacaris sp*. and *Diabrotica speciosa*.

Table 5. Predictive model based on multiple linear regression (StepWise) for grain yield where the other characters were considered as explanatory.

	Grain yield-dependent character
Agronomic components	y = 139,75 + 5,706 (GWV2) - 270,252 (GWV3) + 394,003 (GWP)
Phenomics	y = 3071998,5 - 4533,4 (BGI) - 1139221,8 (GLI2) + 613,9 (GRAY) - 595,7 (GRAY2) + 328926,7 (IGB) - 3834,5 (IGR) - 559636,3 (IRB) + 3093315 (NGBDI) - 1346473 (NRBDI) - 6886494,9 (NG) + 35519,4 (RGRI)
Abiotic effects	y = -21093,18 + 382,96 (F_E_Spot) - 185,11 (Browsing) - 37,89 (Anthracnose) - 79,63 (Macrophomina) + 356,08 (Target_spot) - 1744,01 (Mildew) - 835,54 (Grasshopper) - 106,86 (Diabrotica)

*significant at 5% by t-test.

Analyzing the quantitative characters, the positive contributions to yield came from the grain weight of vegetables with 2 grains, and the grain weight of the plant, having a strong influence on the average grain yield. The vegetable grain weight with 3 grains contributed negatively to the yield, as the average grain weight was lower than expected, lowering the average grain yield.

For the vegetation indices that contributed positively, the GRAY, IGB and RGRI index stand out, while the BGI, GLI2, GRAY2, IGR, IRB, NRBDI and NG indices had negative contributions to the average grain yield.

Conclusions

The NEO 581 E cultivar showed better yield performance, reaching 5780 kg ha^{-1}, followed by the SOYTECH 541 I2X cultivar, which reached a yield of 5356 kg ha^{-1}.

The predictive model identified the main variables that influenced final yield, with *Cercospora sojina* and *Corynespora casiicola*, grain weight in three-grain legumes, plant grain weight, GRAY index, IGB, NGBDI and RGRI, the variables that contributed positively to grain yield.

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