Agronomy Science and Biotechnology

MECENAS PUBLISHING

Research Article

Determining factors for the selection of soybean cultivars and the cause and effect relationships with grain yield

Lara Laís Schünemann[1], Júlia Sarturi Jung[1], Ivan Ricardo Carvalho[1], Jean Michel Schneider[1], Willyan Júnior Adorian Bandeira[1], Jaqueline Piesanti Sangiovo[1], Gabriel Mathias Weimer Bruinsma[1], José Antonio Gonzalez Da Silva[1] and Gerusa Massuquini Conceição[1]

[1]Universidade Regional do Noroeste do Rio Grande do Sul, Departamento de Estudos Agrários, Avenida do Comércio, nº 3.000, Bairro Universitário, Ijuí, RS, Brazil, CEP 98700-000.
*Corresponding author, E-mail: carvalhoirc@gmail.com

Citation: Schünemann, L. L., Jung, J. S., Carvalho, I. R., Schneider, J. M., Bandeira, W, J. A., Sangiovo, J. P., Bruinsma, G. M. W., Silva, J. A. G., & Conceição, G. M. (2024). Determining factors for the selection of soybean cultivars and the cause and effect relationships with grain yield. *Agronomy Science and Biotechnology*, *10*, 1-18. https://doi.org/10.33158/ASB.r207.v10.2024

Received: July 16, 2024.
Accepted: August 8, 2024.
Published: October 7, 2024.

English by: Ivan Ricardo Carvalho

Abstract

The objective of the present study was to apply the trail analysis model to extract the cause and effect action on soybean grain yield as a function of agronomic attributes. The present study was developed in the agricultural years of 2023 and 2024. The experimental design used was strips with randomized blocks, consisting of 10 cultivars and five replications. Through the means comparison test, the highest grain yields were observed in the cultivars C 2531 E, BMX Vênus CE, B 5595 CE and NEO581 CE. It was observed that in addition to the higher grain yield, the cultivar C 2531 CE also presented a higher grain weight per plant, despite having the lowest final plant height and productive zone height among the cultivars. As for BMX Vênus CE, it was observed that despite its medium height, it presented a shorter internode length on the main stem, which optimized the number of total nodes on the main stem, in addition to presenting a high grain weight per plant. Cultivar B 5595 CE can be highlighted for its greater final plant height, as well as greater height of the productive zone, promoting a greater number of total nodes on the main stem. Another highlight of this cultivar is the high number of plants per final linear meter, indicating its adaptability in the field. The cultivar NEO581 E, despite having one of the smallest heights among the cultivars, presented one of the highest grain yields, which can be attributed to the stability of the cultivar in the field, as it showed intermediate performance for all agronomic traits.

Keywords: *Glycine max*; direct and indirect selection; yield components; biofuel; production system; adaptation of soybean; tropical environment.

Introduction

Soybean (*Glycine max* L. Merr.) is one of the most prominent crops in the world economy, due to the use of the grain in the agroindustry, aimed at producing vegetable oil and animal feed, in addition to the chemical and food industries. Recently, its use as an alternative source of biofuel has been growing significantly (Oliveira, Benett, Benett, Silva, & Vieira, 2017). In the production system, soybeans enable the profitability and profitability of grain-producing crops, being the main summer crop from north to south of Brazil (Artuzo, Foguesatto, Souza, & Silva, 2018).

According to the United States Department of Agriculture (USDA) (2023), approximately 365 million tons are currently produced in the world, where Brazil alone is responsible for more than 147 million tons, being considered the largest producer in the world. In the country, the crop occupies an area of approximately 45 million hectares, with an average yield of Brazilian soybeans of 3,229 kg ha^{-1} of grains (Companhia Nacional de Abastecimento [CONAB], 2024). The vast Brazilian territory and the successful adaptation of soybeans to the tropical environment offered the necessary conditions for the development and improvement of the crop in increasingly complex environments across the Brazilian territory (Vieira Filho & Fishlow, 2017).

Therefore, due to this great importance, it is essential to develop new cultivars with good agronomic performance specifically for the different growing regions (Leite, Pavan, Matos Filho, Feitosa, & Oliveira, 2015). According to Marcon, Romio, Maccari, Klein and Lájus (2017), the cultivar is responsible for 50% of the crop's final yield, making the choice of the appropriate cultivar crucial for the success of grain production. The new seeds that reach the market have attributes developed through large investments in research, which involve the creation of new cultivars, genetic modifications and manipulations, and the insertion of new genes (Lima & Santos, 2018). These improvements give cultivars tolerance to diseases and pests, adaptations to different macro-regions through manipulation of their cycle, and even tolerance to herbicides (Dan et al., 2010).

To achieve this, it is essential to know the correlations between traits of interest for selection in a population, as this has been highly relevant in plant breeding. This knowledge provides useful information to the breeder, helping with indirect selection for main traits (Leite et al., 2015). Understanding the associative behavior and correlations between desirable agronomic traits allows us to identify those that can be used in selection, indirectly favoring other traits. In other words, it shows how the selection of a certain trait influences the expression of others, especially for quantitative traits that have low heritability (Santos, Spehar, Capone, & Pereira, 2018).

Studies of linear relationships between a set of traits can be carried out using Pearson's linear correlation coefficient (r) and linear regression. Two variables can present a perfect negative linear correlation (r = -1), a perfect positive correlation (r = 1) or no linear relationship (r = 0). Regression analysis allows predicting the value of the dependent variable based on the independent variable. Correlation is only a measure of association, not allowing conclusions about cause and effect. To overcome this limitation, path analysis is used, which allows the decomposition of correlation coefficients into direct and indirect effects (Semnaninejad, Nourmohammadi, Rameeh, & Cherati, 2021). In this sense, the objective of the present study was to apply the trail analysis model to extract the cause and effect action on soybean grain yield as a function of agronomic attributes.

Materials and Methods

The present study was developed in the agricultural years of 2023 and 2024, in the experimental area of the Regional Institute for Rural Development (IRDeR), located in the municipality of Augusto Pestana, in the state of Rio Grande do Sul, Brazil. The geographical position is 28° 26’ 30’’ S latitude and 54° 00’ 58’’ W longitude, and an approximate altitude of 400 meters. The soil in the experimental area is classified as a typical dystroferric Oxisol, according to SiBCS (Brazilian Soil Classification System), with a deep profile, well drained, dark red color, with high

clay contents and a predominance of 1:1 clay minerals and iron and aluminum oxyhydroxides (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2018). According to Köeppen's climate classification (Köeppen, 1948), the region's climate fits the description of Cfa, with hot summers and no prolonged droughts.

The experimental design used was strips with randomized blocks, consisting of 10 cultivars and five replications. The experimental units consisted of seven lines 15 meters long, spaced 0.5 meters apart, as recommended for soybean cultivation. In this study, 10 cultivars were analyzed, namely ST 616 I2X, BMX Fúria CE, BMX Vênus CE, NEO581 E, B 5595 CE, B 5560 CE, B 5540 E, C 2550 E, C 2534 E and C 2531 E, which were characterized regarding qualitative attributes (Table 1). Prior to sowing and beginning of management, a physical and chemical analysis of the soil was carried out (Table 2), to diagnose its fertility. Sowing was carried out on November 8, 2023, with the aid of a seeder-fertilizer and a population of 14 seeds per meter, for all cultivars, fertilizing with 250 kg ha^{-1} in the 05-20-10 NPK formulation. Phytosanitary management (Table 3) was carried out preventively, following technical recommendations for soybean cultivation, in order to avoid the effects of biotic factors on the results of the experiment.

In the first analysis, the variables analyzed in the reproductive period were: Number of plants per final linear meter (NPLM_F, No.); final plant height (PH_F, cm); height of the productive zone (HPZ, cm); insertion height of the first vegetable (IHFV, cm); number of total nodes on the main stem (NTN_MS, No); number of total nodes in the branches (NTN_B, No.); number of vegetables on the main stem (NVMS, No.); number of vegetables on the branches (NVB, No.); number of branches (NB, No.); branch length (BL, cm); root length (ROOT_L, cm); number of vegetables with one grain (NV1, No.); number of vegetables with two grains (NV2, No.); number of vegetables with three grains (NV3, No.); number of vegetables with four grains (NV4, No.); number of abortive vegetables (NV0, No.); main stem internode length (MS_IL, cm); and branching internode length (B_IL, cm).

Furthermore, to identify the level of tolerance of cultivars to the treatments applied the percentage of disease incidence (PDI, %) was evaluated; percentage incidence of pest insects (PIPI, %); percentage of incidence of invasive plants (PIIP, %). The assessment of the severity of diseases, invasive plants and insect pests present in the experimental units was carried out using a visual rating scale ranging from zero to 10, where zero (0% - absence), 10 (100% - high severity). At physiological maturity, sampling was carried out on the 2nd, 18th and 20th of March 2024, where 50 plants of each of the cultivars were collected. From the collected plants, the following variables were measured to determine grain yield: vegetables weight with one grain (VW1G, g); vegetables weight with two grains (VW2G, g); vegetables weight with three grains (VW3G, g); vegetables weight with four grains (VW4G, g), grain weight per plant (GWP, g) and total grain yield (GY, kg ha^{-1}). The meteorological attributes were obtained through the NASA Power platform (National Aeronautics and Space Administration [NASA], 2023), these being: mean air temperature (Tmean, °C), minimum air temperature (Tmin, °C), maximum air temperature (Tmax, °C) and precipitation (P, mm).

In all evaluations carried out, the plants were collected within the five internal lines (discarding the two external lines) randomly within the experimental units of each of the cultivar blocks. Initially, the data was subjected to outlier analysis to remove outlayers. All variables with a coefficient of variation greater than 35% were used for descriptive analysis. For the remaining variables, the assumptions of the statistical model were verified, based on tests of normality of errors and homogeneity of variances, using the Shapiro-Wilk and Bartlett tests.

Table 1. Qualitative traits of cultivars.

Cultivars	Flower color	Pod color	Seed Shape	Integument color	Anthocyanic hypocotyl pigm.	Pubescence color	Pubescence density	Hilum color	Peroxidase reaction	Type of growth	Seed shine	Observation
ST 616 I2X	Purple	Dark gray	Flattened spherical	Yellow	Present	Gray	Medium	Imperfect black	Negative	Undetermined	Medium	ND
BMX Fúria CE	White	Light gray	Spherical	Yellow	Absent	Gray	Medium	Light brown	Positive	Undetermined	Low	ND
BMX Vênus CE	Purple	Light gray	Flattened spherical	Yellow	Present	Gray	Medium	Imperfect black	Negative	Undetermined	Low	Features environmental variation
NEO 581 E	White	Dark gray	Spherical	Yellow	Absent	Gray	Medium	Light brown	Positive	Undetermined	Low	ND
B 5595 CE	Purple	Light gray	Flattened spherical	Yellow	Present	Gray	Medium	Imperfect black	Negative	Undetermined	Low	ND
B 5560 E	White	Dark gray	Spherical	Yellow	Absent	Gray	High	Light brown	Positive	Undetermined	Low	ND
B 5540 E	White	Dark gray	Flattened spherical	Yellow	Absent	Gray	Medium	Light brown	Positive	Undetermined	Medium	ND
C 2550 E	Purple	Light gray	Spherical	Yellow	Present	Gray	Medium	Imperfect black	Negative	Undetermined	Medium	ND
C 2534 E	White	Dark Brown	Alongada	Yellow	Absent	Gray	Medium	Brown	Positive	Undetermined	Low	ND
C 2531 E	White	Med. brown	Flattened spherical	Yellow	Absent	Gray	Medium	Light brown	Negative	Undetermined	Low	ND

ND = not described. Source: MAPA -National Cultivars Registry (RNC) .

Table 2. Physical and chemical soil analysis of the study area.

Clay	Sand	Silt	Soil Type	Textural class	
(%)					
59	19	22	3	Clay	

Area	Clay (%)	pH	Index SMP	Phosphorus (mg/dm³)	Potassium (mg/dm³)
IRDeR	54	5,2	5,8	39,5	328

Organic Matter (%)	Aluminum ($cmol_c/dm^3$)	Calcium ($cmol_c/dm^3$)	Magnesium ($cmol_c/dm^3$)	H + Al ($cmol_c/dm^3$)	$CTC_{pH\ 7,0}$ ($cmol_c/dm^3$)
3,3	0,1	5,3	2,9	5,5	14,5

$CTC_{effective}$	Sat $CTC_{pH7,0}$ per base	Sat $CTC_{effective}$ per aluminum	Copper	Zinc	Manganese	Sulfur	Sodium
$Cmol_c/dm^3$	(%)		Mg/dm³				
9,2	62,3	1,2	12,0	4,6	35,1	16,1	NB

NB = analysis not performed. Source: UNIJUÍ soil laboratory.

Table 3. Phytosanitary management carried out on cultivars.

Moment/stadium	Class	Commercial name	Active principle	Dose
30 DBS[1]	Herbicide	Zapp QI 620	glyphosate-potassium salt	2.0 L ha^{-1}
	Herbicide	2,4 D Nortox	2,4- dichlorophenoxy	1.5 L ha^{-1}
	Herbicide	Cletodim Nortox	Clethodim	0.6 L ha^{-1}
	pH reducer	NP 10	10%N + 10%P	50 ML ha^{-1}
2 DPS[2]	Herbicide	Reglone	Diquate	2.5 L ha^{-1}
	pH reducer	NP 10	10%N + 10%P	50 ML ha^{-1}
V4	Herbicide	Zapp QI 620	glyphosate-potassium salt	2.0 L ha^{-1}
	Insecticide	Sperto	Acetamiprid + Bifenthrin	200 g ha^{-1}
	Insecticide	Dimilin	Diflubenzuron	60 g ha^{-1}
	Fungicide	Erradik	Difenoconazole	250 ml ha^{-1}
	Foliar fertilizer	Foltron	N, P_2O_5, K_2O)	0.8 L ha^{-1}
	pH reducer	NP 10	10%N + 10%P	50 ML ha^{-1}
R1	Insecticide	Engeo Pleno	Tiametoxam + Cipermetrina	250 ml ha^{-1}
	Fungicide	Alade	Benzovindiflupir + Ciproconazole + Difenoconazole	0.5 L ha^{-1}
	pH reducer	NP 10	10%N + 10%P	50 ML ha^{-1}
R3	Insecticide	Sperto	Acetamiprid + Bifenthrin	200 g ha^{-1}
	Fungicide	Mitrion	Benzovindiflupir + Prothioconazole	0.5 L ha^{-1}
	pH reducer	NP 10	10%N + 10%P	50 ML ha^{-1}
R5	Insecticide	Sperto	Acetamiprid + Bifenthrin	200 g ha^{-1}
	Fungicide	Evolution	Azoxystrobin + Dithiocarbamate + Mancozeb	2.0 kg ha^{-1}
	pH reducer	NP 10	10%N + 10%P	50 ML ha^{-1}

[1]DBS = days before sowing; [2]DPS = days post-sowing.

With the assumptions met, analysis of variance was carried out to detect the effect of cultivars on the measured variables, at 5% probability using the F test. Subsequently, a mean comparison test was carried out using Tukey at 5% probability. Pearson's linear correlation coefficients were obtained to determine the degree of association between the quantitative variables. Path analysis was carried out to determine the cause and effect relationships, setting grain yield as the dependent variable and the others as independent. Multicollinearity diagnosis was carried out using the variance inflation factor. Statistical analyzes were carried out using the Microsoft Office Excel® application and the R software (R CORE TEAM, 2024), in which the AgroR (Shimizu, Marubayashi, & Goncalves, 2023) and Metan (Olivoto & Lúcio, 2020) packages were used.

Results and Discussion

According to physical and chemical analysis (Table 2), the soil in the area is type 3, clay textural class, with a sand, silt and clay content of 22%, 19% and 59%, respectively. Still according to Table 2, it is observed that the soil pH is 5.2, however the ideal for soybean cultivation is between 5.5 and 6.0. With slightly acidic soil, it promotes an increase in aluminum content, which despite being at low levels (in this case with 0.1 cmolc/dm3), can still interfere with root growth, preventing it from seeking nutrients and water in depth, and causing a reduction in yield (Hajiboland et al., 2023). As for macronutrients, both phosphorus and potassium are very high, calcium and magnesium are high in the soil, as well as the micronutrients copper, zinc and manganese.

According to Figure 1, when analyzing meteorological factors in the 2023/2024 harvest, it was observed that the mean temperature in November remained around 23ºC, the maximum at 28ºC and the minimum at 17ºC. As for precipitation, most of the month there was precipitation of 7mm, with isolated occurrences of precipitation of 80mm. The air temperature during the sowing period exceeded the minimum value of 18ºC, indicated by Minosso, Sostisso and Dranski (2021) as sufficient to allow rapid and uniform emergence of the crop. In the month of December, the mean temperature remained around 24ºC, the maximum temperature around 29ºC, and the minimum temperature 18ºC. Precipitation for the month remained around 7mm, with an isolated occurrence of 80mm.

Still according to Figure 1, in the months of January and February an average temperature of approximately 24ºC was recorded, and maximum and minimum temperatures remained close to 30ºC and 18ºC, respectively. Considering the behavior of meteorological factors in the months that covered the soybean cycle, the maximum, average and minimum temperatures remained within the ideal cited by Kopf and Brum (2019) where soybean adapts best at temperatures between 20°C and 30°C, with the ideal temperature for plant development being around 25°C.

As for precipitation, rainfall was identified by Oliveira, Knies, Rodrigues, Schmidt and Kury (2021) as the main meteorological variable determining fluctuations in soybean grain yield in Rio Grande do Sul. Even considering that the total rainfall accumulation exceeded 1000mm, and that according to Nepumoceno, Farias and Neumaier (2017) soybeans need a total of 450 mm and 800 mm of water to complete its development cycle. In most of the months of January and February it remained with a daily average of 5 mm, with precipitation of up to 80 mm. However, with irregular distribution, with consecutive days without rain in this reproductive period, where the water demand required is 7 to 8 mm per day (Ferrari, Paz and Silva, 2015).

The descriptive analysis of the percentage of disease incidence (PDI) (Table 4) revealed that the cultivar ST 616 I2X presented the highest number of diseases, and of the four that were manifested, the highest incidence was of *Phakopsora pachyrhizi* (50%), followed by *Colletotrichum truncatum* (10%), *Cercospora sojina* (5%) and *Septoria glycines* (5%). Cultivar B 5595 CE showed an incidence of three diseases, namely *Phakopsora pachyrhizi*, *Corynespora cassiicola* (both at an intensity of 20%) and *Pseudomonas savastanoi pv. glycinea* (30%). The cultivars BMX Vênus CE, NEO581 E, B 5560 CE and C 2531 E, present only two diseases, with the cultivar

BMX Vênus CE presenting *Corynespora cassiicola* (10%) and the highest incidence of *Phakopsora pachyrhizi* (85%) compared to others cultivars.

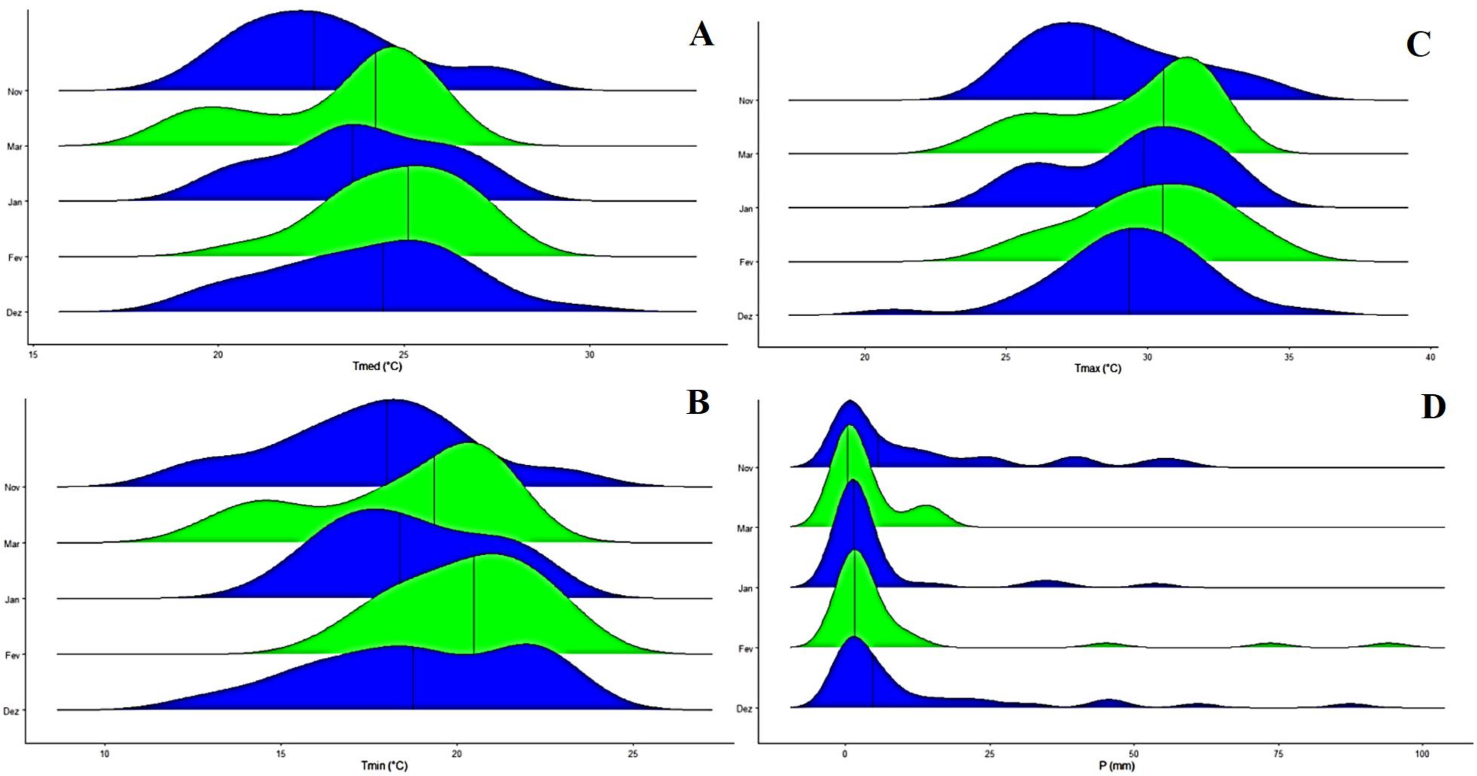

Figure 1. Descriptive analysis of average temperature (A - Tmean, ºC), minimum temperature (B - Tmin, ºC), maximum temperature (C - Tmax, ºC), and precipitation (D - P, mm) from November 2023 to March 2024 (axes).

The NEO581 E cultivar presented *Phakopsora pachyrhizi* (53%) and *Peronospora manshurica*, B 5560 CE presented *Phakopsora pachyrhizi* (20%) and *Fusarium solani f. sp. glycines* (10%) and C 2531 E, presented an incidence of *Phakopsora pachyrhizi* (15%) and *Corynespora cassiicola* (10%). The cultivar BMX Fúria CE only showed an incidence of *Phakopsora pachyrhizi* (35%), and the cultivars B 5540 E, C 2550 E and C 2534 E, due to the advancement of physiological maturity at the time of evaluation, were not evaluated for the presence of diseases.

Still according to Table 4, it is observed that the disease that had an incidence in the largest number of cultivars was *Phakopsora pachyrhizi*, which affected seven cultivars, followed by *Corynespora cassiicola*, which affected three cultivars, the other diseases affected only one cultivar. As described by Godoy et al. (2016), *Phakopsora pachyrhizi* is one of the most serious diseases that affects the crop, limiting production in several producing countries around the world by up to 90%, especially when environmental conditions are favorable and significantly increase its damage potential.

The highest incidence of pests insects (PIPI) (Table 5) occurred in the cultivar ST 616 I2X, with the presence of *Dichelops furcatus*, *Euschistus heros*, *Diabrotica speciosa* (all at an intensity of 3%), and *Thysanoptera* (30%). The cultivars BMX Fúria CE, BMX Vênus CE and B 5595 CE presented three species of insect pests, in which the cultivar BMX Fúria presented *Thysanoptera* (35%) and *Diabrotica speciosa* (3%), the cultivar BMX Vênus CE presented *Polyphagotarsonemus latus*, and the highest incidence of *Thysanoptera* (65%), compared to other cultivars, and in cultivar B 5595 CE, the species *Thysanoptera* (15%) and *Chrysodeixis includens* (5%) occurred.

In the cultivars NEO581 E and C 2531 E, only *Thysanoptera* occurred, at an intensity of 45% and 30% respectively. Cultivar B 5560 CE did not present an incidence of insect pests, while cultivars B 5540 E, C 2550 E and C 2534 E were not evaluated for the presence of insect pests due to the advancement of physiological maturity at the time of evaluation. Still according to Table 3, it is observed that the insect pests that affected the largest number of cultivars were *Thysanoptera*, which affected seven cultivars and *Diabrotica speciosa*, which affected two cultivars, the other species of insect pests affected a single cultivar.

Table 6, which represents the descriptive analysis of the percentage incidence of invasive plants (PIIP), shows that cultivars B 5540 E and C 2550 E presented an incidence of *Conyza bonariensis* (20%), *Ipomoea triloba* (10%), *Sida rhombifolia* (20%), *Richardia brasiliensis* (15%) and *Bidens pilosa* (15%). According to Siqueira, Oliveira, Peixoto, and Amaral, (2021), when invasive plants are not managed efficiently, they result in reduced yield, as they compete for light, water and nutrients with the crop.

In the ST 616 I2X cultivars there was the presence of *Digitaria insularis* and *Amaranthus sp*., both with 5% intensity, and *Ipomoea triloba* (2%). In the BMX Fúria CE cultivar there was an incidence of *Conyza bonariensis* (5%), *Amaranthus sp.* (15%) and *Ipomoea triloba* (10%). In cultivar B 5560 CE, there was the presence of *Conyza bonariensis* (20%), *Amaranthus sp*. and *Ipomoea triloba*, both at an intensity of 15%. In cultivar C 2534 E, *Conyza bonariensis* (20%), *Amaranthus sp.* (15%) and *Richardia brasiliensis* (10%). Finally, *Conyza bonariensis* was present in nine of the ten cultivars in the study, which can reduce soybean yield by 4 to 12% with the presence of just one plant per square meter.

The cultivar BMX Vênus CE presented a high number of total nodes in the branch (Table 7), being an important component to be evaluated as it demonstrates the productive potential of the soybean plant, being able to indicate positions for the emergence of flowers and, consequently, pods (Herrera et al., 2020). For vegetables in branches (NVB), the cultivars BMX Vênus CE, B 5540 E, C 2550 E and C 2534 E presented the highest values, favoring an increase in the number of fertile vegetables in the plants, which can contribute up to 70% of the grain yield, according to the arrangement of plants in space (Mello & Brum, 2020).

For the branching internode length (B_IL), the cultivar BMX Fúria CE presented the lowest measurement. In work carried out by Silva, Souza, Santos, and Souza (2019), it was found that plants from cultivars with an indeterminate growth habit were superior to plants from cultivars with determinate growth, largely associated with the distance between one reproductive node and another (internode length - IL). Smaller distances promote greater utilization of the main stem, by reducing the distance between one node and another, enabling the development of a greater number of reproductive nodes on the stem, consequently, an increase in the yield of this cultivar.

It was noted that all cultivars presented a high number of vegetables with three grains (NV3), with emphasis on the cultivars ST 616 I2X, BMX Fúria CE, BMX Vênus CE and C 2550 E. In contrast, the cultivar C 2531 E presented low number of vegetables with three grains (NV3), with a greater number of vegetables with one grain (NV1) and an intermediate number of vegetables with two grains (NV2) and number of abortive vegetables (NV0).

According to Derretti et al. (2022), the greater grain production per plant is related to the high number of vegetables containing three grains. It is worth noting that the number of grains per vegetable and the grain mass are less influenced by the environment (Franz et al., 2020). Furthermore, it was noted that cultivar B 5540 CE presented higher NV0.

The summary of the analysis of variance (Table 8) showed a significant effect of the cultivars on the variables insertion height of the first vegetable (IHFV), main stem internode length (MS_IL), final plant height (PH_F), height of the productive zone (HPZ), number of total nodes on the main stem (NTN_MS), root length (ROOT_L), number of vegetables on the main stem (NVMS), number of plants per final linear meter (NPLM_F), vegetable weight with one grain (VW1G), vegetable weight with 2 grains (VW2G), vegetable weight with three grains (VW3G), grain weight per plant (GWP) and grain yield (GY). The coefficient of variation ranged from 11.31 to 30.63%.

For the means comparison test (Table 9), the cultivar that presented the highest GY was C 2531 E (3855.7 Kg ha^{-1}), followed by BMX Vênus CE (3780.1 Kg ha^{-1}), B 5595 CE (3751.9 kg ha^{-1}) and NEO581 CE (3583.3 kg ha^{-1}). Regarding final plant height (PH_F) and height of the productive zone (HPZ), the cultivars ST 616 I2X and B 5595 CE presented the highest averages. The cultivars ST 616 I2X and B 5595 CE had plant heights of 103.4 and 110.2 centimeters, respectively. According to Bagateli, Franco, Meneghello and Villela (2020), soybean plants taller than 100 centimeters tend to become lodging, hinder the efficiency of harvesters and tend to produce less.

Table 4. Descriptive analysis of the percentage of disease incidence (PDI) of cultivars.

CULTIVARS	***Pseudomonas savastanoi* pv. *Glycinea*[1]**	***Colletotrichum truncatum***	***Phakopsora pachyrhizi***	***Corynespora cassiicola***	***Cercospora sojina***	***Septoria glycines***	***Peronospora manshurica***	***Fusarium solani* f. sp. glycines**
ST 616 I2X	0	10	50	0	5	5	0	0
BMX Fúria CE	0	0	35	0	5	0	0	0
BMX Vênus CE	0	0	85	10	0	0	0	0
NEO581 E	0	0	53	0	0	0	2	0
B 5595 CE	30	0	20	20	0	0	0	0
B 5560 CE	0	0	25	0	0	0	0	10
B 5540 E	NE	NE	NE	NE	NE	NE	NE	NE
C 2550 E	NE	NE	NE	NE	NE	NE	NE	NE
C 2534 E	NE	NE	NE	NE	NE	NE	NE	NE
C 2531 E	0	0	15	10	0	0	0	NE

[1]*Pseudomonas savastanoi pv. glycinea* = bacterial blight; *Colletotrichum truncatum* = anthracnose; *Phakopsora pachyrhizi* = Asian rust; *Corynespora cassiicola* = target spot; *Cercospora sojina* = frog's eye spot; *Septoria glycines* = brown spot; *Peronospora manshurica* = mildew; *Fusarium solani f. sp. glycines* = sudden death. NE = not evaluated.

Table 5. Descriptive analysis of the percentage incidence of pests insects (PIPI) of cultivars.

CULTIVARS	***Dichelops furcatus*[1]**	***Euschistus heros***	***Thysanoptera***	***Diabrotica speciosa***	***Chrysodeixis includens***	***Polyphagotarsonemus latus***
ST 616 I2X	3	3	20	3	0	0
BMX Fúria CE	0	0	35	3	0	0
BMX Vênus CE	0	0	65	0	0	10
NEO581 E	0	0	45	0	0	0
B 5595 CE	0	0	15	0	5	0
B 5560 CE	0	0	0	0	0	0
B 5540 E	NE	NE	NE	NE	NE	NE
C 2550 E	NE	NE	NE	NE	NE	NE
C 2534 E	NE	NE	NE	NE	NE	NE
C 2531 E	0	0	30	0	0	0

[1]*Dichelops furcatus* = green belly bug; *Euschistus heros* = brown bed bug; *Thysanoptera* = Trips; *Diabrotica speciosa* = cucurbit beetle; *Chrysodeixis includens* = soybean looper; *Polyphagotarsonemus latus* = broad mite. NE = not evaluated.

Table 6. Descriptive analysis of the percentage incidence of invasive plants (PIIP) of cultivars.

CULTIVARS	*Conyza bonariensis*[1]	*Digitaria insularis*	*Amaranthus sp.*	*Ipomoea triloba*	*Sida rhombifolia*	*Richardia brasiliensis*	*Bidens pilosa*
ST 616 I2X	0	5	5	2	0	0	0
BMX Fúria CE	5	0	15	10	0	0	0
BMX Vênus CE	10	0	10	15	0	5	0
NEO581 E	20	0	5	20	0	0	20
B 5595 CE	10	0	15	15	0	15	0
B 5560 CE	20	0	15	15	0	0	0
B 5540 E	20	0	0	10	20	15	15
C 2550 E	20	0	0	10	20	15	15
C 2534 E	20	0	0	10	0	15	15
C 2531 E	20	0	15	0	0	10	0

[1]*Conyza bonariensis* = Hairy fleabane*; Digitaria insularis* = Sourgrass; *Amaranthus sp*. = Amaranths; *Ipomoea triloba* = Littlebell; *Sida rhombifolia* = Arrowleaf aids; *Richardia brasiliensis* = White-eye; *Bidens pilosa* = Cobblers pegs.

Table 7. Descriptive analysis of the performance of each cultivar related to agronomic traits.

CULTIVARS	B_IL (cm)[1]	BL (cm)	NV0 (un.)	NV1 (un.)	NV2 (un.)	NV3 (un.)	NV4 (un.)	NVB (un.)	NTN B (un.)	NB (un,)
ST 616 I2X	2.6	41.6	0	1.6	17.4	39,0	1.0	25.2	19.2	3.2
BMX Fúria CE	0.7	33.4	0	1.2	9.4	35,0	2.0	21.6	27.4	3.6
BMX Vênus CE	1.1	45.8	0	2.0	34.2	38,8	0	39.6	40.4	5.2
NEO581 E	1.3	39.7	0	1.4	19.8	34,6	0	24.5	27.8	4.8
B 5595 CE	1.5	30.0	0	1.6	23.0	29,8	0	13.8	13.8	2.0
B 5560 CE	2.1	39.2	1.6	2.6	11.8	32,0	0	17,2	15.8	2.2
B 5540 E	2.5	50.6	3.5	1.3	20.4	31,0	0	34.8	21.8	2.4
C 2550 E	2.8	53.2	0	3.2	31.2	38,8	0	35.0	19.2	3.2
C 2534 E	3.1	60.7	0	3.3	23.8	31,0	0	33.0	22.8	2.6
C 2531 E	3.3	35.4	1.2	4.0	16.6	19,2	0	14.2	9.8	2.0

[1]B_IL = branching internode length; BL = branch length; NV0 = number of abortive vegetables; NV1 = number of vegetables with one grain; NV1 = number of vegetables with two grains; NV3 = number of vegetables with three grains; NV4 = number of vegetables with four grains; NVB = number of vegetables in the branch; NTN B = number of total nodes in the branch; NB = number of branches.

Table 8. Summary of the analysis of variance for the effect of cultivars on soybean agronomic traits.

SV[1]	DF	Probability (%5)												
		IHFV	MS_IL	PH_F	HPZ	NTN_MS	ROOT_L	NVMS	NPLM_F	VW1G	VW2G	VW3G	GWP	GY
Cultivars	9	0.0001	0.021	0.0001	0.0001	0.0001	0.503	0.065	0.003	0.0001	0.0001	0.0003	0.0001	0.0001
Block	4	0.177	0.151	0.863	0.433	0.128	0.665	0.277	0.074	0.585	0.484	0.443	0.364	0.122
Residual	36	-	-	-	-	-	-	-	-	-	-	-	-	-
CV%	-	17.26	13.08	11.68	11.31	14.36	27.89	26.58	16.73	30.63	20.74	20.60	19.94	28.94

[1]SV: source of variation; DF: degrees of freedom; IHFV: insertion height of the first vegetable; MS_IL: length of the internode in the main stem; PH_F: final plant height; HPZ: height of the production zone; NTN_MS: number of total nodes on the main stem; ROOT_L: root length; NVMS: number of vegetables on the main stem; NPLM_F: number of plants per final linear meter; VW1G: vegetable weight with one grain; VW2G: vegetable weight with two grains; VW3G: vegetable weight with three grains; GWP: grain weight per plant; GY: grain yield; and CV: coefficient of variation. *: significant at 5% probability of error using the F test.

Table 9. Mean comparison test for the agronomic traits of 10 soybean cultivars.

Cultivars	PH_F[1]	HPZ	NPLM_F	IHFV	NTN_MS	MS_IL	VW1G	VW2G	VW3G	GWP	GY
ST 616 I2X	103.4 a	77.2 ab	6.47 b	23.4 b	24.0 a	3.2 ab	0.5 d	5.0 d	10.1 abc	15.8 bcd	2278.9 ab
BMX Fúria CE	97.4 ab	65.2 bc	6.4 b	37.0 a	22.8 abc	2,9 b	0.7 bcd	5.1 d	13.7 a	23.9 a	3273.9 ab
BMX Vênus CE	76.0 c	63.6 bc	7.2 ab	19,0 bc	21.4 abcd	2.9 ab	1.2 b	9.3 ab	12.3 ab	23.0 ab	3780.1 a
NEO581 E	73.6 c	66.0 abc	7.5 ab	17.6 bc	19.8 abcd	3.3 ab	1.1 bc	8.4 abc	10.9 abc	20.9 abc	3583.3 a
B 5595 CE	110.2 a	81.4 a	9.3 a	35.6 a	23.4 ab	3.5 ab	0.7 bcd	6.9 bcd	10.1 abc	18.1 abcd	3751.9 a
B 5560 CE	79.8 bc	66.6 abc	8.4 ab	14.6 c	17.8 bcd	3.7 ab	0.6 cd	5.6 cd	9.2 bc	16.1 bcd	3086.3 ab
B 5540 E	69.4 c	56.8 c	6.6 b	12.2 c	17.4 bcd	3.3 ab	0.5 d	5.2 d	8.7 bc	14.6 cd	2139.5 ab
C 2550 E	69.4 c	58.0 c	6.3 b	12.0 c	16.2 d	3.4 ab	0.5 d	4.1 d	6.6 c	11.4 d	1634.0 b
C 2534 E	74.4 c	61.8 bc	6.7 b	14.0 c	16.2 d	3.8 a	0.5 d	4.0 d	6.7 c	11.6 d	1757.6 b
C 2531 E	68.4 c	54.0 c	6.7 b	15.4 c	17.4 bcd	3.1 ab	1.8 a	11.3 a	11.8 ab	25.2 a	3855.7 a
CV (%)	11.6	11.3	16.7	17.2	14.3	13.0	30.6	30.7	20.6	19.9	28.9

[1]PH_F = plant height; HPZ = height of the production zone; NPLM _F = plants per final linear meter; IHFV = insertion height of the first vegetable; NTN_MS = number of total nodes on the main stem; MS_IL = length of the internode in the main stem; VW1G = vegetable weight with one grain; VW2G = vegetable weight with two grains; VW3G = vegetable weight with three grains; GWP = grain weight per plant; GY = grain yield; CV = coefficient of variation; Means followed by the same lowercase letter in the column do not differ statistically by the 5% Tukey probability matrix.

Still regarding plant height (PH_F), cultivar C 2531 E stands out as the lowest among the cultivars evaluated, with 68.4 centimeters, and which consequently presented the lowest height of the productive zone (HPZ) (54.0 centimeters). The other cultivars adapted to the conditions described by Almeida, Oliveira, Matos, Souza and Ribeiro (2018), which recommends plants 70 to 90 centimeters tall for better harvesting efficiency. Furthermore, Carmo, Braz, Simon, Silva and Rocha, (2018) report that smaller plants in soybeans result in an increase in the number of grains per vegetable, grains per plant and grain mass, contributing to the productive potential of the crop.

Cultivar B 5595 CE presented a higher productive zone height (HPZ) (81.4 centimeters) compared to the others, since the larger the productive zone, the greater the area for the development of nodes and vegetables (Cruz, Sena Junior, Santos, Lunezzo, & Machado, 2016), both related to the insertion height of the first vegetable (IHFV), for which the highest averages were observed in the cultivars BMX Fúria CE and B 5595 CE and, on the other hand, the cultivars B 5540 E and C 2550 E did not present an insertion height of the first vegetable exceeding 13 centimeters, being the minimum preferable height of a soybean plant to avoid harvest losses, which occur at heights lower than this (Meier et al., 2019).

For the number of final plants per linear meter (NPLM_F), cultivar B 5595 CE stood out compared to the others, with 9.3 plants, while the other cultivars had similar averages. Menegon et al. (2024) highlights that the population of plants per area is a component of soybean yield that influences the number of vegetables and grains per plant, due to the plasticity of the crop. Furthermore, the number of total nodes on the main stem (NTN_MS) of the plants was higher in the ST 616 I2X cultivar.

For the traits vegetable weight with one grain (VW1G) and vegetable weight with two grains (VW2G) the highest averages belong to cultivars C 2531 E, while for vegetable weight with three grains (VW3G) the cultivar BMX Fúria CE presents the highest average. Regarding grain weight per plant (GWP), two cultivars stand out for presenting higher averages, namely BMX Fúria CE and C 2531 E.

Pearson's linear correlation coefficient (r) varies from -1 to 1, with the sign indicating the positive or negative direction of the relationship and the value indicating the strength of the relationship between the variables (Grácio & Oliveira, 2015). As shown in Figure 2, there was a strong linear correlation between the traits vegetables weight with three grains (VW3G) and grain yield (GY) (r=0.76), and number of plants per final linear meter (NPLM_F) and grain yield (GY) (r=0.63). In Pearson's linear correlation matrix (r), the r among the nine positive values varied between 0.08 and 0.73. Between the traits vegetable weight with four grains (VW4G) and number of plants per final linear meter (NPLM_F) there was a negative linear correlation.

When two explanatory variables are highly associated, it becomes difficult to estimate the relationships of each one individually, as several configurations can solve the system of normal equations. This characteristic is known as multicollearity (Blalock Jr, 1963). In the multicollinearity diagnosis, carried out in the correlation matrix of explanatory traits (NPLM_F, HPZ, VW3G and VW4G), a condition number of 4.01 was obtained, which characterizes adequate conditions for the path analysis, since all variables met the assumption of multicollinearity. In path analysis, correlation coefficients are broken down into direct and indirect effects, which allows measuring the influence of one variable on another, independently of the others (Follmann et al., 2017).

In the path analysis (Table 10), the explanatory trait number of plants per final linear meter (NPLM_F) showed a positive direct effect (0.562) on grain yield, indicating that when NPLM_F increases, grain yield also increases. As for the indirect effect of NPLM_F on other variables, there is a positive indirect effect on the variables height of the production zone (HPZ) (0.1674) and mass of vegetables with three grains (VW3G) (0.044). A negative indirect effect was observed on the variable mass of vegetables with four grains (VW4G) (-0.114), indicating that the increase in NPLM_F causes a reduction in VW4G. As for the VW3G trait, it can be considered that it demonstrated a positive direct effect (0.803) on grain yield, and a positive indirect effect on the variables NPLM_F (0.083), HPZ (0.083) and VW4G (0.427).

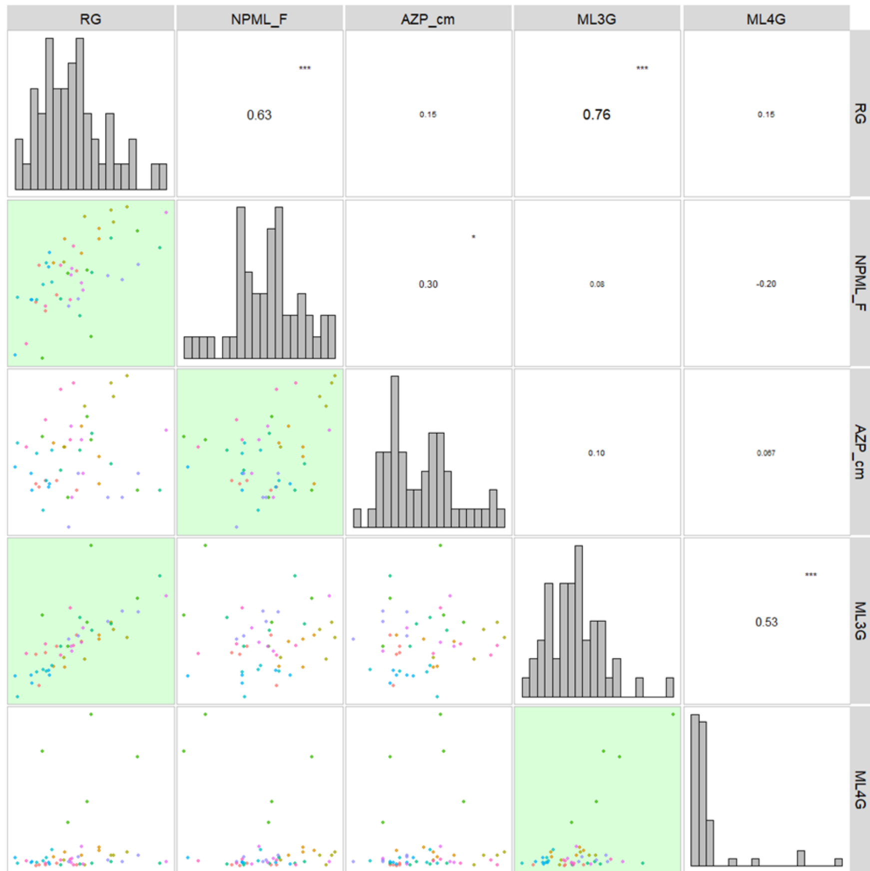

Figure 2. Matrix of linear correlations and scatter plots of agronomic traits and grain yield. (GY = grain yield; NPLM _F = number of plants per final linear meter; HPZ = height of the productive zone; VW3G = vegetable weight with three grains; VW4G = vegetable weight with four grains).

Table 10. Path analysis to estimate direct (bold diagonal) and indirect (off-diagonal) effects of agronomic traits on grain yield of soybean cultivars.

	NPLM F	HPZ	VW3G	VW4G	Pearson's Correlation (r)
NPLM F	**0.562**	-0.027	0.064	0.031	0.630*
HPZ	0.167	**-0.093**	0.083	-0.010	0.147
VW3G	0.044	-0.009	**0.803**	-0.082	0.756*
VW4G	-0.114	-0.006	0.427	**-0.150**	0.150

GY = grain yield; NPLM _F = number of plants per final linear meter; HPZ =height of the production zone; VW3G = vegetable weight with three grains; VW4G = vegetable weight with four grains. * Significant at 5% probability of error by Student's t test.

Conclusion

Through the means comparison test, the highest grain yields were observed in the cultivars C 2531 E, BMX Vênus CE, B 5595 CE and NEO581 CE. It was observed that in addition to the higher grain yield, the cultivar C 2531 CE also presented a higher grain weight per plant, despite having the lowest final plant height and productive zone height among the cultivars. As for BMX Vênus CE, it was observed that despite its medium height, it presented a shorter internode length on the main stem, which optimized the number of total nodes on the main stem, in addition to presenting a high grain weight per plant.

Cultivar B 5595 CE can be highlighted for its greater final plant height, as well as greater height of the productive zone, promoting a greater number of total nodes on the main stem. Another highlight of this cultivar is the high number of plants per final linear meter, indicating its adaptability in the field. The cultivar NEO581 E, despite having one of the smallest heights among the cultivars, presented one of the highest grain yields, which can be attributed to the stability of the cultivar in the field, as it showed intermediate performance for all agronomic traits.

References

Almeida, L. G. B., Oliveira, R., Matos, D. J. C., Souza, J. E. B., & Ribeiro, V. A. (2018). Phenotypic variation of agronomic traits in soybean genotypes. *Ipê Agronomic Journal, 2* (2), 58 – 67.

Artuzo, F. D., Foguesatto, C. R., Souza, Â. R. L. D., & Silva, L. X. D. (2018). Costs management in maize and soybean production. *Revista Brasileira de Gestão de Negócios, 20*, 273-294. https://doi.org/10.7819/rbgn.v20i2.3192

Bagateli, J. R., Franco, J. J., Meneghello, G. E., & Villela, F. A. (2020). Seed vigor and population density: effects on plant morphology and soybean productivity. *Brazilian Journal of Development, 6* (6), 38686-38718. DOI:10.34117/bjdv6n6-422

Blalock Jr, H. M. (1963). Correlated independent variables: The problem of multicollinearity. *Social Forces, 42*(2), 233-237. https://doi.org/10.2307/2575696

Carmo, E. L., Braz, G. B. P., Simon, G. A., Silva, A. G., & Rocha, A. G. C. (2018). Soybean performance at different sowing times and plant distribution. *Journal of Agroveterinary Sciences, 17* (1), 61-69. https://doi.org/10.5965/223811711712018061

CONAB – Companhia Nacional de Abastecimento. (2024). *Monitoring the Brazilian grain harvest*. Brasília, DF: CONAB.

Cruz, S. C. S., Sena Junior, D. G., Santos, D. M. A., Lunezzo, L. O., & Machado, C. G. (2016). Soybean cropping under different seeding densities and spatial arrangements. *Neotropical Agriculture Journal, 3* (1), 1-6.https://doi.org/10.32404/rean.v3i1.431

Dan, H. A., Dan, L. G. M., Barroso, A. L. L., Procópio, S. O., Oliveira, J. R. S., Silva, A. G., Lima, M. D. B., & Feldkircher, C. (2010). Residual activity of herbicides used in soybean agriculture on grain sorghum crop succession. *Planta Daninha, 28*, 1087–1095. https://doi.org/10.1590/S0100-83582010000500016

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. (2018). *Brazilian system of soil classification*. (5^{th} ed.). Brasília, DF: Embrapa.

Ferrari, E., Paz, A., & Silva, A. C. (2015). Water deficit on the soybean metabolism in early sowing. *Nativa, 3* (1), 67-77. https://doi.org/10.31413/nativa.v3i1.1855

Follmann, D. N., Cargnelutti Filho, A., Souza, V. Q., Nardino, M., Carvalho, I. R., Demari, G. H., Ferrari, M., Pelegrin, A. J., & Szareski, V. J. (2017). Linear relationships between off-season soybean traits. *Journal of Agricultural Sciences, 40* (1), 213-221.

Franz, E., Tironi, S. P., Luz, G. L., Cezarotto, L. A., Zago, D. V., Munaretto, D., & Dalcanton, F. (2020). Competitive ability of canola cultivars in competition with turnip. Brazilian *Journal of Development, 6* (10), 82507-82523. https://doi.org/10.34117/bjdv6n10-617

Godoy, C. V., Seixas, C. D. S., Soares, R. M., Marcelino-Guimarães, F. C., Meyer, M. C., & Costamilan, L. M. (2016). Asian soybean rust in Brazil: past, present, and future. *Pesquisa Agropecuária Brasileira, 51* (5), 407-421. https://doi.org/10.1590/S0100-204X2016000500002

Grácio, M. C. C., & Oliveira, E. F. T. (2015). Proximity indicators in author co-citation analysis: a comparative study between Pearson's Correlation coefficient and Salton's Cosine. *Information & Society: Studies, 25* (2), 105-116.

Hajiboland, R., Panda, C. K., Lastochkina, O., Gavassi, M. A., Habermann, G., & Pereira, J. F. (2023). Aluminum toxicity in plants: Present and future. *Journal of Plant Growth Regulation, 42*(7), 3967-3999. https://doi.org/10.1007/s00344-022-10866-0

Herrera, GC., Poletine, JP., Brondani, ST., Barelli, M. A. A., & Silva, VP. (2020). Adaptability and stability of soybean lines in southern Brazil through mixed modeling. *Journal of Agronomic Sciences, 9*, 185-202.

Köeppen, W. (1948). Climatology. Buenos Aires: Panamericana.

Kopf, J. C., & Brum, A. L. (2019). The exports of the agricultural metallomechanical sector as a factor of development: the case of the functional region of planning 7 of Rio Grande do Sul. *Brazilian Journal of Development, 5* (10), 19.287-19.307. https://doi.org/10.34117/bjdv5n10-156

Leite, W. D. S., Pavan, B. E., Matos Filho, C. H. A., Feitosa, F. S., & Oliveira, C. B. (2015). Estimates of genetic parameters and correlations between agronomic traits in soybean genotypes. *Nativa, 3* (4), 241-245. http://hdl.handle.net/11449/158365

Lima, L. G., & Santos, F. (2018). In the Semiarid of Alagoas, the resistance germinates on the land: the territorial struggle in defense of native seeds. *Nera Journal, 21*(41), 192-217.

Marcon, E. C., Romio, S. C., Maccari, V. M., Klein, C., & Lájus, C. R. (2017). Use of different sources of nitrogen in soybean cultivation. *Thema Journal, 14* (2), 298-308. https://doi.org/10.15536/thema.14.2017.298-308.427

Meier, C., Meira, D., Marchioro, V. S., Olivoto, T., Klein, L. A., Moro, E. D., Lunkes, A., Rigatti, A., Bello, R. F., Bueno, R. B., & Souza, V. Q. (2019). Agronomic performance and linear correlation between yield traits in the second–harvest soybean. *Journal of Agricultural Sciences*, *42* (4), 933-941. https://doi.org/10.19084/rca.17995

Mello, E. S., & Brum, A. L. (2020). The soybean production chain and some impacts on the regional development of Rio Grande do Sul. *Brazilian Journal of Development*, *6* (10), 74734-74750. https://doi.org/10.34117/bjdv6n10-049

Menegon, AHM., Lima, SF., Alves, VCD., Contardi, LM., Cordeiro, MAS., Vendruscolo, EP., Nunes, R. C. B., & Nogueira, A. R. F. (2024). Soybean Population Management Seeking Greater Grain Productivity. *Social and Environmental Management Magazine*, *18* (2), e04294-e04294. https://doi.org/10.24857/rgsa.v18n2-017

Minosso, R. R., Sostisso, G. L., & Dranski, J. A. L. (2021). Yield and yield components of soybeans cultivated with hydrogel. *Rural Scientific Journal*, *23* (1), 62-82. https://doi.org/10.30945/rcr-v23i1.3139

NASA - National Aeronautics and Space Administration. (2023). *NASA Prediction of Worldwide Energy Resources*. Florida, EUA: NASA. Available in: https://power.larc.nasa.gov/. Access in: Abril 20th, 2024.

Nepumoceno, A., Farias, J., & Neumaier, N. (2017). Characteristics of Soya. Londrina, PR: Embrapa Technological Information Agency, EMBRAPA.

Oliveira, F. C., Benett, C. S., Benett, K. S., Silva, L. M., & Vieira, B. C. (2017). Different doses and application times of zinc in soybean crop. *Neotropical Agriculture Journal*, *4* (5), 28-35. https://doi.org/10.32404/rean.v4i5.2188

Oliveira, Z. B., Knies, A. E., Rodrigues, L. R., Schmidt, D. A., & Kury, A. G. (2021). Soybean productivity as a function of sowing time and supplementary irrigation in the central region of RS. *IRRIGA Journal (Brazilian Journal of Irrigation & Drainage)*, *26* (4), 774-786.

Olivoto, T., Lúcio, A. D. (2020). Metan: An R package for multi-environment trial analysis. *Methods in Ecology and Evolution*, *11* (6), 783-789. https://doi.org/10.1111/2041-210X.13384

R Core Team. (2024). *A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Available in: <https://www.R-project.org> Accessed in: April 20th, 2024.

Santos, E. R., Spehar, C. R., Capone, A., & Pereira, P. R. (2018). Estimation of genetic variation parameters in F2 soybean progenies and parents with the presence and absence of lipoxygenases. *Nucleus (16786602)*, *15* (1). https://doi.org/10.3738/1982.2278.2169

Semnaninejad, H., Nourmohammadi, G., Rameeh, V., & Cherati, A. (2021). Correlation and path coefficient analyses of phenological traits, yield components and quality traits in wheat. *Brazilian Journal of Agricultural and Environmental Engineering*, *25*(9), 597-603. https://doi.org/10.1590/1807-1929/agriambi.v25n9p597-603

Shimizu, G. D., Marubayashi, R. Y. P., & Goncalves, L. S. A. (2023). AgroR: Experimental Statistics and Graphics for Agricultural Sciences. Londrina, PR. https://agronomiar.github.io/AgroR_package/index.html

Silva, S. I. A., Souza, T., Santos, D., & Souza, R. F. S. (2019). An assessment of production components in landraces of broad beans cultivated in the Agreste of Paraíba. *Journal of Agricultural Sciences, 42* (3), 731-742.

Siqueira, C. B., Oliveira, F. S., Peixoto, P. M. C., & Amaral, A. A. D. (2021). Importance and management of spontaneous plants from the perspective of agroecology-review. *Nucleus, (16786602), 18* (2).

USDA - United States Department of Agriculture. (2023). *Production, supply and distribution*. (2023). Available in: https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery. Accessed in: May 25th.

Vieira Filho, J. E. R., & Fishlow, A. (2017). *Agriculture and industry in Brazil*. Brasília, DF: Institute of Applied Economics Research.