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*Research Article*

# Agronomic aspects of soybean and predicted genetic relationships

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## Abstract

The objective of the study is to understand the performance of cultivars, highlight the genetic contribution to the phenotypic manifestation and predict the ranking of genotypes. This study was developed in the agricultural years 2023/2024, in the experimental area of the farm school of the Universidade Regional do Noroeste do Estado do Rio Grande do Sul. The experimental design used was strips with randomized blocks, consisting of 10 cultivars and five blocks. Sowing was carried out on November 8, 2023, with a target population of 14 seeds per linear meter. FPS 2063 IPRO cultivar presented the highest grain yield. Plant height, height of the productive zone, vegetable grain weight with two grains, vegetable weight with three grains and plant grain weight stands out as the components with the greatest genetic influence.

**Keywords**: *Glycine max*; REML/BLUP; selection; genotypes; phenotypic manifestation; yield.

# Introduction

Soybean (Glycine max (L. Merril)) is a crop of great importance for Brazilian agribusiness (Duval, Galantini, Capurro, & Martinez, 2016; Foleto et al., 2024; Prauchner et al., 2024; Schünemann et al., 2024; Zuse et al., 2024). According to (Companhia Nacional de Abastecimento [CONAB] 2024), in the 2023/2024 harvest, production was estimated at 147,353.5 million tons of grains and productivity of 3,205.0 kg $ha^{-1}$ in an area of 45,978.0 million hectares. In Rio Grande do Sul, an increase in the cultivated area of 244.8 thousand hectares was recorded and a reduction in average productivity, estimated at 2,985.0 kg $ha^{-1}$ of grains, influenced by the impacts of the heavy precipitation occurring in the state (CONAB, 2024).

Soy stands out as one of the great global powers in food production, being an important producer of a variety of grains used in various applications (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2020). It is important to highlight that the population will continue to grow in the coming years, and global agriculture will need to increase its production by 80% by 2050 to meet the needs of an estimated population of 9.7 billion people. Given this scenario, Brazil will have to contribute practically half of this increase (Di Pietro & Moreira, 2020).

Soybean culture is of great importance in human and animal nutrition due to its nutritional value, containing on average 36% protein and 22% oil on a dry basis (Pípolo & Mandarino, 2016). Its wide use caused its demand to increase, leading to the expansion of cultivation areas and greater demands for better productivity (Bergamini & Streit, 2023). Most soybean cultivars have high plasticity characteristics, that is, they have an abundance of climate adaptation, environmental and management conditions (Giordani et al., 2019). This reflects the introduction of new cultivars on the market that present high productivity in different regions of the country, interfering in a positive way in the entire production chain and, one of the tools used is genetic improvement (Silva, Borém, Sediyama, & Câmara, 2022).

Understanding the genetic value of a given genotype is crucial to improvement, where the prediction of these values became possible from 1963 onwards through studies by Henderson (1963), who compiled Yates' least squares method into a single model of 1931, least squares method into a single model, the selection indices from Lush and Wright of 1931, and the inferences obtained by the best linear predictor, calling the new model the best linear unbiased predictor (Best Linear Unbiased Prediction - BLUP). These iterative computational techniques are commonly associated with mixed model methodologies (REML) to obtain variance components and genetic parameters (Cruz, Carneiro, & Regazzi, 2014; Resende, Silva, & Azevedo, 2014). Restricted maximum likelihood (REML) is used combined with the best linear unbiased predictor (BLUP), where it is assumed that the variance components are known and genetic effects are considered random (Cruz et al., 2014). This methodology maximizes the relationship between the prediction of genetic value and the true genetic value, where the aim is to minimize the prediction error (Resende et al., 2014).

In this context, the search for an increase in productivity and quality is constant in soybean production, and it is crucial that breeding programs select progenies, lineages, populations and cultivars that are resilient to the most adapted environments (Port et al., 2024). Therefore, it is extremely important to have an adequate approach to the management that constitutes the production system, so that the culture can express the productive genetic potential built over the years. Therefore, the objective of the study is to understand the performance of cultivars, highlight the genetic contribution to the phenotypic manifestation and predict the ranking of genotypes.

## Materials and Methods

This study was developed in the agricultural years 2023/2024, in the experimental area of the farm school of the Universidade Regional do Noroeste do Estado do Rio Grande do Sul (UNIJUÍ), 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 (U.M. Santo Ângelo), with a deep profile, well drained, dark red color, with high clay content and a predominance of 1:1 clay minerals and iron and aluminum oxyhydroxides. According to the Köeppen climate classification, the region's climate fits the description of Cfa, with hot summers and no prolonged droughts (Dubreuil, Fante, Planchon, & Sant'Anna Neto, 2018).

The experimental design used was strips with randomized blocks, consisting of 10 cultivars and five blocks. The experimental unit consists of seven 15 m long lines, spaced 0.5 m apart, as recommended for soybean cultivation. In this study, 10 cultivars were analyzed and subsequently, their qualitative characteristics (Table 1). Sowing was carried out on November 8, 2024, with a target population of 14 seeds per linear meter, using base fertilization with 250 kg ha$^{-1}$ of mineral fertilizer in the NPK formulation (05-20-10). Prior to sowing and beginning of management, physical and chemical soil analysis was carried out in the area, to diagnose soil fertility. Phytosanitary management was carried out preventively, in order to avoid the effect of biotic factors on the results of the experiment (Table 2).

In an initial analysis, the following establishment variables were evaluated in soybean cultivars: number of plants per initial linear meter (I_NPLM); plantability (%); tipping (%); nodulation (%); cotyledon retention (CR); cotyledon damage (CD); initial root system depth (I_SR_DEPTH) and initial leaflet health (I_L_HEAL). The variables analyzed in the reproductive period were: number of plants per final linear meter (NPLM_F); plant height (PH, cm); insertion height of the 1st vegetable (IHFV, cm); production zone (PZ, cm); number of total nodes on the main stem (NTNMS); number of total nodes on the branches (NTNB); number of vegetables on the main stem (NVMS); number of vegetables on the branches (NVB); number of branches (NB); branch length (BL, cm); root length (ROOT, cm); number of vegetables with one grain (NV1); number of vegetables with two grains (NV2); number of vegetables with 3 grains (NV3); number of vegetables with 4 grains (NV4); number of vegetables with 0 grains (NV0); Percentage of disease incidence (PDI); percentage incidence of pest insects (PIPI); percentage of incidence of invasive plants (PIIP); main stem internode length (MSIL, cm); branch internode length (BIL, cm).

The harvest was carried out on March 25, 2024. The following variables were analyzed: productivity of vegetables with one grain (PV1G, g); productivity of vegetables with two grains (PV2G, g); productivity of vegetables with three grains (PV3G, g); productivity of vegetables with four grains (PV4G, g); total productivity (TP); total grain yield (TOTAL_GY); vegetable yield with one grain (VY1G); vegetable yield with two grains (VY2G); vegetable yield with three grains (VY3G); vegetable yield with four grains (VY4G).

The meteorological attributes were obtained through the NASA Power platform (NASA POWER, 2024), these being: mean air temperature (Tmean, °C), minimum air temperature (Tmin, °C), maximum air temperature (Tmax, ° C) and precipitation (Prec, mm). The data obtained were subjected to descriptive analyzes and the Mean Deviance test (RELM). Subsequently, the variance components and genetic parameters were estimated using the BLUP method, to estimate the new genotype values based on the general average (y= m + bj + eij). The analyzes were carried out using the R software (R Core Team, 2023).

**Table 1.** Qualitative characteristics of soybean cultivars.

| Cultivars | RMG | Flower color | Hilum color | Growth habit | Pubescence color | Vegetable color | Seed shape | Integument color |
|---|---|---|---|---|---|---|---|---|
| FPS 2063 IPRO | 6.3 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Spherical | Yellow |
| FPS 1859 RR | 5.9 | White | Imperfect black | Indeterminate | Gray | Light gray | Spherical | Yellow |
| FPS 2457 RR | 5.7 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Flattened spherical | Yellow |
| FPS 1954 RR | 5.4 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Spherical | Yellow |
| GH 6433 I2X | 6.4 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Flattened spherical | Yellow |
| GH 2258 IPRO | 5.9 | White | Light brown | Indeterminate | Gray | Dark gray | Flattened spherical | Yellow |
| GH 5933 IPRO | 6.0 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Flattened spherical | Yellow |
| GH 5115 I2X | 5.2 | Purple | Black | Indeterminate | Brown | Brown | Flattened spherical | Yellow |
| AS 3615 I2X | 6.1 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Flattened spherical | Yellow |
| AS 3606 I2X | 6.0 | Purple | Imperfect black | Indeterminate | Gray | Light gray | Flattened spherical | Yellow |

**Source:** Ministério da Agricultura, Pecuária e Abastecimento (MAPA) (2024).

**Table 2.** Phytosanitary management carried out in soybean cultivation.

| TIME OF APPLICATION | HERBICIDES | INSECTICIDES | FUNIGICIDES | MINERAL OIL | pH REDUCER |
|---|---|---|---|---|---|
| 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$^{-1}$ |
| PRE - SOWING 2 days after | 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 + Lambdacyhalothrin (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$^{-1}$ |

## Results and Discussion

According to the physical analysis (Table 3), the soil in the area is type three, clay textural class, with sand, silt and clay content of 22%, 19% and 59%, respectively. In the chemical analysis (Table 4), 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 cmol $dm^{-3}$), It can also interfere with root growth, preventing it from seeking nutrients and water in depth, and causing a reduction in productivity. 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.

**Table 3.** Chemical analysis of the soil in the experimental area.

| SAMPLE | Clay | Sand | Silt | Soil type | Textural class |
|---|---|---|---|---|---|
| | % | | | | |
| | 59 | 19 | 22 | 3 | Clay |
| | **Determination of Available Water - AW[2]** | | | | |
| **Predicted AW** | **AW Class** | AW values greater than or equal to 0.80 and less than 1.06 millimeters of water per centimeter of soil | | | |
| 1,05 mm. $cm^{-1}$ | AW4 | | | | |

**Source:** UNIJUÍ soil laboratory.

**Table 4.** Chemical analysis of the soil in the experimental area. *Results for soybean crop.

| Analyzed Index | Result obtained in the analysis | Interpretation of the result |
|---|---|---|
| Clay (%) | 54 | Class 3 |
| pH | 5.2 | * |
| SMP index | 5.8 | * |
| Organic Matter (%) | 3.3 | Medium |
| Aluminum | 0.1 | * |
| Calcium ($cmol_c/dm^3$) | 5.3 | High |
| Magnesium ($cmolc/dm^3$) | 2.9 | High |
| H + Al ($cmolc/dm^3$) | 5.5 | * |
| $CEC_{pH7,0}$ | 14.5 | High |
| $CEC_{effective}$ ($cmolc/dm^3$) | 9.2 | * |
| Sat $CEC_{pH7}$ by bases (%) | 62.3 | * |
| Sat $CEC_{effective}$ by aluminum (%) | 1.2 | * |
| Copper ($mg/dm^3$) | 12.0 | High |
| Zinc ($mg/dm^3$) | 4.6 | High |
| Manganese ($mg/dm^3$) | 35.1 | High |
| Sulfur ($mg/dm^3$) | 16.1 | * |
| Sodium ($mg/dm^3$) | NB | * |
| Phosphorus* ($mg/dm^3$) | 39.5 | Very high |
| Potassium* ($mg/dm^3$) | 328 | Very high |

**Source:** UNIJUÍ soil laboratory; *No interpretation.

In Figure 1, throughout the cycle of soybean cultivars, total precipitation was 1268.62 mm with the highest accumulated volume of 90 mm at 100 days after emergence (DAE). According to Neumaier et al. (2020), the need for water is greater as the plant develops, reaching a maximum during flowering-grain filling, decreasing after this period.

The mean air temperature was 24°C and the maximum temperature averaged 30°C, with high peaks of 29.6°C and 35.4°C respectively, at 40 DAE. The average minimum temperature remained at 19°C, reaching the lowest temperature of 12°C at 15 DAE. Studies state that the ideal temperature for growing soybeans, the air temperatures at which soybeans show better growth and development, are between 20 ºC and 30 ºC, remaining above 13 ºC during flowering. However, during the maturation period, high temperatures and high humidity levels can interfere with the quality of the grain. Low humidity conditions contribute to mechanical damage (Neumaier et al., 2020).

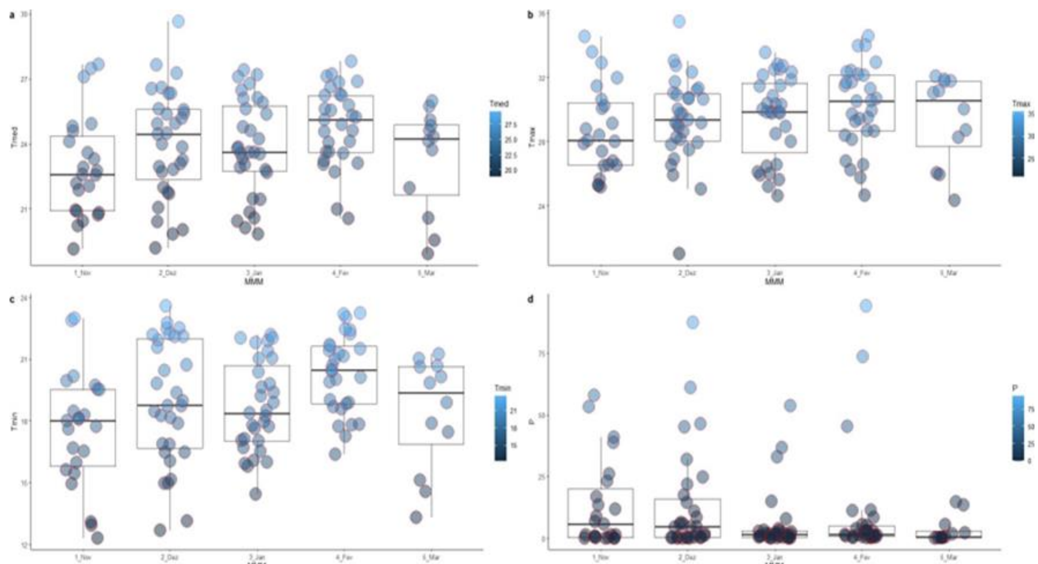

**Figure 1.** Precipitation data, mean, minimum and maximum daily temperature during the soybean growing cycle. Tmean,°C: mean air temperature; Tmin,°C: minimum air temperature; Tmax,°C: maximum air temperature; Prec, mm: precipitation.

To understand the behavior of soybean cultivars, descriptive morphological analyzes were carried out. In Table 5, for root length (ROOT_L), the cultivar FPS 2063 IPRO was superior, presenting a value of 19 cm. The cultivar GH 5115 I2X presented the lowest value (12.80 cm). For the variable branch internode length (BIL), the cultivar GH 6433 I2X was superior with a value of 4.05 cm and the cultivar FPS 1954 RR was inferior, with a value of 1.35 cm. For branch length, the cultivar GH 6433 I2X showed the highest value (95.60 cm) and the cultivar AS 3606 I2X showed the lowest value. The differences in the number of grains between the soybean cultivars analyzed provide valuable data on their respective production capabilities.

The GH 2258 IPRO cultivar stands out as the most promising in terms of yield potential due to its higher average number of grains. Finally, the cultivar AS 3606 I2X shows a lower average number of grains. When analyzing the number of vegetables in the branches of the soybean cultivars evaluated, we observed that the FPS 2457 RR cultivar stands out with the highest average number of vegetables, followed by GH 2258 IPRO, which also presented significant values in this aspect.

On the other hand, the cultivars GH 5933 IPRO, FPS 2063 IPRO and FPS 1954 RR present the lowest values. However, these values can be influenced by the genetics of the cultivar in terms of branching, and by the arrangement of plants in the areas (Agudamu, Yoshihira, & Shiraiwa, 2016). For the number of total nodes in the branch, the results are similar to the previous one, as both have high correlation.

**Table 5.** Descriptive morphological measurements stratified by soybean cultivars.

| Cultivars | ROOT_L (cm) [1] | BIL | BL_(cm) | NV 0 | NV1 | NV2 | NV3 | NVB | NTNB | NB |
|---|---|---|---|---|---|---|---|---|---|---|
| FPS 2063 IPRO | 19.00 | 3.07 | 75.00 | 2.60 | 5.80 | 27.00 | 24.00 | 16.40 | 24.60 | 2.80 |
| FPS 1859 RR | 15.40 | 1.59 | 45.60 | 3.00 | 5.60 | 23.00 | 22.20 | 22.00 | 22.40 | 3.00 |
| FPS 2457 RR | 14.40 | 3.55 | 76.80 | 2.20 | 5.20 | 22.20 | 40.20 | 38.80 | 30.60 | 3.60 |
| FPS 1954 RR | 15.80 | 1.35 | 40.80 | 1.40 | 5.00 | 20.20 | 22.20 | 16.40 | 20.80 | 3.00 |
| GH 6433 I2X | 17.00 | 4.05 | 95.60 | 2.00 | 3.60 | 21.20 | 30.60 | 22.80 | 26.80 | 2.80 |
| GH 2258 IPRO | 15.00 | 2.83 | 72.40 | 3.00 | 5.60 | 29.80 | 44.60 | 36.20 | 24.20 | 2.40 |
| GH 5933 IPRO | 15.80 | 2.87 | 40.60 | 2.00 | 3.40 | 27.20 | 24.80 | 12.80 | 12.60 | 1.40 |
| GH 5115 I2X | 12.80 | 3.42 | 61.80 | 1.00 | 10.20 | 25.20 | 14.20 | 23.20 | 22.20 | 2.60 |
| AS 3615 I2X | 18.20 | 2.73 | 66.40 | 1.00 | 2.20 | 19.80 | 22.80 | 21.40 | 23.80 | 3.60 |
| AS 3606 I2X | 14.20 | 1.58 | 34.60 | 2.00 | 4.60 | 13.60 | 20.20 | 9.60 | 8.80 | 1.20 |

[1]Root_L: root length; BIL: branch internode length; BL: branch length; NV0: number of vegetables with 0 grains; NV1: number of vegetables with 1 grain; NV2: number of vegetables with 2 grains; NV3: number of vegetables with 3 grains; NVB: number of vegetables on the branch; NTNB: number of total nodes on the branch; NB: number of branches.

Table 6 shows the percentage of incidence of invasive plants, in which there was a higher incidence of dicotyledonous plants (broad leaves), as it was not possible to apply herbicides for control during the vegetative period of the crop.

For the percentage of disease incidence (Table 7), the cultivars AS 3615 I2X and AS 3606 I2X were the only ones that showed anthracnose in their leaves, and the cultivars FPS 2457 RR, GH 2258 IPRO and AS 3615 I2X were the ones that showed *Macrophomina*. For diseases such as rust, frog's eye spot and mildew all showed signs.

In the incidence of pests (Table 8), it is observed that all cultivars with IPRO and I2X technology did not present *Spodoptera eridania*, as this technology grants tolerance. Cochineal was observed only in the FPS 2457 RR cultivar. For thrips, all cultivars showed the presence of the pest.

**Table 6.** Percentage of incidence of *Conyza bonariensis* (L.), *Amarantus viridis*, *Ipomoea spp.*, *Sida rhombifolia*, *Richardia brasiliensis* and *Commelia benghalensis*.

| Cultivars | *Conyza bonariensis*[1] *(L.)* | *Amarantus viridis* | *Ipomoea spp* | *Sida rhombifolia* | *Richardia brasiliensis* | *Commelia benghalensis* |
|---|---|---|---|---|---|---|
| FPS 2063 IPRO | 4 | 8 | 20 | 12 | 0 | 0 |
| FPS 1859 RR | 4 | 4 | 12 | 12 | 0 | 4 |
| FPS 2457 RR | 4 | 4 | 16 | 8 | 4 | 0 |
| FPS 1954 RR | 8 | 0 | 16 | 0 | 0 | 0 |
| GH 6433 I2X | 8 | 4 | 4 | 4 | 0 | 0 |
| GH 2258 IPRO | 4 | 0 | 16 | 8 | 0 | 0 |
| GH 5933 IPRO | 0 | 0 | 8 | 4 | 0 | 0 |
| GH 5115 I2X | 0 | 4 | 16 | 8 | 4 | 0 |
| AS 3615 I2X | 0 | 0 | 4 | 0 | 0 | 0 |
| AS 3606 I2X | 0 | 4 | 0 | 0 | 0 | 0 |

[1]*Conyza bonariensis* (L): hairy fleabane; *Amarantus viridis*: green amaranth; *Ipomoea spp*: morming glory; *Sida rhombifolia*: arrowleaf aids; *Richardia brasiliensis*: white-eye; and *Commelia benghalensis*: tropical spiderwort.

**Table 7.** Percentage of incidence of *Colletotrichum truncatum*, *Phakopsora pachyrhizi*, *Macrophomina phaseolina*, *Cercospora sojina* and *Plasmora viticola* in soybean cultivars.

| Cultivars | *Colletotrichum truncatum*[1] | *Phakopsora pachyrhizi* | *Macrophomina phaseolina* | *Cercospora sojina* | *Plasmopara viticola* |
|---|---|---|---|---|---|
| FPS 2063 IPRO | 0 | 20 | 0 | 20 | 20 |
| FPS 1859 RR | 0 | 20 | 0 | 20 | 20 |
| FPS 2457 RR | 0 | 20 | 12 | 12 | 20 |
| FPS 1954 RR | 0 | 20 | 0 | 20 | 20 |
| GH 6433 I2X | 0 | 20 | 0 | 20 | 20 |
| GH 2258 IPRO | 0 | 20 | 4 | 20 | 20 |
| GH 5933 IPRO | 0 | 20 | 0 | 20 | 20 |
| GH 5115 I2X | 0 | 20 | 0 | 20 | 20 |
| AS 3615 I2X | 20 | 20 | 4 | 20 | 20 |
| AS 3606 I2X | 20 | 20 | 0 | 20 | 20 |

[1]*Colletotrichum truncatum*: anthracnose; *Phakopsora pachyrhizi*: Asian rust; *Macrophomina phaseolina*: macrophomina; *Cercospora sojina*: frog-eye spot; *Plasmora viticola*: mildew.

**Table 8.** Percentage of incidence of *Dysmicoccus brevipes*, *Euschistus heros*, *Spodoptera* and *Thysanoptera* in soybean cultivars.

| Cultivars | *Dysmicoccus brevipes*[1] | *Euschistus heros* | *Spodoptera eridania* | *Thysanoptera* |
|---|---|---|---|---|
| FPS 2063 IPRO | 0 | 4 | 0 | 20 |
| FPS 1859 RR | 0 | 0 | 0 | 20 |
| FPS 2457 RR | 4 | 4 | 4 | 20 |
| FPS 1954 RR | 0 | 4 | 0 | 20 |
| GH 6433 I2X | 0 | 0 | 0 | 20 |
| GH 2258 IPRO | 0 | 0 | 0 | 20 |
| GH 5933 IPRO | 0 | 4 | 0 | 20 |
| GH 5115 I2X | 0 | 0 | 0 | 20 |
| AS 3615 I2X | 0 | 8 | 0 | 20 |
| AS 3606 I2X | 0 | 0 | 0 | 20 |

[1]*Dysmicoccus brevipes*: cochineal; *Euschistus heros*: brown-bed bug; *Spodoptera eridania*: Southern armyworm; *Thysanoptera*: thrips.

In Table 9, for the variables vegetable weight with two grains (VW2G), vegetable weight with three grains (VW3G) and vegetable weight with four grains (VW4G), six parameters are considered. LogLik values range from -145.62 to 149.46. The AIC values range from 303.24 to 314.92 and the LRT values range from 37.21 to 14.84. The value of Pr(>Chisq) is 1 for all, indicating no significant difference between the models. For the other variables, which also have six parameters, the LogLik values differ between -109.14 to 126.91. AIC values range from 265.83 to 238.28. The LRT results range from 14.84 to 22.28 and the Pr(>Chisq) values range from 2.43E-06 to 1.00. This indicates that some models are significantly better than the null model, with Pr(>Chisq) values lower than 0.05.

Thus, it is observed that models with lower AIC values are preferable. Pr(>Chisq) values less than 0.05 indicate that the model is significantly better than the null model. The grain weight per plant (GWP), plant height (PH) and insertion height of the first vegetable (IHFV) models stand out from the null model, as indicated by the Pr(>Chisq) values.

Table 10 presents the results of the analysis of genetic and environmental variability of different parameters. Heredity ($H^2$) shows a high magnitude (greater than 0.70), which indicates a strong genetic influence. This parameter varies significantly between plant height (PH), insertion height of the first vegetable (IHFV), height of the productive zone (HPZ), number of total nodes on the main stem (NTN_MS), number of vegetables on the main stem (NVMS) and vegetable weight with one grain (VW1G). On the other hand, parameters such as number of total nodes on the branch (NTN_B), number of vegetables on the branch (NVB), number of branches (NB), number of vegetables with two grains (NV2) and number of vegetables with four grains (NV4) has low heritability (less than 0.25), having greater environmental influence.

**Table 9.** Estimates of variance components and genetic parameters (REML).

| VAR[1] | Model | Npar | LogLik | AIC | LRT | Df | Pr(>Chisq) |
|---|---|---|---|---|---|---|---|
| VW2G | Genotype | 6 | -92.24 | 196.48 | 37.21 | 1 | 1.06E-09 |
| VW3G | Genotype | 6 | -115.66 | 243.32 | 25.05 | 1 | 5.58E-07 |
| VW4G | Genotype | 6 | -31.81 | 75.62 | 14.84 | 1 | 1.17E-04 |
| GWP | Genotype | 6 | -126.91 | 265.83 | 22.28 | 1 | 2.36E-06 |
| PH_cm | Genotype | 6 | -191.28 | 394.55 | 48.43 | 1 | 3.42E-12 |
| IHFV_cm | Genotype | 6 | -144.64 | 301.27 | 12.26 | 1 | 4.64E-04 |
| HPZ_cm | Genotype | 6 | -188.78 | 389.57 | 31.65 | 1 | 1.85E-08 |
| NTN_MS | Genotype | 6 | -110.97 | 233.93 | 10.22 | 1 | 1.39E-03 |
| NTN_B | Genotype | 6 | -183.29 | 378.57 | 0.00 | 1 | 1.00E+00 |
| NVMS | Genotype | 6 | -175.19 | 362.37 | 9.85 | 1 | 1.70E-03 |
| NVB | Genotype | 6 | -190.19 | 392.38 | 0.01 | 1 | 9.14E-01 |
| NB | Genotype | 6 | -98.51 | 209.03 | 0.00 | 1 | 1.00E+00 |
| BL_cm | Genotype | 6 | -228.30 | 468.61 | 2.21 | 1 | 1.37E-01 |
| ROOT_L_cm | Genotype | 6 | -131.80 | 275.59 | 0.07 | 1 | 7.96E-01 |
| MSIL | Genotype | 6 | -56.97 | 125.95 | 13.09 | 1 | 2.96E-04 |
| BIL | Genotype | 6 | -102.87 | 217.74 | 0.00 | 1 | 1.00E+00 |
| NV1 | Genotype | 6 | -129.54 | 271.08 | 1.53 | 1 | 2.17E-01 |
| NV2 | Genotype | 6 | -175.08 | 362.16 | 0.00 | 1 | 1.00E+00 |
| NV3 | Genotype | 6 | -190.55 | 393.09 | 4.22 | 1 | 3.99E-02 |
| NV4 | Genotype | 6 | -70.39 | 152.79 | 0.62 | 1 | 4.29E-01 |
| NV0 | Genotype | 6 | -101.28 | 214.57 | 0.00 | 1 | 1.00E+00 |
| GY | Genotype | 6 | -373.51 | 759.01 | 7.99 | 1 | 4.70E-03 |
| VW1G | Genotype | 6 | -27.31 | 66.62 | 12.39 | 1 | 4.32E-04 |

[1]VAR: lists the variables or models being tested. Model: type of model used; Npar: number of parameters in the model. LogLik: model log-likelihood value. AIC: compare the quality of different models; LRT: test that compares the goodness of fit of two models. Df: test of degrees of freedom. Pr(>Chisq): values less than 0.05 indicate that the model is significantly better than the null model; VW1G: vegetable weight with 1 grain; VW2G: vegetable weight with 2 grains; VW3G: vegetable weight with 3 grains; VW4G: vegetable weight with 4 grains; GWP: grain weight per plant; PH: plant height; IHFV: insertion height of the first vegetable; HPZ: height of the production zone; NTN_MS: number of total nodes on the main stem; NTN_B: number of total nodes in the branch; NVMS: number of vegetables on the main stem; NVB: number of vegetables on the branch; NB: number of branches; BL: branch length; ROOT_L: root length; MSIL: main stem internode length; BIL: branch internode length; NV1: number of vegetables with 1 grain; NV2: number of vegetables with 2 grains; NV3: number of vegetables with 3 grains; NV4: number of vegetables with 4 grains; NV0: number of vegetables with 0 grains; and GY: grain yield.

Genetic variance (Gen var) is high in the parameters plant height (PH), insertion height of the first vegetable (IHFV), height of the productive zone (HPZ), number of total nodes on the main stem (NTN_MS), number of vegetables on the main stem (NVMS) and vegetable weight with one grain (VW1G), presenting greater genetic variability. In contrast, other parameters such as number of vegetables on the branch (NVB), number of branches (NB), number of vegetables with two grains (NV2) and number of vegetables with four grains (NV4) exhibit low genetic variance. Residual variance (Res var) is notable in the number of vegetables with two grains (NV2), number of vegetables with three grains (NV3) and grain yield (GY), indicating a significant influence of environmental factors on these parameters.

The ratio between the coefficient of variation for genetic variance (CVg) and residual variance (CVr) indicates the relationship between genetic and environmental variability. Values above 1, such as plant height (PH), insertion height of the first vegetable (IHFV), height of the productive zone (HPZ), number of vegetables on the main stem (NVMS), vegetable weight with one grain (VW1G), vegetable weight with two grains (VW2G) and vegetable weight with three grains (VW3G), have a greater influence of genetic variability. Values below 1 such as number of vegetables on the branch (NVB), number of branches (NB), number of vegetables with two grains (NV2) and number of vegetables with four grains (NV4) indicate greater environmental influence.

Genetic variability is an important factor for parameters such as plant height (PH), insertion height of the first vegetable (IHFV), height of the productive zone (HPZ), number of total nodes on the main stem (NTN_MS), number of vegetables on the main stem (NVMS) and vegetable weight with one grain (VW1G). While other parameters such as number of vegetables on the branch (NVB), number of branches (NB), number of vegetables with two grains (NV2) and number of vegetables with four grains (NV4) are influenced by environmental factors.

Understanding the genetic value of a given genotype is crucial to improvement, where the prediction of these values became possible from 1963 onwards through studies by Henderson, who compiled in a single model the least squares method of Yates (1931), the selection indices of Lush and Wright (1931) and the inferences obtained by the best linear predictor, calling the new model the best linear unbiased predictor (Best Linear Unbiased Prediction - BLUP).

In Table 11, the BLUP test aims to estimate the new values of the genotypes based on the general average. As a result, the FPS 2063 IPRO cultivar achieved the highest grain yield. The cultivar GH 5115 I2X presented the lowest grain yield. The cultivar GH 2258 IPRO showed a higher grain weight per plant (GWP) value. For non-significant components, the values are the same for all tested cultivars.

**Table 10.** Effect of genotype and environment on the expression of soybean agronomic parameters

| Parameters | PH_(cm) | IHFV_(cm) | HPZ_(cm) | NTN_MS | NTN_B | NVMS | NVB | NB | BL_(cm) | ROOT_L(cm) | MSIL | BIL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gen_var[1] | 182.66 | 12.63 | 140.34 | 2.57 | 0.00 | 43.78 | 2.96 | 0.00 | 205.45 | 0.44 | 0.27 | 0.00 |
| Gen (%) | 81.89 | 45.00 | 70.29 | 40.91 | 0.00 | 40.12 | 1.15 | 0.00 | 17.76 | 2.79 | 46.56 | 0.00 |
| Res_var | 40.40 | 15.44 | 59.33 | 3.71 | 187.54 | 65.34 | 253.71 | 3.61 | 951.03 | 15.42 | 0.30 | 4.39 |
| Res (%) | 18.11 | 55.00 | 29.71 | 59.09 | 100.00 | 59.88 | 98.85 | 100.00 | 82.24 | 97.21 | 53.44 | 100.00 |
| Phen_var | 223.07 | 28.06 | 199.67 | 6.28 | 187.54 | 109.11 | 256.68 | 3.61 | 1156.48 | 15.86 | 0.57 | 4.39 |
| H2 | 0.82 | 0.45 | 0.70 | 0.41 | 0.00 | 0.40 | 0.01 | 0.00 | 0.18 | 0.03 | 0.47 | 0.00 |
| h2mg | 0.96 | 0.80 | 0.92 | 0.78 | 0.00 | 0.77 | 0.06 | 0.00 | 0.52 | 0.13 | 0.81 | 0.00 |
| Accuracy | 0.98 | 0.90 | 0.96 | 0.88 | 0.00 | 0.88 | 0.23 | 0.00 | 0.72 | 0.35 | 0.90 | 0.00 |
| CVg | 13.97 | 15.02 | 15.43 | 8.89 | 0.00 | 18.82 | 8.49 | 0.00 | 23.51 | 4.22 | 12.02 | 0.00 |
| CVr | 6.57 | 16.61 | 10.03 | 10.68 | 65.98 | 22.99 | 78.52 | 72.00 | 50.59 | 24.92 | 12.87 | 77.43 |
| CV ratio | 2.13 | 0.90 | 1.54 | 0.83 | 0.00 | 0.82 | 0.11 | 0.00 | 0.46 | 0.17 | 0.93 | 0.00 |

| Parameters | NV1 | NV2 | NV3 | NV4 | NV0 | VW1G | VW2G | VW3G | VW4G | GWP | GY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gen_var | 2.08 | 0.00 | 54.74 | 0.10 | 0.00 | 0.07 | 2.05 | 4.93 | 0.09 | 7.71 | 263450.43 |
| Gen (%) | 14.51 | 0.00 | 25.35 | 8.99 | 0.00 | 45.25 | 74.84 | 63.66 | 49.62 | 60.38 | 35.88 |
| Res_var | 12.26 | 108.60 | 161.20 | 1.01 | 4.09 | 0.08 | 0.69 | 2.81 | 0.09 | 5.06 | 470730.28 |
| Res (%) | 85.49 | 100.00 | 74.65 | 91.01 | 100.00 | 54.75 | 25.16 | 36.34 | 50.38 | 39.62 | 64.12 |
| Phen_var | 14.35 | 108.60 | 215.94 | 1.11 | 4.09 | 0.15 | 2.73 | 7.74 | 0.19 | 12.77 | 734180.71 |
| $H^2$ | 0.15 | 0.00 | 0.25 | 0.09 | 0.00 | 0.45 | 0.75 | 0.64 | 0.50 | 0.60 | 0.36 |
| $h^2$mg | 0.46 | 0.00 | 0.63 | 0.33 | 0.00 | 0.81 | 0.94 | 0.90 | 0.83 | 0.88 | 0.74 |
| Accuracy | 0.68 | 0.00 | 0.79 | 0.58 | 0.00 | 0.90 | 0.97 | 0.95 | 0.91 | 0.94 | 0.86 |
| CVg | 28.18 | 0.00 | 27.84 | 36.81 | 0.00 | 31.23 | 23.26 | 21.75 | 71.04 | 15.83 | 15.71 |
| CVr | 68.40 | 45.47 | 47.77 | 117.13 | 100.08 | 34.35 | 13.49 | 16.43 | 71.58 | 12.82 | 21.00 |
| CV ratio | 0.41 | 0.00 | 0.58 | 0.31 | 0.00 | 0.91 | 1.72 | 1.32 | 0.99 | 1.23 | 0.75 |

[1]Gen var: genetic variance; Res var: residual variance; $H^2$: heritability; CVg: coefficient of variation for genetic variance; PH: plant height; IHFV: insertion height of the first vegetable; HPZ: height of the production zone; NTN_MS: number of total nodes on the main stem; NTN_B: number of total nodes on the branch; NVMS: number of vegetables on the main stem; NVB: number of vegetables in the branch; NB: number of branches; BL: branch length; ROOT_L: root length; MSIL: main stem internode length; BIL: branch internode length; NV1: number of vegetables with 1 grain; NV2: number of vegetables with 2 grains; NV3: number of vegetables with 3 grains; NV4: number of vegetables with 4 grains; NV0: number of vegetables with 0 grains; VW1G: vegetable weight with 1 grain; VW2G: vegetable weight with 2 grains; VW3G: vegetable weight with 4 grains; GWP: grain weight per plant; and GY: grain yield.

**Table 11.** Estimates of the components of the average specific combining capacity per BLUP.

| GEN[1] | PH_(cm) | IHFV_(cm) | HPZ_(cm) | NTN_MS | NTN_B | NVMS | NVB | NB | BL_(cm) | ROOT_L_(cm) | MSIL | BIL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2457 RR | 102.16 | 23.45 | 81.96 | 18.32 | 20.76 | 34.73 | 20.33 | 2.64 | 69.19 | 15.59 | 4.45 | 2.70 |
| AS 3606 I2X | 101.20 | 25.06 | 83.07 | 16.61 | 20.76 | 34.73 | 19.70 | 2.64 | 47.27 | 15.56 | 5.02 | 2.70 |
| AS 3615 I2X | 96.80 | 22.33 | 73.48 | 16.92 | 20.76 | 27.80 | 20.35 | 2.64 | 63.78 | 16.07 | 4.47 | 2.70 |
| FPS 1859 RR | 83.20 | 23.77 | 65.18 | 18.16 | 20.76 | 30.11 | 20.39 | 2.64 | 52.98 | 15.71 | 3.68 | 2.70 |
| FPS 1954 RR | 91.24 | 26.83 | 66.47 | 18.01 | 20.76 | 32.42 | 20.08 | 2.64 | 50.49 | 15.77 | 3.77 | 2.70 |
| FPS 2063 IPRO | 93.16 | 24.42 | 74.40 | 19.87 | 20.76 | 39.66 | 20.08 | 2.64 | 68.25 | 16.17 | 3.80 | 2.70 |
| GH 2258 IPRO | 110.97 | 21.04 | 92.66 | 18.78 | 20.76 | 47.05 | 21.17 | 2.64 | 66.90 | 15.66 | 4.86 | 2.70 |
| GH 5115 I2X | 70.18 | 17.02 | 58.36 | 15.37 | 20.76 | 30.26 | 20.45 | 2.64 | 61.40 | 15.39 | 3.98 | 2.70 |
| GH 5933 IPRO | 103.31 | 23.93 | 79.75 | 18.47 | 20.76 | 40.58 | 19.88 | 2.64 | 50.39 | 15.77 | 4.32 | 2.70 |
| GH 6433 I2X | 115.38 | 28.75 | 92.29 | 19.87 | 20.76 | 34.27 | 20.43 | 2.64 | 78.95 | 15.92 | 4.55 | 2.70 |

| GEN | NV1 | NV2 | NV3 | NV4 | NV0 | VW1G | VW2G | VW3G | VW4G | GWP | GY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2457 RR | 5.16 | 22.92 | 35.15 | 1.16 | 2.02 | 0.57 | 5.23 | 10.43 | 0.53 | 16.77 | 2946.91 |
| AS 3606 I2X | 4.88 | 22.92 | 22.56 | 0.96 | 2.02 | 0.77 | 5.49 | 8.89 | 0.89 | 15.82 | 2941.04 |
| AS 3615 I2X | 3.78 | 22.92 | 24.20 | 0.70 | 2.02 | 0.73 | 4.60 | 10.03 | 0.14 | 15.27 | 3164.17 |
| FPS 1859 RR | 5.34 | 22.92 | 23.82 | 1.03 | 2.02 | 0.86 | 5.78 | 10.64 | 0.88 | 18.20 | 3587.86 |
| FPS 1954 RR | 5.06 | 22.92 | 23.82 | 0.63 | 2.02 | 1.13 | 8.51 | 11.33 | 0.12 | 20.91 | 3733.86 |
| FPS 2063 IPRO | 5.43 | 22.92 | 24.96 | 0.70 | 2.02 | 1.01 | 7.86 | 9.41 | 0.29 | 18.49 | 3738.23 |
| GH 2258 IPRO | 5.34 | 22.92 | 37.92 | 1.03 | 2.02 | 1.03 | 7.31 | 13.68 | 0.44 | 22.35 | 3585.17 |
| GH 5115 I2X | 7.45 | 22.92 | 18.79 | 0.83 | 2.02 | 1.12 | 6.55 | 5.61 | 0.18 | 13.50 | 2333.98 |
| GH 5933 IPRO | 4.33 | 22.92 | 25.46 | 0.81 | 2.02 | 0.80 | 5.85 | 10.22 | 0.45 | 17.15 | 3379.43 |
| GH 6433 I2X | 4.42 | 22.92 | 29.11 | 0.70 | 2.02 | 0.41 | 4.32 | 11.85 | 0.36 | 16.96 | 3253.47 |

[1]GEN: genotype; PH: plant height; IHFV: insertion height of the first vegetable; HPZ: height of the production zone; NTN_MS: number of total nodes on the main stem; NTN_B: number of total nodes on the branch; NVMS: number of vegetables on the main stem; NVB: number of vegetables in the branch; NB: number of branches; BL: branch length; ROOT_L: root length; MSIL: main stem internode length; BIL: branch internode length; NV1: number of vegetables with 1 grain; NV2: number of vegetables with 2 grains; NV3: number of vegetables with 3 grains; NV4: number of vegetables with 4 grains; NV0: number of vegetables with 0 grains; VW1G: vegetable weight with 1 grain; VW2G: vegetable weight with 2 grains; VW3G: vegetable weight with 4 grains; GWP: grain weight per plant; and GY: grain yield.

## Conclusions

With this study it is possible to understand the performance of the cultivars, highlight the genetic contribution to the phenotypic manifestation and predict the ranking of the genotypes, through statistical analyzes using the RELM and BLUP tests. It was found the FPS 2063 IPRO cultivar with the highest grain yield.

Plant height, height of the productive zone, vegetable grain weight with two grains, vegetable weight with three grains and plant grain weight stand out as the components with the greatest genetic influence. Cultivars with IPRO technology showed no caterpillars, indicating tolerance to pests during the evaluation period. In the FPS 2457 RR cultivar, it was possible to verify the presence of the pest.

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