GENETIC DISSIMILARITY OF SOYBEAN CULTIVARS AND ITS INTERRELATIONS WITH AGRONOMIC ATTRIBUTES

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ABSTRACT

The objective of this study was to reveal the genetic dissimilarities between cultivars and their interrelationships with agronomic attributes in the northwest region of the state of Rio Grande do Sul. The study was developed in 2023/2024, at the Escola Fazenda da Universidade Regional do Noroeste do Estado do Rio Grande do Sul, located in Augusto Pestana, in the state of Rio Grande do Sul, Brazil. The experimental design used was a randomized complete block design, with 43 soybean cultivars arranged in five replicates per cultivar, totaling 215 experimental units. The experimental units consisted of seven sowing lines, with spacing of 0.5 meters and 15 meters in length, totaling 52.5 m^2. Sowing was carried out in the first half of November 2023 with a sowing density of 16 seeds m^{-1} and base fertilization with 250 kg ha^{-1} in the formulation 05-20-10. Phytosanitary management was carried out in order to minimize the biotic effects on the results of the experiment. Abiotic factors such as air temperature and precipitation were not limiting for the development of the cultivars, with no effects on grain yield, number of pods on the main stem, number of total pods and seed mass per plant. The cultivars are dissimilar regarding cotyledon retention, root system depth, cotyledon damage, seed mass per plant and grain yield. The cultivars BRASMAX 66 E and FTR 1554 IPRO are the most productive and dissimilar to the other cultivars for the Northwest Region of Rio Grande do Sul.

Keywords: Soybean cultivars; Genetic dissimilarities; Agronomic attributes.

INTRODUCTION

Soybean (*Glycine max* L.) is the main oilseed cultivated in the world, due to its great agricultural, social, economic and nutritional importance (GOMES, 2023). Currently, Brazil is the world's largest producer of this commodity, according to a survey by the National Supply Company, in the 2023/2024 harvest the cultivated area was 45.7 million hectares and production of 147.6 million tons of grains (CONAB, 2024).

Therefore, each year breeding companies develop new cultivars to meet market demands, which aim for increasingly stable and productive genotypes over time. The development of genotypes with superior phenotypic response in adverse environmental conditions is the strategy to guarantee productivity in conditions of lower availability of environmental resources (DARONCH *et al*., 2019). The success of this strategy is associated with the availability of genetic variability. In this way, identifying genotypes that have favorable alleles is one of the main tools used by genetic improvement programs to increase genetic variability between genotypes (RAMALHO *et al*., 2012).

Soybean grain productivity is a complex quantitative characteristic and controlled by a high number of genes, thus, a great influence of the environment and the genotype x environment interaction (LI *et al*., 2008). According to Knebel *et al*. (2021), the expression of grain productivity is determined by 17% genetic effects and 83% due to environmental effects. Pradebon *et al*. (2023), observed that 73% of grain yield expression was due to environmental effects and only 27% was due to genetic origin.

Studies by Scarton *et al*. (2023), observed negative effects of high altitudes above 338 meters, as well as latitudes above 24º. Several studies have been carried out in order to position genotypes adapted to different growing regions and identify high-yield and stable soybean environments (KNEBEL *et al*., 2021; PRADEBON *et al*., 2023; SCARTON *et al*., 2023; KEHL *et al*., 2022). Another tool for identifying superior genotypes is the use of linear correlations, which is an effective means of partitioning genotypic correlation coefficients into direct and indirect effects and enabling a clear understanding of their associations with grain yield (DEBEBE *et al*., 2014).

The large number of cultivars available on the market makes it difficult to differentiate them in their agronomic aspects, making it extremely important to carry out trials in various locations and agricultural years, so that the effect of the interaction of genotypes by environments is measured and can be explored. Develop detailed studies of the response of each genotype, aiming to identify those with predictable behavior and that are responsive to environmental variations, with the aim of better differentiating genotypes (BLANC *et al*., 2018).

Based on the great importance of soybeans at a global and national level, the most varied agricultural scenarios and accumulated knowledge about the crop, doubts arise about which cultivars perform best in the northwest region of the state of Rio Grande do Sul. In this context, the objective of this work was to reveal the genetic dissimilarities between cultivars and their interrelationships with agronomic attributes in the northwest region of the state of Rio Grande do Sul.

MATERIAL AND METHODS

The work was developed in 2023/2024, at the Escola Fazenda of the Universidade Regional do Noroeste of the State of Rio Grande do Sul, located in Augusto Pestana in the state of Rio Grande do Sul, Brazil. The geographic coordinates of latitude and longitude: 28º26’25’S and 54º00’07’W, respectively, and its altitude is 280 m. In this area, the climate, according to Köppen’s characterization, is of the *Cfa* type, the soil is classified as Distroferric Red Latosol (SANTOS *et al*., 2018).

The experimental design used was complete randomized blocks, with 43 soybean cultivars (Table 1) arranged in five replications per cultivar, totaling 215 experimental units. The experimental units were composed of seven sowing lines, spaced 0.5 meters apart and 15 meters long, totaling 52.5 m^2. Sowing was carried out in the first fortnight of November 2023 with a sowing density of 16 seeds m^{-1} and base fertilizer with 250 kg ha^{-1} in the 05-20-10 formulation. Phytosanitary management was carried out in order to minimize biotic effects on the results of the experiment.

In the five central lines of each experimental unit, Plantability (P_PLANT_V4, %), Root system depth (RS_DEPTH_V4, cm), Plant height (PH_V4, cm), Cotyledon retention (CR_V4, %), Cotyledon damage (CD_V4, %), Sanity (SANITY_V4, %), Tipping (TIP_V4, %), Number of plants per linear meter (NPLM_V4, units), Plant height (PH_R5, cm), Insertion height of the first pod (IHFP_R5, cm), Area of the productive zone (APZ_R5, cm), Number of total plant nodes (NTPN_R5, units), Number of nodes on main stem (NNMS_R5, units), Number of nodes on branches (NNB_R5, units) , Number of branches (NB_R5, units), Number of pods on main stem (NPMS_R5, units), Number of pods on branches (NPB_R5, units), Number of total pods (NTP_R5, units), Branch length (BL_R5, cm), Root length (RootL_R5, cm) and Seed weight per plant (SWP, g).

Subsequently, grain productivity estimates (kg ha^{1}) were carried out, where 50 plants were collected per experimental unit randomly, productivity was weighted by the final population of plants per cultivar. Meteorological information such as mean air temperature (Tmean, °C), minimum temperature (Tmin, °C) and maximum air temperature (Tmax, °C), precipitation (Prec, mm), were obtained by the NASA Power platform (2024).

The management adopted began with pre-sowing desiccation with Glyphosate (2.0 lt ha^{-1}), 2.4-D (1.5 lt ha^{-1}) and Clethodim (0.6 lt ha^{-1}). At stage V4, chemical injection was carried out with Glyphosate (2.0 lt ha^{-1}), insecticide Acetamiprid + Bifenthrin (200 gr ha^{-1}) and Diflubenzuron (60 gr ha^{-1}), fungicide Difenoconazole (250 ml ha^{-1}) and Foltron foliar nutrient (0.8 lt ha^{-1}). The second application of fungicides was carried out at stage R1, fungicide Benzovindiflupyr + Ciproconazole (0.5 lt ha^{-1}) and insecticide Thiamethoxam + Lambda-Cialothrin (250 ml ha^{-1}), the third application at R3 fungicide Benzovindiflupyr + Prothioconazole (0.5 lt ha^{-1}) and insecticide Acetamiprid + Bifenthrin (200 g ha^{-1}) and fourth application in R5 fungicide Azoxystrobin + Mancozeb + Prothioconazole (2.0 kg ha^{-1}), insecticide and Acetamiprid + Bifenthrin (200 gr ha^{-1}). All applications used mineral oil (0.25 lt ha^{-1}) and pH reducer (50 ml ha^{-1}).

The data were subjected to the assumptions of the mathematical model of normality of errors using the Shapiro-Wilk and Homogeneity Test of residual variances using Bartlet. The association between variables was estimated using linear correlation analysis. As a way to complement the explanation, principal component analysis (PCA) was carried out using the *Biplot* method. The dissimilarity tests considered all individuals from both generations, using the UPGMA grouping method (Unweighted Pair Group Method using Arithmetic Averages) and the Self Organizing Maps methodology (Kohonen map). Genotypes were grouped using K-means. The analyzes were carried out using the *Multivariate Analysis, dendextend, ape, metan, kohonen*, *ggplot2* and *EnvRtype* packages, through the R software (R CORE TEAM, 2024).

RESULTS AND DISCUSSION

According to the variations in air temperature throughout the experiment (Figure 1), it was observed that the mean temperature was 24ºC, with small fluctuations between 17ºC and 29ºC. Regarding the maximum air temperature, it had a mean of 30ºC and a maximum of 37ºC and a minimum of 24ºC. For the minimum temperature, fluctuations ranged between 12°C and 24°C. In general, it was observed that temperatures were optimal for soybeans (10 to 40ºC) and were not limiting for the crop. For Silva *et al*. (2020), the ideal temperature for the development of the crop is around 30°C, being below 10°C which can harm the growth and development of soybeans, with temperatures above 40°C there is a negative influence on flowering and soybean pod retention. Precipitation throughout the cycle presented an accumulated total of 792 mm, corresponding to the crop's demand, where an average daily precipitation of 5.91 mm day^{-1} was obtained. For Neumaier *et al*. (2020), the aim is to accumulate at least 450 mm, with 2.7 mm day^{-1} in the vegetative period and 7.5 mm day^{-1} in the reproductive period.

Based on significant correlations using the *t* test at 5% probability (Figure 2), it was shown that grain yield (GY) was determined by the positive increase in the number of pods on the main stem (r=0.34), number of total pods (r=0.36) and seed weight per plant (r=0.84). For Bertolino *et al*. (2022), grain yield is constructed by the joint action of the magnitude of plants per unit area, productive units per plant and grain weight adjusted by the population of plants per hectare. The number of pods on the main stem, number of total pods and seed weight per plant are positively associated with root length, plant height, area of the productive zone, number of nodes on the main stem, number of total nodes on the plant and number of plants per initial linear meter in V4. These morphological attributes are decisive to establish the linear relationship in which soybean plants with balance in the production zone, correct extension of the internode length, result in adequate node formation reproductive crops, pods and grains partitioned in order to maximize soybean productivity.

Mondo *et al*. (2018), reveal that sowing densities determine the balance of morphological aspects that indirectly determine the components of productivity. The initial plant density correlates negatively with plant height, initial start-up, branch length both at V4 and at the end of soybean cultivation. Santos *et al*. (2018), determines that the initial assertiveness of plant density per linear meter will be decisive for the retention of cotyledons and effective photosynthetic machinery for optimal growth and development of soybeans with maximum use of available resources.

The length of the branch is positively associated with the number of branches, pods on the branches, total nodes per plant and nodes on the branches, as well as the insertion height of the first pod and negatively with the percentage of plantability. The erroneous arrangement of plants per meter, which means a low percentual of plantability, results in an immediate modification of the dynamics of the partitioning of plant assimilates, the excess of plants causes apical dominance and lower proportions of the compensatory effect of the lateral branches of soybean. However, low plantability increases the proportion of dominated and dominant plants, differentiation of branches with a low probability of resulting in reproductive nodes and culminating in the increase of pods and grains per plant. In this way, the assertiveness of the plant density per meter, sowing depth and the high vigor of the seeds is seen so that the optimal prioritized plantability of each cultivar is obtained, which will undoubtedly reflect on the success of the crop.

The plantability attribute has gained notoriety nowadays, but it can be harmed due to the main fungi that cause root rot, plant damping-off, stem rot caused by the genera *Macrophomina*, *Fusarium* and *Rhizoctonia* (MEDEIROS *et al*., 2022). The branches, when emitted and maintained in a balanced manner, supply the photosynthetic capacity of the plants, generating more assimilated substances and targeting the true reproductive needs of soybeans (NAVARO *et al*., 2002).

The genetic dissimilarity expressed by the dendrogram (Figure 3) using the qualitative and quantitative attributes of soybean, the cultivars were divided into eight groups, the first formed by NEO 590 I2X, NEO 510 IPRO, BRASMAX 66 E, NEO 560 IPRO, BMX ZEUS (55I57RSFIPRO), NEO 531 I2X, DM 64I63 RSF IPRO and M 6130 I2X, these being similar phenotypically for cotyledon retention, number of plants per linear meter in V4, area of the productive zone in R5, number of branches in R5, number of pods at main stem and root length.

Mendes *et al*. (2018), reports the importance of the correct number of plants established per linear meter, were poorly distributed individuals in the sowing line can result in points of seed accumulation, generating taller, less branched plants, with a greater tendency to lodging and lower individual production, while empty spaces or gaps, in addition to facilitating the development of weeds, lead to the establishment of smaller specimens, with larger diameter stems, more branched and with greater individual production, although production per area is lower.

The second group brings together the cultivars DM 65I67 RSF I2X, BMX VÊNUS (57K58RSF CE), FT 2858 IPRO and DM 54IX57 RSF I2X, assigning the grouping by the depth of the root system, number of branches, root length and grain yield. Balbinot Junior *et al*. (2018), have described the importance of adopting management practices that aim to increase the depth of the root system for the roots to explore the soil in search of water and nutrients in depth.

The third group was composed of the cultivars DM 60IX64 RSF I2X and BMX FIBRA (64I61RSF IPRO), revealing this similarity in response to mean temperature, maximum temperature and minimum air temperature. Soybean adapts best to air temperatures between 20ºC and 30ºC, sowing should not be carried out when the soil temperature is below 20ºC as it impairs germination (FERREIRA NASCIMENTO *et al*., 2018).

The fourth group combined the cultivars M 5947 IPRO, BMX NEXUS (64IX66RSF I2X), NEO 610 IPRO, BRS 5804 RR, NS 6601 IPRO, M 5710 I2X, BMX TORQUE (57I60RSF I2X) and DM 56I59 IPRO were similar for the starting attributes initial measurements measured at stage V4. One way to enhance the initial start of crop development is through the use of insecticides, nematicides and fungicides for seed treatments, a practical and assertive way to guarantee the initial start of the crop (LAJÚS *et al*., 2022).

The fifth grouping results in the cultivars FTR 1155 RR, M 6100 XTD and NEO 620 IPRO based on the variables number of plants per linear meter, plant height, number of nodes on the main stem, number of branches per plant and maximum temperature response from the air. Sowing at later periods promotes a reduction in the soybean cycle with greater influence on the vegetative stage in addition to smaller plants, fewer nodes per plant and reduced yield (PETER *et al*., 2021).

The sixth group combines the cultivars GH 5933 IPRO, BMX TROVÃO (51I51RSF I2X), NEO 581 E, BMX FURIA (65K67RSF E), BMX TITANIUM (56IX58RSF I2X), FPS 1859 RR, ST 622 IPRO, NS 6433 I2X, M 5939 I2X and NEO 661 I2X, with phenotypic similarity imposed by initial soybean establishment and mean air temperature. De Deus Conceição *et al*. (2023), indicate that soybean emergence is reduced by lower vigor and increased sowing depth, reinforcing the need to use seeds with high vigor and adequate sowing depth for the establishment of the crop in the field.

The seventh group brings together the cultivars Paraguaçu 64HO130, FPS 2063 IPRO and NEO 590 I2X through the similarity of root development, cotyledon retention time, number of nodes and seed weight per plant. Seed weight per plant is one of the components of soybean yield, this variable is very susceptible to biotic and abiotic effects, such as precipitation and pest attacks (BARCELOS *et al*., 2019).

Based on the eighth group, for the cultivars M 5997 I2X, M 5834, there is no ideal soybean spacing or densities for all environments and genotypes, so it is important to observe the interaction between spacing and plant density within each growing condition (BAGATELI *et al*., 2020). Studies by Melo *et al*. (2019), define that the formation of groups of cultivars is constructed by genetic characteristics and their expression phenotypically, making it necessary to understand which characteristics are decisive for the differentiation of genetic constitutions available to producers.

The K-means algorithm allows identifying the similarity between cultivars and placing them in homogeneous groups (CRUZ *et al*., 2012). It was possible to represent 32.6% of the study's overall variability (Figure 4). The first group comprises the cultivars BMX VÊNUS (57K58RSF CE), DM 54IX57 RSF I2X, DM 60IX64 RSF I2X, BMX FIBRA (64I61RSF IPRO), M5710I2X, FT 2858 IPRO, DM 56I59IPRO and NS 6601 IPRO based on cultivars that it retains its cotyledons for longer and expresses grain yields exceeding 3.8 tons of grains per hectare.

Group two comprises the cultivars DM 65I67 RSF I2X, BMX TORQUE (57IX60RSF I2X), M 5997 I2X, FTR 1554 IPRO, BMX ZEUS (55I57RSF IPRO), BMX TITANIUM (56IX58RSF I2X), BMX FURIA (65K67RSF E) and M5834 XTD with similar trend for initial plant establishment and maximization of lateral branches per plant. Group three allows or to group the cultivars NEO 610 IPRO, NEO 590 I2X, DM 64I63 RSF IPRO, M 6100 IPRO, BMX NE-XUS (64IX66RSF I2X) and NEO 620 IPRO due to the prominence of the initial establishment and the maximum air temperature.

Group four refers to the cultivars NEO 510 IPRO, NEO 580 IPRO, BMX TROVÃO (51IX51RSF I2X), NEO 560 IPRO, M 6410 IPRO, M 5939 I2X, NEO 531 I2X, GH 5933 IPRO, M 6130 I2X, NS 6433 I2X, NEO 581 E and ST 622 IPRO. Group five brings together the cultivars Paraguaçu 64HO130, FPS 2063 IPRO and NEO 590 I2X, due to the depth of the root system, cotyledon retention and seed weight per plant, as well as maximum temperature. The negative effects of high maximum temperature during grain filling have been associated with the rapid mobilization of photoassimilates from vegetative structures and reduction of the time available for such compounds to be deposited in seeds, the reproductive period between pod setting and grain filling has optimal temperatures that are relatively lower than those of the vegetative phase (SEHGAL *et al*., 2018).

Biplot principal component analysis (Figure 5) explains 33.6% of the total variation. The first quadrant identifies the cultivars BMX TORQUE (57IX60RSF I2X), FTR 1554 IPRO and M5997 I2X with affinity for plant health, number of plants per linear meter. In the second quadrant, the initial tipping variable shows a trend with the cultivars BMX TROVÃO (51IX51RSF I2X), NEO 560 IPRO and M6410 IPRO. The third quadrant was constructed by varying plant height and number of branches with the cultivars M 5939 I2X, NEO 531 I2X, M6130 I2X and NEO 590 I2X. The fourth quadrant expresses that grain yield, seed weight per plant, root system length and air temperature attributes correlate with the cultivar NEO 610 IPRO, BRASMAX 66E, NEO 661 I2X, FPS 1859 RR (SRM 5951), BMX NEXUS (64I66RSF I2X), M5947 IPRO and BRS 5804 RR.

Practices that favor better soil structuring and the deepening of the root system, such as the direct planting system (DPS) and crop rotation, contribute to increasing water storage in the soil, water availability in the soil becomes fundamental to ensure the success of agricultural exploration, mainly in regions with irregular rainfall distribution and high evaporative demand from the atmosphere, characterized by the occurrence of high solar radiation, strong winds, high temperatures and low relative air humidity and in the absence of irrigation (NEUMAIER *et al*., 2020)

Kohonen's self-organizing map was obtained from three groups of characters measured in the soybean cultivars (groups A, B, C), all of which were considered to form clusters with similar genotypes. The map (Figure 6) shows that the first group brings together the cultivars BMX NEXUS (64IX66RSF I2X), BRS 5804 RR, DM 64I63 RSF IPRO, M 5947 IPRO and NEO 610 IPRO, combined by the similar trend in the depth of the root system, tipping, number of plants per linear meter, number of pods in the branches and number of pods in the main stem. Research by Farias *et al*. (2023), shows that the volume and characteristics of the root system are effective in differentiating the performance of cultivars in the field, especially in relation to the stressful events of water deficit and stress.

The second group presents the cultivars BMX FIBRA (64I61RSF IPRO) and DM 60IX64 RSF I2X with a great influence on damping-off, health, number of pods on the main stem and seed weight per plant. Studies indicate that these variations attributed to damping-off are due to root rot, resulting from the fungal action of *Macrophomina*, *Fusarium* and *Rhizoctonia* (MEDEIROS *et al*., 2022).

The third group comprises the cultivars BMX FÚRIA (65K67RSF E), BMX TROVÃO (51IX51RSF I2X), GH 5933 IPRO, NEO 510 IPRO, NEO 531 I2X, NEO 560 IPRO, NEO 581 E, NEO 590 I2X and NEO 661 I2X mainly due to retention of cotyledons, health, tipping, length of the root system, number of branches, number of nodes on the branches and number of pods on the branches. Group four, composed of the BRASMAX 66 E and FTR 1554 IPRO cultivars, appears to be the most important, where the number of pods on the main stem, seed weight per plant and grain yield are prominent, defined as target characteristics for the selection of the best cultivars.

The fifth group comprises (ST 622 IPRO), the sixth group corresponds to (FPS 2063 IPRO, M 5939 I2X, M5997 I2X, M 6130 I2X, M 6410 IPRO and NEO 590 I2X), the seventh group is comprised of BMX TORQUE (57IX60RSF I2X), BMX VENUS (57K58RSF CE), DM 65IX67 RSF I2X, M 5710 I2X and M 5834 XTD. The eighth group only presents the cultivar N 6100 XTD. The ninth group is formed by the cultivars DM 56I59 IPRO, and NS 6433 I2X, the tenth group corresponds to the cultivars BMX ZEUS (55I57RSF IPRO), NEO 580 IPRO and NS 6601 IPRO and the twelfth group culminates in the cultivars FT 2858 IPRO and Paraguaçu 64HO130. The thirteenth group presents the cultivar DM 54IX57 RSF I2X, the fourteenth group brings together the cultivars BMX TITANIUM (56IX58RSF I2X) and FPS 1859 RR (SEM 5951), the fifteenth group results in the cultivar FTR 1155 RR and the sixteenth group composed of the cultivar NEO 620 IPRO presents pre-eminence.

According to the results obtained, we can group the cultivars according to the profiles of each analysis, the genetic dissimilarity dendrogram presented eight different profiles, the K-means algorithm five profiles, the biplot principal component analysis four profiles and the Kohonen map sixteen profiles, the main variables that formed these were due to cotyledon retention, number of plants per linear meter, number of branches, depth of the root system, temperature, grain yield and seed weight per plant.

CONCLUSION

Abiotic factors such as air temperature and variety were not limiting for the development of cultivars, with no effects on grain yield, number of pods in the main stem, number of total pods and seed weight per plant. Cultivars differ due to cotyledon retention, root system depth, cotyledon damage, seed weight per plant, and grain yield. The BRASMAX 66 E and FTR 1554 IPRO cultivars are as productive and different from the most productive cultivars for the Northwest Region of Rio Grande do Sul.

REFERENCES

BAGATELI, J. R., FRANCO, J. J., MENEGHELLO, G. E. 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.

BALBINOT JUNIOR, A. A., DEBIASI, H., FRANCHINI, J. C., PRIETO, J. P. C., DE MORAES, M. T., WERNER, F. e FERREIRA, A. S. (2018). **Growth and distribution of soybean roots at different plant densities.**

BARCELOS, M. N., DE SOUZA, T. S., TOSCANO, L. C. e MARUYAMA, W. I. (2019). **Physiological and phytotechnical aspects of Euschistus heros attack on soybeans.** *Science & Technology*, *11*(1), 15-21.

BERTOLINO, K. M.; DUARTE, G. R. B.; PELOSO, O. A. F.; DA SILVA, É. M.; E BOTREL, É. P. (2022). **Soybean yield as a function of sowing density**. *Journal of Agro-Environmental Sciences*, *20*(1), 01-08.

BLANC, R. B., E JÚNIOR, C. V. (2018). **Productivity assessment of soybean cultivars in Pinhão-PR.** *Tech & Campo*, *1*(1), 77-89.

COMPANHIA NACIONAL DE ABAASTECIMENTO – Grain Bulletin – April 2024. Available in: https://www.conab.gov.br/info-agro/safras/graos. Accessed on: May 22, 2024.

CRUZ, C. D.; REGAZZI, A. J.; CARNEIRO, P. C. S. **Biometric models applied to genetic improvement.** 4th ed. Viçosa: Ed. UFV, p. 514,2012.

DARONCH, D. J. *et al*. **Environmental efficiency and genetic divergence of soybean genotypes in the central region of Tocantins.** Agricultural Culture Journal, v.28, n.1, p.1-18, 2019.

DE DEUS CONCEIÇÃO, A. E., REGES, N. P. R. e DOS SANTOS, M. P. (2023). **Influence of vigor, seed diameter and sowing depth on initial soybean establishment.** *Research, Society and Development*, *12*(2), e27412240260-e27412240260.

DE MEDEIROS, F. H. V., BAVIA, G. e SEIXAS, C. (2022). **Management of root fungal diseases in soybeans.**

DEBEBE, A., SINGH, H., TEFERA, H. (2014). **Interrelationship and path coefficient analysis of yield components in F4 progenies of tef (Eragrostis tef).** Pak J. Biol. Sci. 17, 92–97. doi: 10.2135/cropsci1966.0011183X000600010011x

FARIAS, J., MONTEIRO, J. D. A., FRANCHINI, J., SIBALDELLI, R., CRUSIOL, L. e GONCALVES, S. (2023). **Proposal to incorporate the impacts of management levels on the risk estimated by ZARC soy** (ZARC soy-NM).

FERREIRA NASCIMENTO, W., SEVERINO DA COSTA, J., PINHEIRO PADOVESE PEIXOTO, P. e LESMO DUARTE, N. D. (2018). **Effects of temperature on soybeans and corn in the State of Mato Grosso do Sul.** *Investigación Agraria*, *20*(1), 30-37.

FERREIRA, E. B. *et al*. ExpDes.pt: **Experimental Designs Package (Portuguese).** R package version 1.2.2, 2021. Available in: https://CRAN.R-project.org/package=ExpDes.pt

GOMES, M. R. (2023). **Evolution and Perspectives of Economic Performance and Soy Production in the Brazilian and Paraná Contexts.** *Journal (J) DEFINITIONS OF BORDERS*, *1*(2), 349-360.

KEHL, K., CARVALHO, I. R., SACON, D., RIZZARDI, M. A., LANGARO, N. C., LORO, M. V. e LAUTENCHLEGER, F. (2022). **Strategic positioning of soybeans based on agronomic ideotype and fixed and mixed multivariate models**. *Brazilian Agricultural Research*, *57*(Z), 02702.

KNEBEL, E. L. G., CARVALHO, I. R., LORO, M. V., DEMARI, G. H., OURIQUE, R. S. e DALLA ROZA, J. P. (2021). **Strategic positioning of soybean cultivars in the state of Rio Grande do Sul.** *Scientia Agraria Paranaensis*, 378-388.

LAJÚS, C. R., OLIAS, C., PORTO, A. K., e SAUER,

A. V. (2022). **Initial growth of soybeans subjected to doses of insecticide and fungicide in seed treatment.** *Conjecturas*, *22*(2), 749-760.

LI, Y. C., YU, D. Y., XU, R., GAI, J. Y. (2008). **Effects of natural selection of several quantitative traits of soybean RIL populations derived from the combinations of Peking ×7605 and RN-9×7605 under two ecological sites.** Sci. Agric. Sin. 41, 1917–1926. doi: 10.3724/SP.J.1005.2008.01083

MELO, A. V.; SANTOS, V. M.; LOPES, T. M.; DIAS, M. A. R.; NUNES, H. V. **Genetic divergence between corn hybrids under water deficit conditions.** Neotropical Agriculture Journal, Cassilândia, v. 6, n. 3, p. 66-75, 2019.

MENDES, A. L. A., SENO, K. C. A. e OLIVEIRA, R. C. D. (2018**). Influence of the bacterial complex in seed treatment on the agronomic performance of soybean (glycine max) under field conditions 1**. *Nucleus (16786602)*, *15*(1).

MONDO, V. H. V.; E NASCENTE, A. S. (2018). **Common bean productivity affected by plant population.** *Agrarian*, *11*(39), 89-94.

NASA POWER. National Aeronautics and Space Administration. **NASA Prediction of Worldwide Energy Resources 2024.** Available in: <https://power.larc.nasa.gov/>. Accessed on: July 03, 2024.

NAVARRO JUNIOR, H. M.; COSTA, J. A. **Relative contribution of yield components to soybean grain production.** Brazilian Agricultural Research, Brasília, v.37, n.3, p.269-274, 2002.

NEUMAIER, N.; FARIAS, J. R. B.; NEPOMUCENO, A. L.; MERTZ-HENNING, L.M; FOLONI, J. S. S.; MORAES, L. A. C.; GONÇALVES, S. L. Soybean ecophysiology. **Embrapa Soy-Chapter in scientific book** (ALICE), 2020.

OLIVOTO, T.; LÚCIO, A. D. **metan: an R package for multienvironment trial analysis.** Methods in Ecology and Evolution. v.11, p.783-789, 2020. Available in: <https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.13384>. Acesso: 28/02/2022. doi: 10.1111/2041-210X.13384.

PETER, M., LIMA DA SILVA, F., BARÃO MEDEIROS, L., MARIANO, P., ZANATTA AUMONDE, T. e PEDÓ, T. (2021**). Expression of agronomic characteristics of soybean managed under different sowing times and crop densities.** Agronomy College Journal, *120*.

PRADEBON, LC, CARVALHO, IR, LORO, MV, PORT, ED, BONFADA, B., SFALCIN, IC, e CHALLIOL, MA (2023). **Analysis of soybean adaptability and stability to the organic system using AMMI, GGE Biplot and mixed model methodologies.** *Rural Science*, *53* (9), e20220262.

R CORE TEAM. (2024). R: A language and environment for statistical computing. **R Foundation for Statistical Computing.** https://www.Rproject.org

RAMALHO, M. A. P. et al. **Applications of quantitative genetics in the improvement of autogamous plants.** 1.ed. Lavras: UFLA, 2012, 250p

SANTOS, G. X. L.; FINOTO, E. L.; JÚNIOR, P.; TOKUDA, F.; e MARTINS, M. (2018). **Effect of plant density on the agronomic characteristics of two soybean genotypes in the northwest of São Paulo.** *Nucleus*, 115-124.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.Á. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAÚJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Brazilian soil classification system** 5.ed. rev. and ampl. Brasilia: Embrapa, 2018. p. 356

SCARTON, VDB, CARVALHO, IR, PRADEBON, LC, LORO, MV, ALBAN, AA, CHALLIOL, MA, e SFALCIN, IC (2023). **Influence of meteorological variables and geographic factors on the selection of soybean lines.** *NEOTROPICAL AGRICULTURE JOURNAL*, *10* (3), e7246-e7246.

SEHGAL, A., SITA, K., SIDDIQUE, K. H., KUMAR, R., BHOGIREDDY, S., VARSHNEY, R. K., ... & NAYYAR, H. (2018). **Drought or/and heat-stress effects on seed filling in food crops: impacts on functional biochemistry, seed yields, and nutritional quality.** Frontiers in plant science, 9, 1705.

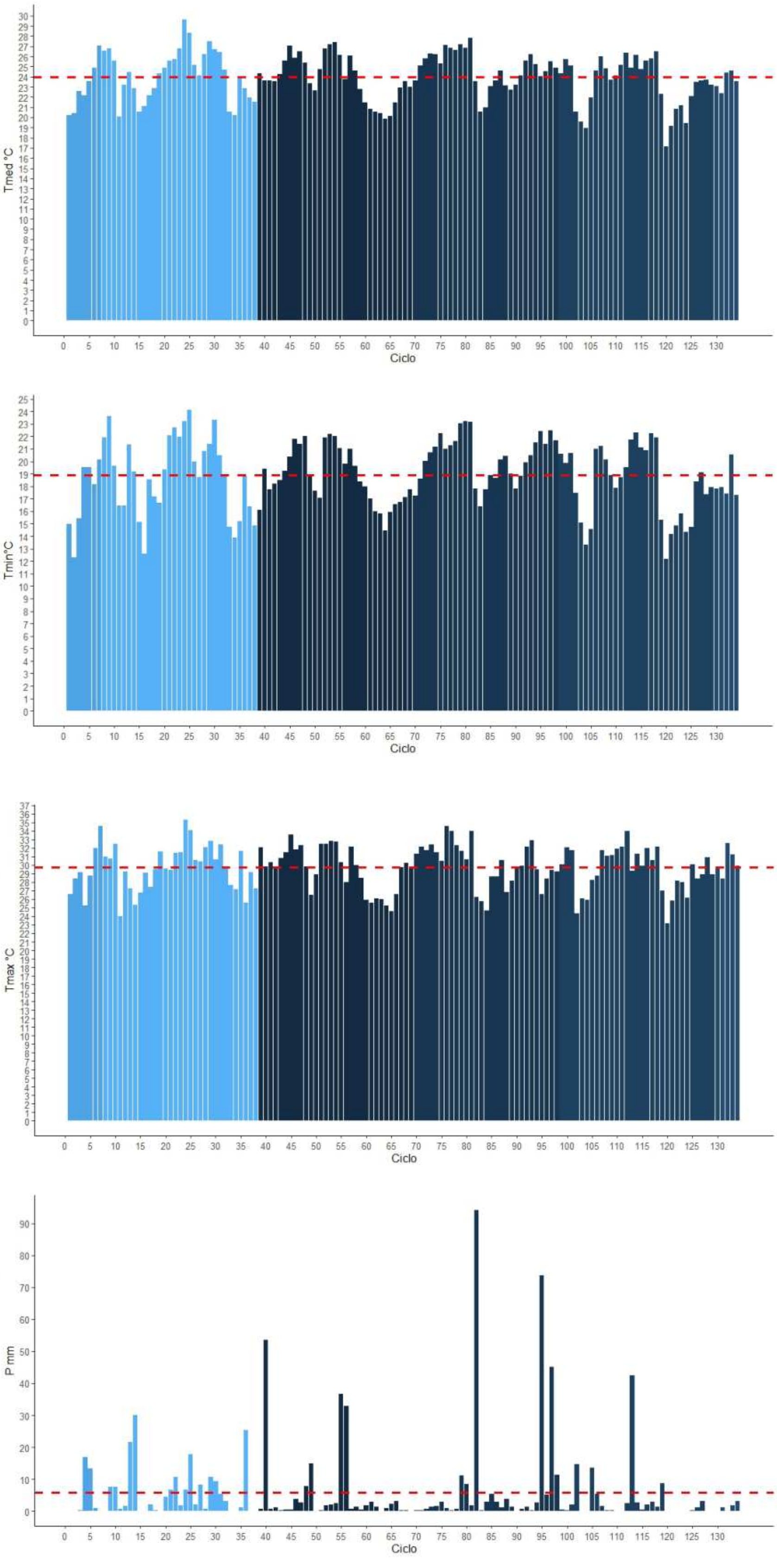
SILVA, F., BORÉM, A., SEDIYAMA, T. e CÂMARA, G. (2022). Soy: from planting to harvest. Text Workshop.

WICKHAM, H. ggplot2: **Elegant Graphics for Data Analysis.** Springer-Verlag New York, 2016.

Table 1. Cultivars evaluated based on the variables breeder (BRE), technology (TEC), thousand seed weight (TSW), relative maturity group (RMG) and flower color.

CULTIVAR	BRE	TEC	TSW	CYCLE	RMG	FLOWER COLOR
BMX FIBRA (64I61RSF IPRO)	Brasmax	Ipro	156	136	6.4	Purple
BMX FÚRIA (65K67RSF CE)	Brasmax	Conkesta Enlist	150	134	6.5	Purple
BMX NEXUS (64IX66RSF I2X)	Brasmax	Xtend	154	135	6.4	Purple
BMX TITANIUM (56IX58RSF I2X)	Brasmax	Xtend	200	129	5.6	Purple
BMX TORQUE (57IX60RSF I2X)	Brasmax	Xtend	177	127	5.7	Purple
BMX TROVÃO (51IX51RSF I2X)	Brasmax	Xtend	182	124	5.2	White
BMX VÊNUS (57K58RSF CE)	Brasmax	Conkesta Enlist	166	127	5.7	Purple
BMX ZEUS (55I57RSF IPRO)	Brasmax	Ipro	209	126	5.5	White
BRASMAX 66 E	Brasmax	Enlist	160	135	6.6	White
BRS 5804 RR	Embrapa	RR	210	125	5.8	White
DM 54IX57 RSF I2X	Don Mario	Xtend	189	126	5.4	White
DM 56I59 IPRO	Don Mario	Ipro	181	126	5.7	White
DM 60IX64 RSF I2X	Don Mario	Xtend	173	133	6	Purple
DM 64I63 RSF IPRO	Don Mario	Ipro	178	138	6.5	White
DM 65IX67 RSF I2X	Don Mario	Xtend	164	134	6.5	White
FPS 1859 RR (SRM 5951)	F. Pró Sementes	RR	170	130	5.9	White
FPS 2063 IPRO	F. Pró Sementes	Ipro	180	138	6.3	Purple
FT 2858 IPRO	FT Sem.	Ipro	185	132	5.8	Purple
FTR 1155 RR	FT Sem.	RR	-	126	5.5	White
FTR 1554 IPRO	FT Sem.	Ipro	-	125	5.4	White
GH 5933 IPRO	Golden Har.	Ipro	178	130	6	Purple
M 5710 I2X	Monsoy	Xtend	-	139	5.8	White
M 5834 XTD	Monsoy	Xtend	-	135	5.8	-
M 5939 I2X	Monsoy	Xtend	175	138	5.9	Purple
M 5947 IPRO	Monsoy	Ipro	140	138	5.9	Purple
M 5997 I2X	Monsoy	Xtend	189	138	5.9	Purple
M 6100 XTD	Monsoy	Xtend	-	142	6.1	Purple
M 6130 I2X	Monsoy	Xtend	-	139	6.1	-
M 6410 IPRO	Monsoy	Ipro	137	135	6.4	Purple
NE0 590 I2X	Neogen	Xtend	160	131	5.9	Purple
NEO 510 IPRO	Neogen	Ipro	195	122	5.1	Purple
NEO 531 I2X	Neogen	Xtend	187	124	5.3	Purple
NEO 560 IPRO	Neogen	Ipro	196	126	5.6	Purple
NEO 580 IPRO	Neogen	Ipro	189	130	5.8	Purple
NEO 581 E	Neogen	Enlist	183	130	5.8	Purple
NEO 610 IPRO	Neogen	Ipro	156	135	6.1	Purple
NEO 620 IPRO	Neogen	Ipro	183	120	6.2	-
NEO 661 I2X	Neogen	Xtend	171	126	6.6	-
NS 6433 I2X	Nidera	Xtend	-	140	6.5	Purple
NS 6601 IPRO	Nidera	Ipro	-	140	6.6	White
PARAGUAÇU 64HO130	HO Gen.	Xtend	172	120	6.4	Purple
ST 622 IPRO	Soytech	Ipro	173	120	6.2	Purple

Figure 1. Satellite data of mean air temperature (ºC), maximum air temperature (ºC), minimum air temperature (ºC) and precipitation (mm) measured during the soybean cycle.



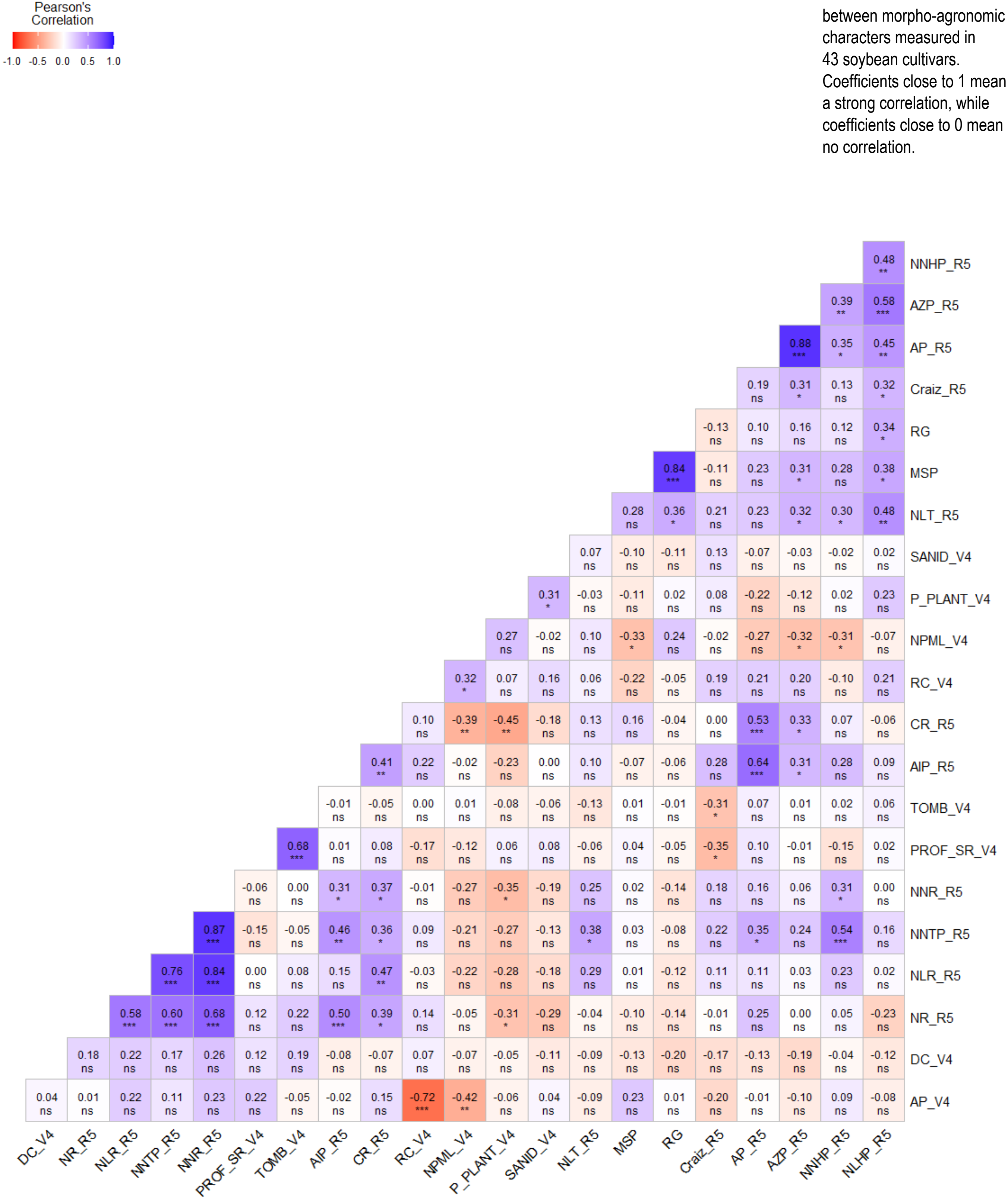
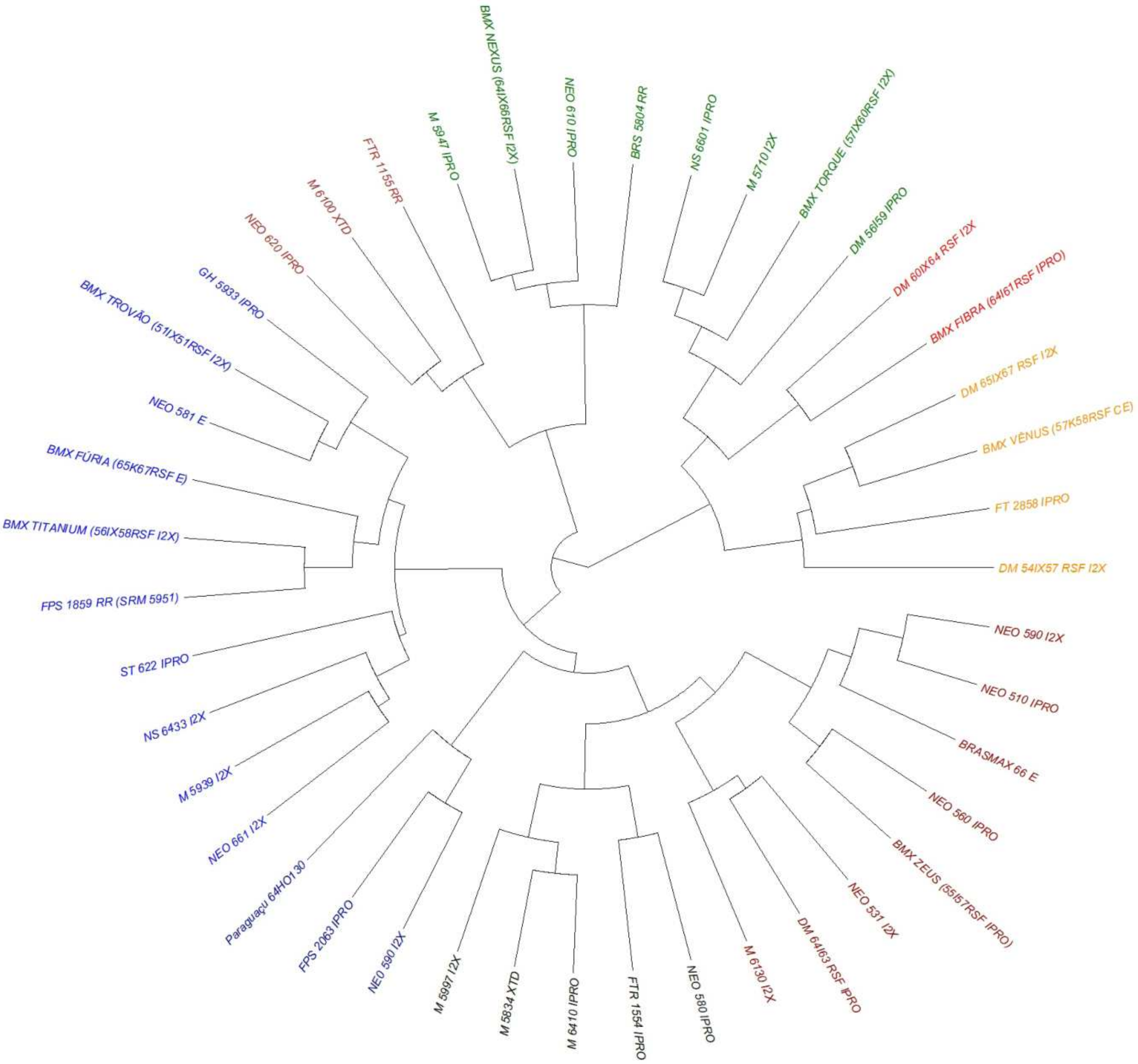


Figure 2. Pearson's linear correlation coefficients between morpho-agronomic characters measured in 43 soybean cultivars. Coefficients close to 1 mean a strong correlation, while coefficients close to 0 mean no correlation.

	DC_V4	NR_R5	NLR_R5	NNTP_R5	NNR_R5	PROF_SR_V4	TOMB_V4	AIP_R5	CR_R5	RC_V4	NPML_V4	P_PLANT_V4	SANID_V4	NLT_R5	MSP	RG	Craiz_R5	AP_R5	AZP_R5	NNHP_R5	NLHP_R5
NNHP_R5																					0.48 **
AZP_R5																				0.39 **	0.58 ***
AP_R5																			0.88 ***	0.35 *	0.45 **
Craiz_R5																		0.19 ns	0.31 *	0.13 ns	0.32 *
RG																	-0.13 ns	0.10 ns	0.16 ns	0.12 ns	0.34 *
MSP																0.84 ***	-0.11 ns	0.23 ns	0.31 *	0.28 ns	0.38 *
NLT_R5															0.28 ns	0.36 *	0.21 ns	0.23 ns	0.32 *	0.30 *	0.48 **
SANID_V4														0.07 ns	-0.10 ns	-0.11 ns	0.13 ns	-0.07 ns	-0.03 ns	-0.02 ns	0.02 ns
P_PLANT_V4													0.31 *	-0.03 ns	-0.11 ns	0.02 ns	0.08 ns	-0.22 ns	-0.12 ns	0.02 ns	0.23 ns
NPML_V4												0.27 ns	-0.02 ns	0.10 ns	-0.33 *	0.24 ns	-0.02 ns	-0.27 ns	-0.32 *	-0.31 *	-0.07 ns
RC_V4											0.32 *	0.07 ns	0.16 ns	0.06 ns	-0.22 ns	-0.05 ns	0.19 ns	0.21 ns	0.20 ns	-0.10 ns	0.21 ns
CR_R5										0.10 ns	-0.39 **	-0.45 **	-0.18 ns	0.13 ns	0.16 ns	-0.04 ns	0.00 ns	0.53 ***	0.33 *	0.07 ns	-0.06 ns
AIP_R5									0.41 **	0.22 ns	-0.02 ns	-0.23 ns	0.00 ns	0.10 ns	-0.07 ns	-0.06 ns	0.28 ns	0.64 ***	0.31 *	0.28 ns	0.09 ns
TOMB_V4								-0.01 ns	-0.05 ns	0.00 ns	0.01 ns	-0.08 ns	-0.06 ns	-0.13 ns	0.01 ns	-0.01 ns	-0.31 *	0.07 ns	0.01 ns	0.02 ns	0.06 ns
PROF_SR_V4							0.68 ***	0.01 ns	0.08 ns	-0.17 ns	-0.12 ns	0.06 ns	0.08 ns	-0.06 ns	0.04 ns	-0.05 ns	-0.35 *	0.10 ns	-0.01 ns	-0.15 ns	0.02 ns
NNR_R5						-0.06 ns	0.00 ns	0.31 *	0.37 *	-0.01 ns	-0.27 ns	-0.35 *	-0.19 ns	0.25 ns	0.02 ns	-0.14 ns	0.18 ns	0.16 ns	0.06 ns	0.31 *	0.00 ns
NNTP_R5					0.87 ***	-0.15 ns	-0.05 ns	0.46 **	0.36 *	0.09 ns	-0.21 ns	-0.27 ns	-0.13 ns	0.38 *	0.03 ns	-0.08 ns	0.22 ns	0.35 *	0.24 ns	0.54 ***	0.16 ns
NLR_R5				0.76 ***	0.84 ***	0.00 ns	0.08 ns	0.15 ns	0.47 **	-0.03 ns	-0.22 ns	-0.28 ns	-0.18 ns	0.29 ns	0.01 ns	-0.12 ns	0.11 ns	0.11 ns	0.03 ns	0.23 ns	0.02 ns
NR_R5			0.58 ***	0.60 ***	0.68 ***	0.12 ns	0.22 ns	0.50 ***	0.39 *	0.14 ns	-0.05 ns	-0.31 *	-0.29 ns	-0.04 ns	-0.10 ns	-0.14 ns	-0.01 ns	0.25 ns	0.00 ns	0.05 ns	-0.23 ns
DC_V4		0.18 ns	0.22 ns	0.17 ns	0.26 ns	0.12 ns	0.19 ns	-0.08 ns	-0.07 ns	0.07 ns	-0.07 ns	-0.05 ns	-0.11 ns	-0.09 ns	-0.13 ns	-0.20 ns	-0.17 ns	-0.13 ns	-0.19 ns	-0.04 ns	-0.12 ns
AP_V4	0.04 ns	0.01 ns	0.22 ns	0.11 ns	0.23 ns	0.22 ns	-0.05 ns	-0.02 ns	0.15 ns	-0.72 ***	-0.42 **	-0.06 ns	0.04 ns	-0.09 ns	0.23 ns	0.01 ns	-0.20 ns	-0.01 ns	-0.10 ns	0.09 ns	-0.08 ns

ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001

Figure 3. Dendrogram of genetic dissimilarity obtained from the morpho-agronomic characters measured in 43 soybean cultivars. The UPGMA (Unweighted Pair Group Method using Arithmetic Averages) clustering method was used. Each different color defines a cluster.



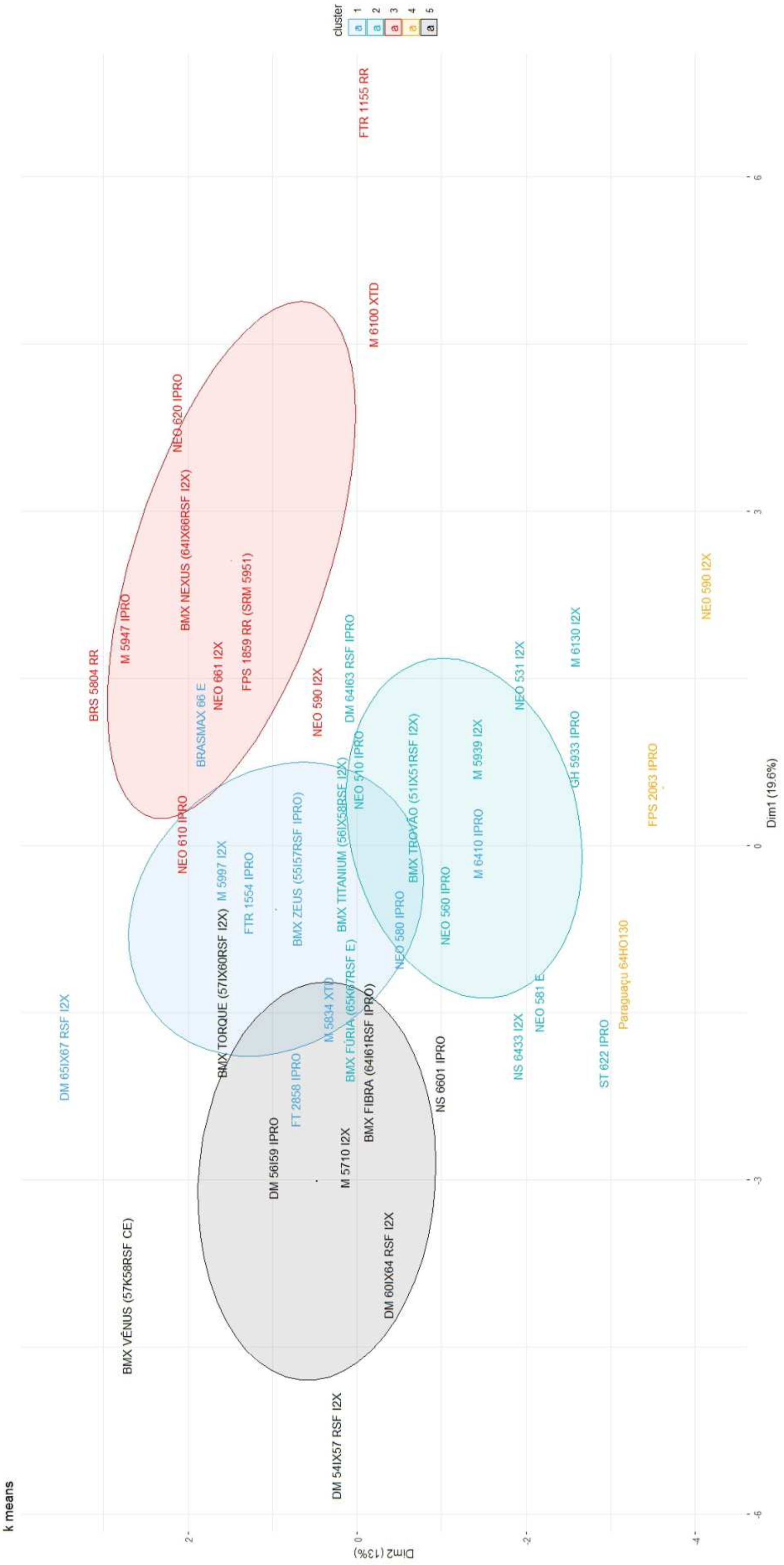
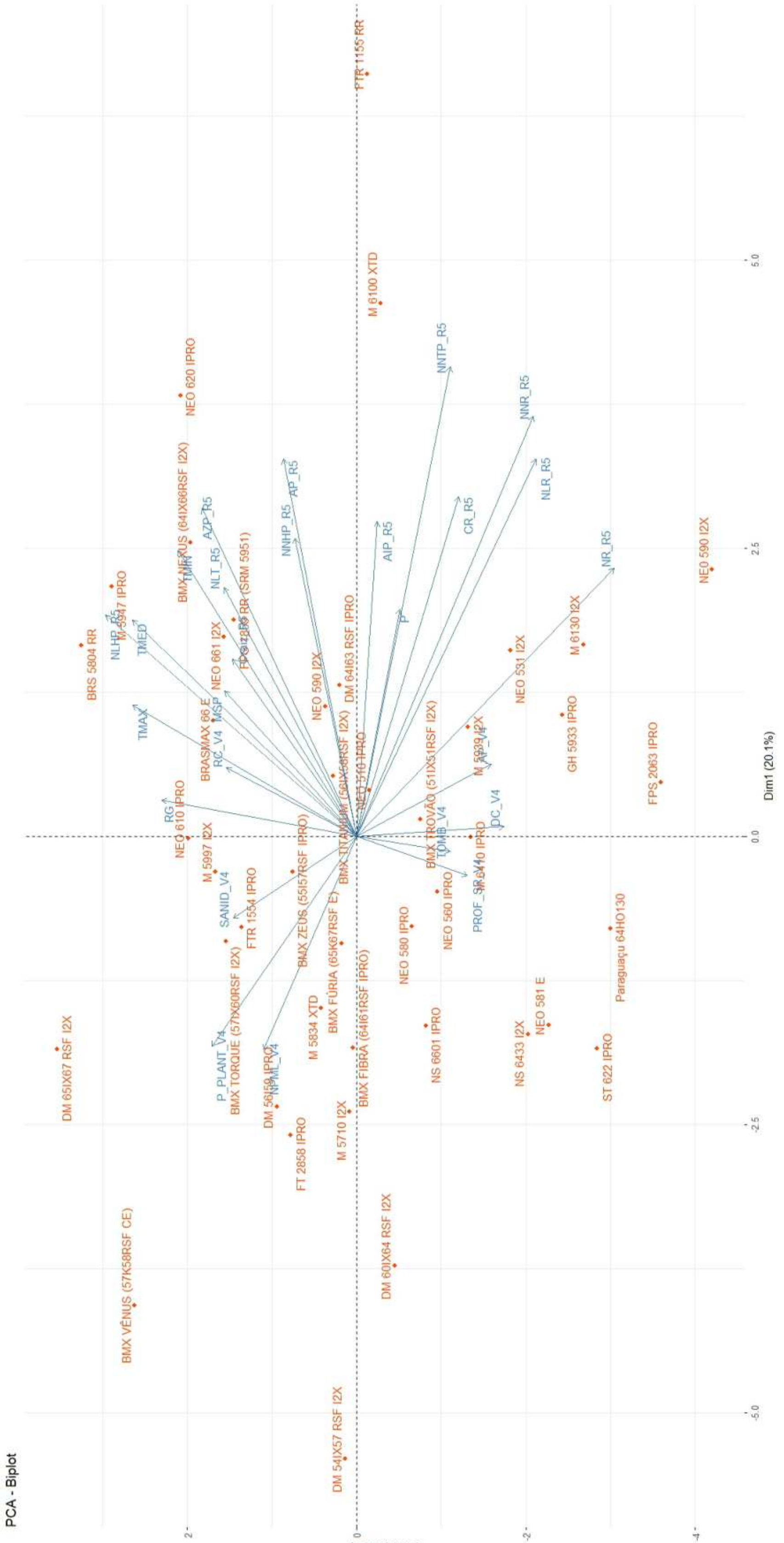


Figure 4. K-means clustering algorithm for classifying 43 soybean cultivars based on measured morpho-agronomic characters.

Figure 5. Principal Component Analysis (PCA) Biplot to identify the degree of association of 43 soybean cultivars with the morpho-agronomic characters measured.



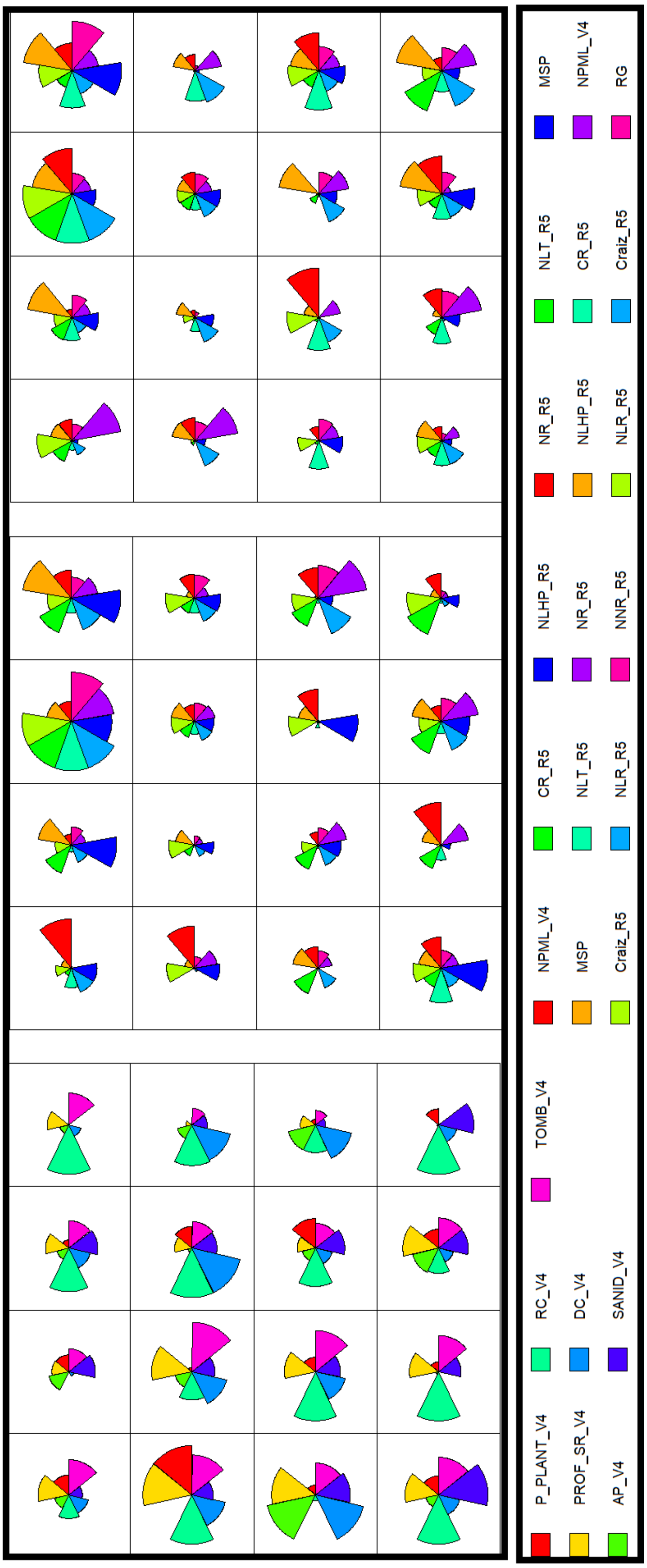


Figure 6. Self-organizing Kohonen map obtained for the morpho-agronomic characters measured in 43 soybean cultivars. Group A clusters were obtained from the following characters: P_PLANT_V4; PROF_SR_V4; AP_V4; RC_V4; DC_V4; SANID_V4; TOMB_V4. Group B clusters were obtained from the following characters: NPML_V4; MSP; Craiz_R5; CR_R5; NLT_R5; NLR_R5; NLHP_R5; NR_R5; NNR_R5. Group C clusters were obtained from the following characters: NR_R5; NLHP_R5; NLR_R5; NLT_R5; CR_R5; Craiz_R5; MSP; NPML_V4; RG. All cultivars were considered for all groups.

Received in: set, 03, 2024
Accepted in: jan, 31, 2025