SOYBEAN AGRONOMIC IDEOTYPE AIMING FOR LEAF HEALTH AND RESILIENCE TO DISEASES

Jaqueline Piesanti Sangiovo[1], Ivan Ricardo Carvalho [1], Christiane de Fátima Colet [1], Murilo Vieira Loro[2], Leonardo Cesar Pradebon[2], Willyan Júnior Adorian Bandeira[1], Victor Delino Barasuol Scarton [1], Arthur Ledermann Van Der Sand [1]

ABSTRACT - The objective of this work was to build the agronomic ideotype of soybean focused on area and leaf architecture, aiming at plants resilient to diseases that affect the aerial part of soybeans, resulting in increased grain productivity. The experimental design used was that of augmented blocks, with interspersed controls, with treatments distributed in four blocks allocated throughout the experiment. 1449 F_3 segregating generation soybean lineages were sown (75% inbreeding). Four commercial cultivars were used as controls, namely VTOP RR®, BMX ZEUS IPRO, Credenz CZ 2607 XTD – BASF Agro and NS 4823 RR, arranged in four replications in a common manner in each block. Based on the agronomic ideotype for leaf health, genotypes are sought that have the maximum healthy leaf area, bearing in mind that the minimum point of leaf area is 23.72 cm² and with each cm² there is an increase of 0.45 grams of grain weight per plant during the flowering period. For the grain filling period, the minimum leaf area point is 21.73 cm² of leaf area with an increase of 0.39 grams in grain weight.

Keywords: cultivars, grain, leaf area, soybean.

IDEÓTIPO AGRONÔMICO DA SOJA VISANDO A SANIDADE FOLIAR E A RESILIÊNCIA A DOENÇAS

RESUMO - O objetivo deste trabalho foi construir o ideótipo agronômico da soja focado em área e arquitetura foliar, visando plantas resilientes a doenças que afetam a parte aérea da soja, resultando no aumento da produtividade de grãos. O delineamento experimental utilizado foi o de blocos aumentados, com testemunhas intercaladas, com os tratamentos distribuídos em quatro blocos alocados ao longo do experimento. Foram semeadas 1.449 linhagens de soja da geração segregante F3 (75% de endogamia). Foram utilizadas quatro cultivares comerciais como controle, sendo elas VTOP RR®, BMX ZEUS IPRO, Credenz CZ 2607 XTD – BASF Agro e NS 4823 RR, dispostas em quatro repetições de maneira comum em cada bloco. Com base no ideótipo agronômico para sanidade foliar, buscam-se genótipos que possuam a área foliar máxima sã, lembrando que o ponto mínimo de área foliar é 23,72 cm² e a cada cm² há um aumento de 0,45 gramas de peso de grãos por planta durante o período de floração. Para o período de enchimento de grãos o ponto mínimo de área foliar é de 21,73 cm² de área foliar com acréscimo de 0,39 gramas na massa de grãos.

Palavras chaves: área foliar, cultivares, grão, soja.

INTRODUCTION

Soybean has several uses that include animal and human nutrition and the manufacture of biofuels, such uses are mainly due to the high protein and oil content present in the grains (CHEN *et al*., 2012). Linked to these factors, it has a high economic value, and technological development seeks to make it increasingly productive and competitive. Selecting genotypes that have greater stability to climate change and biotic factors results in an increase in the productivity and quality of the grains obtained, and for this purpose genetic improvement is necessary (JEONG *et al*., 2011). Linked to this, genotypes with adaptive capacity

[1] Regional University of the Northwest of the State of Rio Grande do Sul, Ijuí, Rio Grande do Sul State, Brazil. E-mail: Jaqueline.sangiovo@sou.unijui.edu.br, carvalho.irc@gmail.com,christiane.colet@unijui.edu.br,willyan.bandeira@sou.unijui.ed u.br,victor.scarton@sou.unijui.edu.br,arthur.sand@sou.unijui.edu.br.

[2] Federal University of Santa Maria, Santa Maria, Rio Grande do Sul State, Brazil. E- mail:loro@gmail.com, pradebonleo@gmail.com

and resilience to the main diseases that affect soybeans are sought (VASCONCELOS *et al*., 2015).

In the search for the agronomic ideotype of soybeans, it is necessary to evaluate the morphological, bromatological characteristics and productivity components, which are important for improvement, as they require accurate selection strategies, knowledge of the genetic contributions to the phenotypic manifestation of these attributes and inter- relationships with the environment in which the new cultivars will be inserted (CARVALHO *et al*., 2017).

By obtaining superior plants that are resilient to leaf diseases, the plant's leaf architecture, cycle, number of leaves and leaflets, as well as reproductive nodes on the main stem and branches are glimpsed. This enhances photosynthetic rates, interception and use of light energy, minimizing costs through tissue respiration. Thus, the balance between growth, development and photosynthesis favors the obtaining of energy and accumulation of assimilates, resulting in lineages with a high harvest rate, productive and resilient (ZHAO *et al*., 2023).

As explained, determining the exact leaf area of soybeans allows the evaluation of the photosynthetic efficiency of the plants, as well as their response to defoliation, arising from the biotic and abiotic factors inherent to the production environment (RITCHER *et al*., 2014). This can be accomplished through destructive and non-destructive techniques, images and the aid of phenomic tools (WILCKEN *et al*., 1998).

With emphasis on the importance of soybean leaf area, studies have already been carried out to compile losses, depending on the plant's defoliation. According to COSTA *et al*. (2003), regarding defoliation levels in the soybean reproductive stage, it was observed that in the R2 stage there are no significant decreases in productivity at any level of defoliation carried out. In R3, reductions of 23, 26 and 70% were compiled for defoliations of 33, 67 and 100% consecutively. Considering that, this is the stadium that presents difficulties in recovering after suffering damage. For stages R4, R5 and R6, damage was observed only with 100% defoliation. In contrast, a study carried out by Bahry *et al*. (2013), it was observed that in crops with high productive potential, any level of defoliation causes losses of up to 420 kilos of grain per hectare. For Souza *et al*. (2014), defoliation during the vegetative period causes reductions of up to 50.3% in the number of flowers, fixation rate and grain filling.

Based on these studies, the divergences and gaps found, it is necessary to formulate a leaf area ideotype that meets the physiological requirements of soybeans. Thus, the objective of this work was to build the agronomic ideotype of soybean focused on area and leaf architecture, aiming at plants resilient to diseases that affect the aerial part of soybeans, resulting in increased grain productivity.

MATERIAL AND METHODS

The study was carried out in the municipality of Ijuí, state of Rio Grande do Sul, under the area of the Regional University of the Northwest of the State of Rio Grande do Sul - Unijuí at geographic coordinates 28°23'37.1" South and 53°56'40.5" West. The soil in the experimental area is classified as a Typical Dystroferric Red Oxisol. The climate is type Cfa according to the Köppen climate classification.

The experimental design used was that of augmented blocks, with interspersed controls, with treatments distributed in four blocks allocated throughout the experiment. 1449 F_3 segregating generation soybean lineages were sown (75% inbreeding), the lineages come from populations IRC_{001} (112 $_L$), IRC_{002} (11$_L$), IRC_{003} (6 $_L$), IRC_{005} (55 $_L$), IRC_{007} (17 $_L$), IRC_{008} (2 $_L$), IRC_{009} (1 $_L$), IRC_{011} (20 $_L$), IRC_{012} (70 $_L$), IRC_{013} (63 $_L$), IRC_{017} (54 $_L$), IRC_{020} (2 $_L$), IRC_{021} (200 $_L$), IRC_{022} (9 $_L$), IRC_{025} (34 $_L$), $_{IRC026}$ (1 $_L$), IRC_{028} (3 $_L$), IRC_{029} (5 $_L$), IRC_{031} (71 $_L$), IRC_{033} (11 $_L$), IRC_{034} (95 $_L$), IRC_{035} (8 $_L$), IRC_{036} (1 $_L$), IRC_{037} (67 $_L$), IRC_{038} (2 $_L$), IRC_{039} (15 $_L$), IRC_{040} (27 $_L$), IRC_{041} (3 $_L$), IRC_{042} (7 $_L$), IRC_{043} (5 $_L$), IRC_{044} (106 $_L$), IRC_{045} (7 $_L$), IRC_{046} (50 $_L$) IRC_{047} (2 $_L$), IRC_{048} (1 $_L$), IRC_{049} (88 $_L$), IRC_{050} (7 $_L$), IRC_{051} (1 $_L$), IRC_{052} (24 $_L$), IRC_{053} (7 $_L$), IRC_{054} (11 $_L$), IRC_{055} (37 $_L$), IRC_{056} (17 $_L$), IRC_{057} (13 $_L$), IRC_{058} (71 $_L$), IRC_{059} (4 $_L$), IRC_{060} (67 $_L$), and IRC_{061} (1 $_L$). Four commercial cultivars were used as controls, namely VTOP RR®, BMX ZEUS IPRO, Credenz CZ 2607 XTD – BASF Agro and NS 4823 RR, arranged in four replications in a common manner in each block. Sowing took place in the first half of October 2022, using 18 seeds per linear meter. Sowing was carried out manually with N-P-K fertilizer in the 03-21-21 formulation, insect pest management took place preventively, with the aim of minimizing biotic effects on the results of the experiment.

The meteorological data obtained were: mean air temperature (C°), minimum air temperature (C°), maximum air temperature (C°) and precipitation (mm), extracted from the NASA Power platform (NASA POWER, 2023) and compared with the meteorological station in the experimental field. For each lineage, representative plants of the experimental unit were listed, and these were sampled, where nine leaflets were removed and the following were measured: Leaf area at the R_1 stage (LEA_R_1; cm^2);

Healthy leaf area in R_1 (HLA_R_1; cm^2); Compromised leaf area by biotic effects in R_1 (CLA_R_1; cm^2); Leaf area in R_5 (LEA_R_5; cm^2); Healthy leaf area in R_5 (HLA _R_5; cm^2); Leaf area compromised by biotic effects in R_5 (CLA_R_5; cm^2); Number of leaflets in R_1 (NL_R_1, unit) and Grain weight per plant (GWP; g $plant^{-1}$).

Leaflets were collected from the middle third of three plants of each lineage, in the respective periods of flowering (R1) and beginning of grain formation (R5), after capturing RGB images, which were obtained under room temperature conditions and diffuse artificial lighting. The images were acquired with a resolution of 1280 x 1024 pixels and 96 dpi (dots per inch) using the LED LIGHT PAD model A3 camera and the leaf area was determined with the PLIMAN (Plant Image Analysis) data analysis package (OLIVOTO, 2021). Descriptive and density analysis was carried out for meteorological data on maximum, minimum and mean air temperature, maximum, average and minimum values for leaf area in the flowering (R1) and grain filling (R5) periods. The variables that showed significance through linear regression at 5% probability using the t test were subjected to construction of the trend model (GWP ~ (LEA_R1, HLA_RS, MFC_F1, LEA_R5, HLA_R5, CLA _R5 and NL)). To identify the tendency of association between the characteristics, linear correlation analysis took place.

Based on the desired agronomic ideotype, the multicharacteristic index of the distance between the genotype and the intended agronomic ideotype (MGDI) was used (OLIVOTO and NARDINO, 2021), with the objective of selection being to increase the area of the healthy leaflet during the flowering period, filling grains and grain weight per plant, as well as reducing the leaflet area during the flowering and grain filling period, the leaflet area compromised during the flowering and grain filling period and the number of leaflets per plant.

$$MGIDI_i = \left[\sum_{j=i}^{f} (\Upsilon ij - \Upsilon j)^2\right]^{0,5}$$

The analyzes were carried out using the R software (R Core Team, 2023) using the *agricolae* (MENDIBURU, 2021), metan (OLIVOTO E LUCIO, 2020) and ggplot2 (WICKHAM, 2016) packages. All analyzes were performed in the R software using the packages readxl, metan, ggplot2, patchwork, dplyr, AgroR, EnvRtype (R CORE TEAM, 2023).

RESULTS AND DISCUSSION

During the experiment, the mean, minimum and maximum air temperatures and precipitation were calculated for the vegetative, reproductive and physiological maturity periods (Figure 1). The vegetative period of soybeans covered the months of October and November 2022 and revealed minimum temperatures of 13°C, maximum temperatures of 25°C and means of 19°C, with the ideal temperature for development in the initial period of soybeans being 31°C (TAGLIAPIETRA *et al*., 2022). The reproductive period, between the months of December 2022, January 2023, February 2023 and early March 2023, revealed minimum, mean and maximum temperatures between 19, 24 and 33°C, respectively. The physiological maturity of the culture occurred between the months of March and April 2023, with maximum temperatures of 30°C, averages of 24°C and minimums of 19°C.

The 2022/2023 harvest presented irregular water distributions, with the daily average in the vegetative period being 2.58 mm, while the reproductive period had daily accumulations of 3.10 mm and in physiological maturity daily averages of 4.21 mm. In order to meet the crop's water needs, supplementation of 13 mm/day was used, to meet the needs of 450 mm to 800 mm regularly, during its cycle (NEUMAIER *et al*., 2020; TAGLIAPIETRA *et al*., 2022).

The leaf area computed in the lineages at the beginning of flowering (Figure 2) presented maximum values of 277 cm^2, average values of 26 cm^2 and minimum values of 4 cm^2. In contrast, it was observed that the commercial cultivars had a maximum of 25 cm^2, an average of 15 cm^2 and a minimum of 5 cm^2, revealing the presence of discrepant leaf area values for the evaluated lines, justified by the level of heterozygosity present in the F3 generation, given that the morphological characteristics of the plant present low stability. Voltan et al. (2000) reveal that cultivars can express from 266 cm^2 to 422 cm^2 for soybeans.

The healthy leaf area demonstrated a maximum of 20.55 cm^2, an average of 11.23 cm^2 and a minimum of 1.64 cm^2, for commercial cultivars, while for the lineages, maximum, average and minimum values of 226 were observed 89 cm^2, 21.67 cm^2 and 4.40 cm^2, respectively. The compromised area presented maximum, average and minimum values of 10.06 cm^2, 4.46 cm^2 and 0.30 cm^2 for the commercial cultivars and 50.75 cm^2, 5 cm^2 and 0.31 cm^2 for the lineages, respectively.

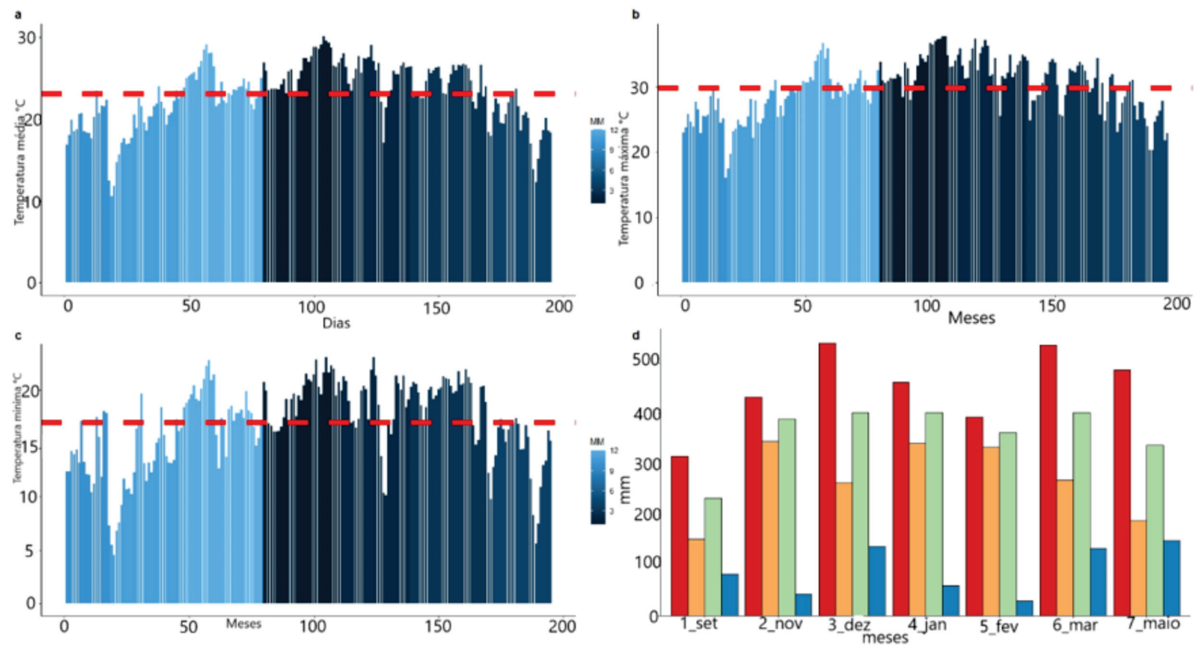

Figure 1 - A - Mean temperature (°C), B - maximum temperature (°C), C - minimum temperature (°C), D - precipitation (mm) for the months of October, November and December 2022 and January, February, March and April 2023. The dashed line for graphs A, B and C presents the average of the values, in graph D the column in red presents the total accumulated in the month (AC, mm), the column in yellow represents the water demand for the crop (WD, mm), the green column shows artificial irrigation (IR, mm) and the blue column shows precipitation (P, mm).

It is defined that the lineages have a larger leaf area with a higher health level. The maximum number of leaflets obtained in the controls was nine leaflets, however, for the lineages, up to 130 leaflets were found, showing heterogeneity in the morphological characteristics of the lineages that have a heterozygous level of 25%, with a high leaf area index and imbalance in the soybean harvest index.

The leaf area during the grain filling period presented maximum values of 31.73 cm^2, average values of 21.90 cm^2 and minimum values of 15.6 cm^2 for commercial cultivars, which are higher than the flowering period, a fact that characterizes the dynamics of growth and development of cultivars with indeterminate habit. For the lineages, maximum, average and minimum values of 811.99 cm^2, 38.00 cm^2 and 8.25 cm^2 were obtained, these being higher than the cultivars. Zanon *et al*. (2015) indicates that, in indeterminate cultivars, the maximum point of leaf area is observed at the R5 stage at full grain filling. In relation to healthy leaf area, maximum, average and minimum values of 29.31 cm^2, 20.33 cm^2 and 14.22 cm^2 were observed for commercial cultivars and 760, 11 cm^2, 35.50 cm^2 and 7.54 cm^2 for lineages, respectively. However, the compromised area showed maximum values of 10.06 cm^2, average values of 4.46 cm^2 and minimum values of 0.30 cm^2.

The linear regression analysis presented coefficients of determination greater than 0.7 for all models for leaf area (LEA:cm^2). In the period at the beginning of flowering (R1) for grain weight per plant, starting at 23.72 cm^2 with an increase of 0.45 g in grain weight each LEA ($Y= 23.72898+ 0.45500338x$). For healthy leaf area (cm^2) in R1, starting from 25.29 cm^2 with an increase of 0.49 g in grain weight at each LEA ($Y= 25.29112+ 0.4908451x$). The compromised leaf area (cm^2) in R1 reveals that to increase productivity, an increase of 4.51 cm^2 is sought ($Y= 116.3002-37.58236x+4.165733x^2$), higher magnitudes reduce productive potential.

For the grain filling period starting at 21.73 cm^2, an increase of 0.39 g in the grain weight per plant for each LEA is revealed ($Y= 21.73666+0.392727x$). For healthy leaf area in R5, we start from a minimum of 22.03 cm^2 and it is identified that 0.41g in the total grain weight are increased due to LEA (Y= 22.03669+0.411662x), for compromised leaf area it is revealed that the maximum point of losses was 6.66 cm² without harming the grain weight (Y= 116.3002- 20.28171x+6.669545x²). The number of leaflets demonstrates a maximum point of six leaflets for increasing grain productivity (Y= 32.50456+0.4795762x-0.08627252x²). The grain weight for commercial controls, the maximum point was 30.66 g per plant, in this way the optimum leaf area point for the lineages was compiled with the aim of exceeding the gram weight per plant, presented by the controls. For leaf area during the flowering period and healthy area, it was shown that 16 cm² can obtain up to 31 grams of grain weight per plant, with controls standing out. For leaf area at the beginning of grain filling, it was observed that 23 cm² results in 30.76 grams of grain weight per plant.

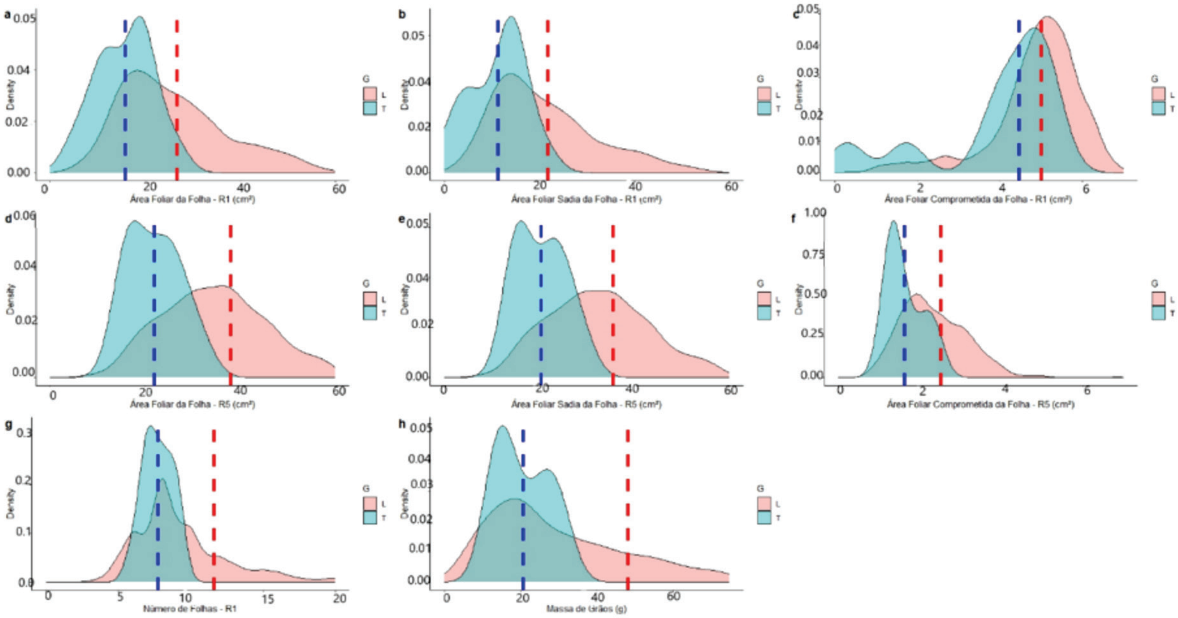

Figure 2 - Descriptive analysis for the maximum, average and minimum values for A - leaf area of the leaf (R1, cm²), B - healthy leaf area of the leaf (R1, cm²), C - compromised leaf area of the leaf (R1, cm²), D - leaf area of the leaf at the beginning of grain filling (R5, cm²), E - healthy leaf area of the leaf at the beginning of grain filling (R5, cm²), F - compromised leaf area of the leaf at the beginning of grain filling (R5, cm²), G - number of leaves (units) and grain weight (g) for the lineages (L) in the pink curve and control commercial cultivars (C) in the blue curve. The dashed lineages indicate the central tendency (control: blue and lineages: red).

The linear correlation analysis (Figure 3) revealed 29 associations between the eight variables, six of which were significant with great magnitude. The leaf area in the flowering period (R1) was significantly correlated with the healthy leaf area in the flowering period R1 (r: 0.99*) and compromised leaf area (r: 0.84*) considering that the increase of total leaf area is directly linked to healthy and compromised leaf area. The compromised leaf area in R1 was related to the healthy area in R1 (r: 0.81*), the leaf area in R5 demonstrated an association with the healthy area in R5 (r: 0.78*), the compromised leaf area in R5 (r: 0.78*). In relation to grain weight per plant (GWP), it is identified that the total leaf area in R1 and R5 are decisive for the increase in this productivity component, therefore indirectly increasing the healthy and compromised leaf area.

The principle of multitrait selection analysis is to select progenies that meet the increase in healthy leaflet area during the flowering and grain filling period, as well as the grain weight per plant, in contrast, reducing the total leaflet area during the flowering and grain filling period, the leaflet area compromised during the flowering and grain filling period and the number of leaflets per plant, all variables were pressed at 100% intensity for selection (positive or negative; Table 1). Factor 1 presented the variables healthy leaf area in R5, leaf area in R5 and compromised leaf area in R5. Factor 2 brought together the components of healthy leaf area in R1, leaf area in R1 and compromised leaf area in R1. The grain weight per plant and the number of soybean leaflets are contained in factor 3.

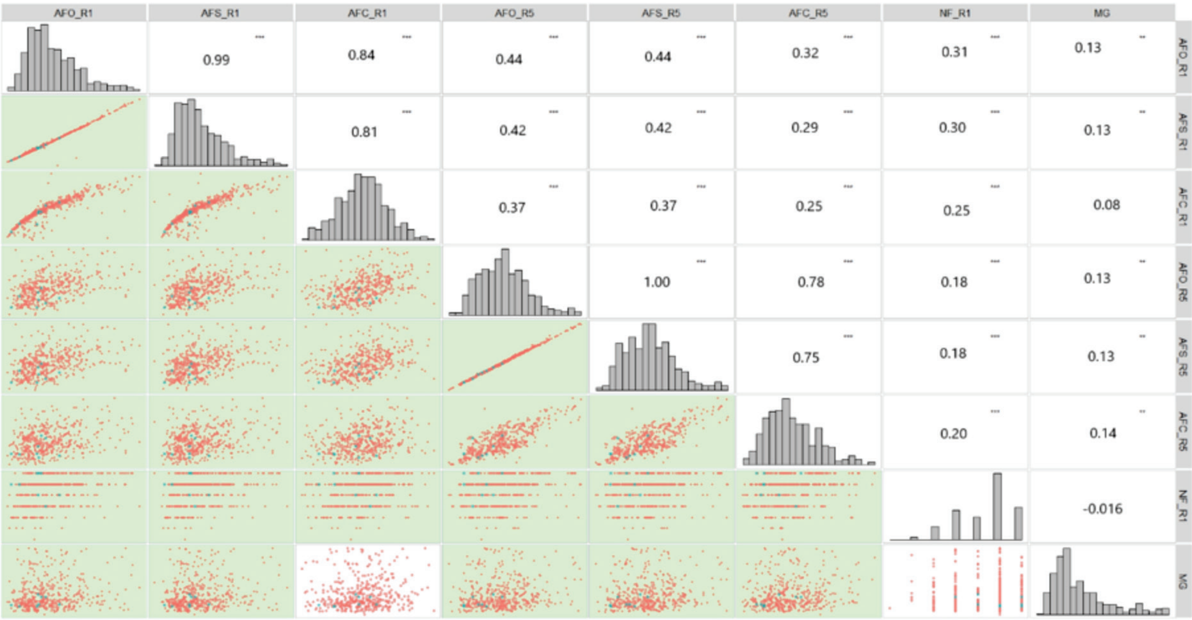

Figure 3 - Linear correlation with sample number of 1449 lineages for the variables healthy leaf area at grain filling (HLA_R5), leaf area at grain filling (LEA_R5), compromised leaf area at grain filling (CLA_R5), healthy leaf area at flowering (HLA_R1), leaf area at flowering (LEA_R1), compromised leaf area at flowering (CLA_R1), grain weight (GWP) and number of leaflets at flowering (NL_R1), with significance based on the t test at 5% probability.

For the leaf area at the beginning of grain filling, 35 cm² was obtained, which was healthy, 37 cm² for the total leaf area and 2.48 cm² of compromised leaf area. Selection requires 53 cm², 57 cm² and 3 cm² respectively. For the beginning of flowering, the healthy leaf area obtained 21.54 cm² of healthy, 26.56 cm² of total leaf area and compromised leaf area was only 5 cm², for selection 38.61 cm², 44.03 cm² and 4 .78 cm², respectively. The grain weight had an average of 47.91 g considering that the average required to meet the ideotype is 111.7 g^{-1}, the average observed for the number of leaflets was 11.58 g and the required is 39, 82 g. The heritability values for leaflet area in R5 resulted in H^2:0.99, leaf area in R5 revealed H^2:0.99, compromised leaf area in R5 was H^2:0.99, healthy leaf area in R1 with H^2:0.93, leaf area in R1 with H^2:0.95, compromised leaf area in R1 with H^2:0.38, grain weight resulted in H^2:0.99 and number of leaflets with H^2:0,99, revealing that most variables show minimum genetic variability to employ selection.

Of the 1449 lineages, only 37 were selected (Figure 4), with: L78, L533, L130, L590, L20, L108, L243, L112, L324, L244, L418, L494, L1086, L36, L129, L49, L37, L137, L178, L308, L34, L241, L175, L855, L30, L487, L237, L29, L183, L75, L1112, L132, L1381, L910, L128, L33, L213, L1362, L320, L459, L35, L46, it is observed that these segregating lineages come from the recombination of maternal parents 15b70IPRO, NS5958 RR, FPS SOLAR, NS5909, 6700 RR, DM 7.0 BMX MAGNA RR, ROOS CAMINO RR, TMG 7062 RR, FPS NETUNO RR, FPS JUPITER RR, BMX POTÊNCIA RR, Variety M4, NS 5908, HO JACUÍ and FPS NETUNO RR. As well as the paternal 6563 IPRO, 6700 RR, FPS JUPITER RR, BMX ATIVA RR, DM 58 BMX APOLO RR, FUNDACEP 66 RR, FPS PARANAPANEMA RR, MONASCA RR, NA 5909, DM 6160 IPRO and HO PURICA. It is concluded that when evaluating commercial controls the variable grain weight per plant presented 30.66 grams, for the leaf area in the flowering and filling period it is observed that, from 16 to 23 cm², 31 grams of grains are obtained per plant and surpasses the controls.

Table 1 - Multitrait distance analysis from genotype to ideotype, selection of soybean lineages (MGDI) for the variables healthy leaf area at grain filling (HLA_R5, cm²), leaf area at grain filling (LEA_R5, cm²), compromised leaf area at grain filling (CLA_R5, cm²), healthy leaf area at flowering (HLA_R1, cm²), leaf area at flowering (LEA_R1, cm²), compromised leaf area at flowering (CLA_R1, cm²), grain weight (GWP, g) and number of leaflets at flowering (NL_R1, units) for factor 1 (FA1), factor 2 (FA2) and factor 3 (FA3) for observed mean (Xo), required mean (Xs), broad sense heritability (H^2).

Variable	Factor	Xo	Xs	H^2	Sense
HLA_R5	1	35.31	53.37	0.9954	Increase
LEA_R5	1	37.79	57.19	0.9955	Decrease
CLA_R5	1	2.487	3.832	0.9930	Decrease
HLA_R1	2	21.54	38.61	0.9363	Increase
LEA_R1	2	26.56	44.03	0.9566	Decrease
CLA_R1	2	5.001	4.878	0.3846	Decrease
GWP	3	47.91	111.7	0.9993	Increase
NL_R1	3	11.58	39.82	0.9967	Increase

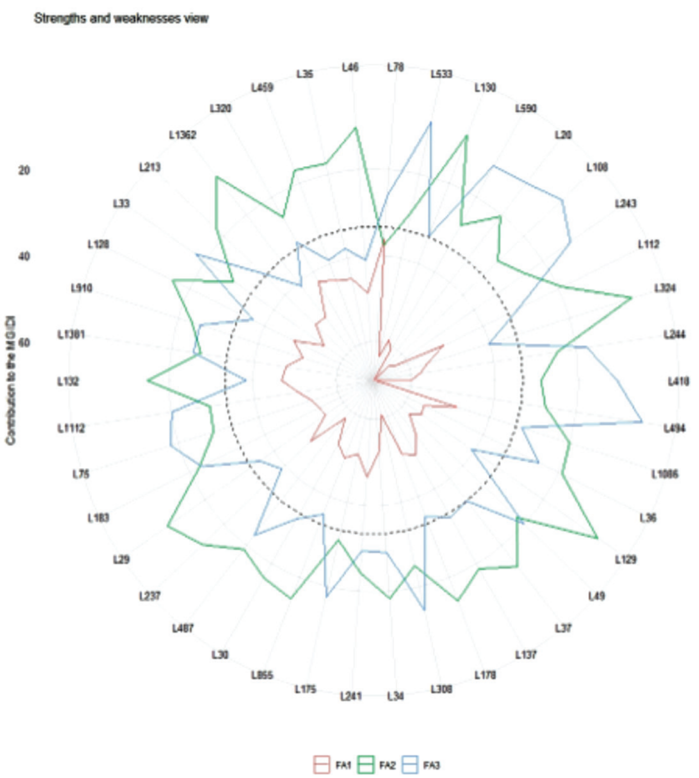

Figure 4 - Multitrait distance analysis from genotype to ideotype, selection of soybean lineages (MGDI), identifying the contribution of factors (1, 2 and 3) in selection.

CONCLUSION

Based on the agronomic ideotype for leaf health, genotypes are sought that have the maximum healthy leaf area, bearing in mind that the minimum point of leaf area is 23.72 cm² and with each cm² there is an increase of 0.45 grams of grain weight per plant during the flowering period. For the grain filling period, the minimum leaf area point is 21.73 cm² of leaf area with an increase of 0.39 grams in grain weight.

The positioning of the maternal and paternal parents is an alternative for meeting the agronomic ideotype of leaf architecture, for this purpose the use of the maternal parent FPS SOLAR RR and the paternal parent FPS JUPITER RR is prioritized.

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