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STRATEGIC POSITIONING OF SOYBEAN CULTIVARS IN THE STATE OF RIO GRANDE DO SUL

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ABSTRACT - This work aims to highlight the best soybean genotypes for specific environments in the Northwest Region of the State of Rio Grande do Sul. The experiment was carried out in the 2018/19 crop season in fifteen cultivation environments in the Northwest region of the state of Rio Grande do Sul, using 52 soybean genotypes in 15 growing environments. The experimental design used was lattice with treatments (growing environments) arranged in three replications. In each useful area of the experimental unit, the grain productivity of the genotypes was evaluated. Then, the Restricted Maximum Likelihood (REML) method was applied to estimate the variance components and genetic parameters. The following variance components were estimated: Genetic variation (Vg) and phenotypic variation (Vp). The genetic parameters estimated were: broad sense heritability (H²), coefficient of genotypic variation (CVg), coefficient of residual variation (CVe), ratio between genetic and residual coefficient (CVr) and selective accuracy (Ac). The phenotypic expression of grain yield is determined by 17% due to genetic effects and 83% by the environment. The NS 6909 RR IPRO, NS 5445 IPRO, DM 5958 IPRO and DM 6563 IPRO genotypes showed greater genetic gains for grain yield. The environments Doutor Maurício Cardoso (RS), Nova Ramada (RS) and Independência (RS) are characterized as favorable environments.
Keywords: *Glycine max* L., heritability, selection of cultivar, *REML/BLUP*.

POSICIONAMENTO ESTRATÉGICO DE CULTIVARES DE SOJA NO ESTADO DO RIO GRANDE DO SUL

RESUMO - Este trabalho tem como objetivo destacar os melhores genótipos de soja para ambientes específicos na Região Noroeste do Estado do Rio Grande do Sul. O experimento foi realizado na safra 2018/19 em quinze ambientes de cultivo na região Noroeste do estado do Rio Grande do Sul, utilizando 52 genótipos de soja em 15 ambientes de cultivo. O delineamento experimental utilizado foi em látice com tratamentos (ambientes de cultivo) dispostos em três repetições. Em cada área útil da unidade experimental foi avaliada a produtividade de grãos dos genótipos. Em seguida, aplicou-se o método de Máxima Verossimilhança Restrita (REML) para estimar os componentes de variância e os parâmetros genéticos. Foram estimados os seguintes componentes de variância: Variação genética (Vg) e variação fenotípica (Vp). Os parâmetros genéticos estimados foram: herdabilidade de sentido amplo (H²), coeficiente de variação genotípica (CVg), coeficiente de variação residual (CVe), razão entre coeficiente genético e residual (CVr) e acurácia seletiva (Ac). A expressão fenotípica do rendimento de grãos é determinada em 17% devido a efeitos genéticos e 83% pelo ambiente. Os genótipos NS 6909 RR IPRO, NS 5445 IPRO, DM 5958 IPRO e DM 6563 IPRO apresentaram maiores ganhos genéticos para produtividade de grãos. Os ambientes Doutor Maurício Cardoso (RS), Nova Ramada (RS) e Independência (RS) caracterizam-se como ambientes favoráveis.
Palavras-chave: *Glycine max* L., herdabilidade, seleção de cultivares, *REML/BLUP*.

INTRODUCTION

Soybean (*Glycine max* L.) is one of the most cultivated species in the world, with great economic and nutritional importance, being widely used in human and animal food in the manufacture of animal feed. Its grains are one of the main sources of proteins, lipids and nutrients (LORO et al., 2021), which promotes it as the main crop in the world, justifying its large area of cultivation. Currently, the largest grain producer of this oilseed is Brazil, which has the greatest potential for the production of the crop, followed by the United States.

According to data from the 2020/21 season, production was 138,15 million tons of grain and a yield of 3,525 kg ha^{-1} (CONAB, 2022). In Rio Grande do Sul, in the 2020/21 season, 20,78 million tons of grain were produced in an area of 6,05 million hectares, with a yield of 3,433 kg ha^{-1}.

The search for increasing soybean grain yield has become fundamental, and there are many factors that influence it, such as agroclimatic zoning, cultivar, physical and chemical soil quality, management and climatic conditions. In addition, the interaction between genotypes x

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environments (G x E) influences the choice of cultivar, with the genotype responding differently to different environments (CARVALHO et al., 2016). This differentiated expression of the phenotype in relation to the G x E interaction occurs because the genic expression is influenced by air temperature and humidity, radiation, rainfall and other abiotic factors, and promotes the phenotypic manifestation according to these conditions (TAIZ et al., 2017).

In Brazil, there is a great availability of cultivars, providing the use of this crop in all producing regions of the country, sown at preferential (season) and non-preferential (off-season) times. Where soybean grain yield is related to the phenotypic adaptability of the genotype to the particular environment and sowing time (MEIRA et al., 2016; CARVALHO et al., 2017; SZARESKI et al., 2018). In this sense, this work aims to highlight the best soybean genotypes for specific environments in the Northwest Region of the State of Rio Grande do Sul.

MATERIAL AND METHODS

The experiment was carried out in the 2018/19 crop season in fifteen cultivation environments in the Northwest region of the state of Rio Grande do Sul, using 52 soybean genotypes, using only the main genotypes for each growing environment. The experimental design used was lattice with treatments (growing environments) arranged in three replications (Table 1).

TABLE 1 - Characterization of growing environments, agricultural zoning microregion, altitude (m), geographic coordinates, rainfall (mm) and soil classification.

Env	City	Altitude (m)	Latitude and Longitude	Rainfall (mm)	Soils
E1	Augusto Pestana (RS)	376	S 28°31'02" W 53°59'39"S	1.2	Latosol
E2	Jóia (RS)	316	S 28°38'51" W 54°07'21"S	1.892	Latosol
E3	Miraguaí (RS)	490	S 27°30'01" W 53°41'01"S	1.929	Latosol
E4	Nova Ramada (RS)	515	S 28°03'52" W 53°41'48"S	1.5	Latosol
E5	Santo Augusto (RS)	531	S 27°51'05" W 53°46'38"S	1.773	Latosol
E6	Tenente Portela (RS)	501	S 27°22'15" W 53°45'28"S	1.884	Latosol /Chernosol
E7	Três Passos (RS)	420	S 27°27'31" W 53°55'49"S	1.423	Latosol
E8	Bozano (RS)	429	S 28°22'07" W 53°46'14"S	1.425	Latosol
E9	Campo Novo (RS)	666	S 28°55'55" W 52°19'19"S	1.252	Latosol
E10	Chiapetta (RS)	423	S 27°55'52" W 53°56'45"S	1.83	Latosol /Chernosol
E11	Doutor Maurício Cardoso (RS)	275	S 27°30'23" W 54°21'45"S	1.6	Chernosol
E12	Horizontina (RS)	316	S 27°37'28" W 54°18'32"S	1.684	Latosol
E13	Humaitá (RS)	59	S 27°33'46" W 53°58'26"S	2.3	Latosol
E14	Ijuí (RS)	238	S 28°23'19" W 53°54'56"S	1.774	Latosol
E15	Independência (RS)	372	S 27°50'44" W 54°11'33"S	1.75	Latosol

Env = environment.

The soybean genotypes used in the experiment were NS 6909 RR (G1), Don Mario 5.9 I RR (G2), Don Mario 5.8 I RR (G3), AS 3570 IPRO (G4), AS 3610 IPRO (G5), FPS Atalanta IPRO (G6), BMX Ativa RR (G7), BA 5770 Xi (G8), BA 6011 Xi (G9), BA 6230 Xi (G10), BA 6380 Xi (G11), BA 6525 Xi (G12), Don Mario 5.9 I RR IPRO (G13), 5855 RSF RR (G14), Don Mario 70 I RR (G15), 6863 RSF RR (G16), BRS 5601 RR (G17), BS 2606 IPRO (G18), BS 2601 RR (G19), DM 5958 IPRO (G20), DM 6563 IPRO (G21), 5855 RSF RR IPRO (G22), BMX Força RR (G23), FPS Antares RR (G24), FPS Urano RR (G25), IGRA RA 626 RR (G26), FPS Júpiter RR (G27), LG 60163 IPRO (G28), M 5892 IPRO (G29) M 5947 IPRO (G30), M 6410 IPRO (G31), NS 4823 RR (G32), NS 5445 IPRO (G33), NS 5909 RR (G34), NS 5959 IPRO (G35), NS 6006 IPRO (G36), NS 6211 RR (G37), NS 6906 IPRO (G38), NS 6909 RR IPRO (G39), NS 7237 IPRO (G40), 7166 RSF IPRO (G41), BMX Potência RR (G42), PY 95R51 (G43), SYN 1257 RR (G44), TEC 6029 IPRO (G45), TMG 7062 IPRO (G46), TMG 7262 RR (G47), 6863 RSF RR (G48), BMX Turbo RR (G49), SYN 1059 RR (G50), 6968 RSF RR (G51), 6160 RSF IPRO (G52).

The sowing of the environments was carried out in the second half of November 2018, the population density used was 10 viable seeds per linear meter. The nutritional management consisted of 250 kg ha^{-1} of NPK with a 10-20-20 formulation at the base and 200 kg ha^{-1} of potassium chloride, the management of weeds, pest insects and diseases were carried out as needed. The analyzed variable was the grain yield, performed from the harvest in the first half of April 2019, 10 plants were evaluated per 10 m^2 plot, estimating the grain mass in kg ha^{-1}.

The data obtained were submitted to Deviance analysis at 5% probability. The error normality test was performed using the Shapiro Wilk test and the homogeneity of residual variances using the Bartllet test. Then, the Restricted Maximum Likelihood (REML) method was applied to estimate the variance components and genetic parameters using the statistical model (Equation 1):

$$y = Xr + Zg + Wi + \mathcal{E} \qquad \text{(Equation 1)}$$

Where:

y = is the data vector,

r = is the (fixed) repeat effects,

g = is the genotypic (random) effects,

i = is the genotype interaction effects x environments (random) and

Ɛ = are the residues (random).

X, Z and W = are known incidence matrices, formed by values 0 and 1, which associate the unknowns r, g and i to the data vector y, respectively.

The following variance components were estimated: Genetic variation (Vg) and phenotypic variation (Vp). The genetic parameters estimated were: broad sense heritability (H^2), coefficient of genotypic variation (CVg), coefficient of residual variation (CVe), ratio between genetic and residual coefficient (CVr) and selective accuracy (Ac). Next, the BLUP analysis was performed to obtain the components of the means and the percentage of genetic gain. Analyzes were performed using the R program (R Core Team, 2020).

RESULTS AND DISCUSSION

Deviance analysis revealed significance at 5% probability by the chi-square test (x^2) for the grain yield variable (GY) (Table 2), a fact that proves the significance of the parameters obtained by the biometric model. The importance of the magnitude of the phenotypic character is strictly related to the effects of the environment, and a fraction is due to the genetic variation that is present (CARVALHO et al., 2018). Thus, when establishing a relationship between the phenotypic variation (Vp) and the genotypic variation (Vg), for the grain yield character, 17% was determined by the genetic effect. Heritability indicates what fraction of genetic variance exists in the phenotypic variance, and it can be an indicator of experimental precision and reliability for the phenotype (RAMALHO et al., 2012).

TABLE 2 - Estimation of the variance component and genetic parameters (REML) for the 52 soybean genotypes grown in fifteen environments in Rio Grande do Sul State, Brazil.

Variance components	Character[2]
REML[1]	GY
Vg	43322,921
Vp	251087,593
H^2	0,172
CVg (%)	3,209
CVe (%)	3,907
CVr	0,821
Ac	0,953
Overall mean	3242,412

[1]Vg = genetic variation, Vp = phenotypic variation, H2 = broad sense heritability, CVg = genotypic coefficient of variation, CVe = residual coefficient of variation, CVr = ratio between the genetic and residual coefficient, Ac = accuracy, overall mean = overall mean of the experiment. [2]GY = grain yield.

The broad sense heritability (H^2: 0.172) for the character grain yield (GY), it was possible to verify that 83% are due to effects attributed to the edaphoclimatic conditions of the environment, managements and practices used and 17% due to the effect genetic, this being a medium to low heritability.

The genotypic coefficient of variation (CVg: 3.209 %) of the grain yield was lower than the residual (CVe: 3.907%), where the genetic variation could have been greater, because not all cultivars had an unbalanced scheme. The CVe value (3.907%) according to Lúcio et al. (1999), in a study of 480 soybean genotype competition trials, identified very low precision with values below 5% for CVe. The ratio (CVr: 0.82) between the genetic coefficient (CVg) and the residual (CVe) indicates that when equal or higher, the unit reflects the predominance of genetic effects, and the population that is used can provide gains for improvement of the character (CARVALHO et al., 2018).

Accuracy (Ac) reveals experimental precision and effectiveness in selection strategies and genetic gains to traits (COSTA et al., 2000). Resende and Duarte (2007) classify the accuracies as high ($0.70<Ac$), moderate ($0.50<Ac<0.65$) and low ($0.10<Ac<0.40$). Where for the grain yield (GY) character the accuracy is 0.95 (95%) which indicates a high experimental precision. The average grain yield (GY) for soybean genotypes cultivated in the fifteen growing environments of Rio Grande do Sul was 3,242.4 kg ha^{-1}, the average result obtained is 3% lower than the Brazilian average (3,337 kg ha^{-1}) and 4% lower than the average yield obtained in Rio Grande do Sul (3,379 kg ha^{-1}) for the 2018/19 season (CONAB, 2022). In the study by Prado (2019), with forty-six soybean genotypes in eight environments, the overall mean of the experiment for grain yield was 3,802.6 kg ha^{-1}, a value approximately 17% higher than in the present study.

The model below (Figure 1) demonstrates the genetic gain of the fifty-two genotypes regardless of the growing environment. It can be observed that the cultivars that obtained the greatest genetic gains in grain yield, (kg ha^{-1}), were NS 6909 RR IPRO (G_{39}) which obtained the greatest genetic gain with 259 kg ha^{-1}, followed by NS 5445 IPRO (G_{33}) with 224 kg ha^{-1}, DM 5958 IPRO (G_{20}) with 186 kg ha^{-1} and DM 6563 IPRO (G_{21}) with 165 kg ha^{-1} of grains.

In the study by Prado (2019), it was possible to observe even greater genetic gains where the best genotype achieved a gain of 539.69 kg ha^{-1}. However, it can be observed by the same analysis the cultivars that obtained the lowest genetic gains in grain yield (kg ha^{-1}), the cultivar BMX Potência RR (G_{42}) did not obtain any gain in grain yield, followed by AS 3610 IPRO (G_5) with a gain of 4 kg ha^{-1}, BMX Turbo RR (G_{49}), with 8 kg ha^{-1} and SYN 1059 RR (G_{50}), with 11 kg ha^{-1}.

Figure 2 demonstrates the grain yield of the genotypes evaluated independently of the growing environments. The genotypes that obtained the best results were NS 6909 RR IPRO (G_{39}), NS 5445 IPRO (G_{33}), DM 5958 IPRO (G_{20}) and DM 6563 IPRO (G_{21}) with yields of 3,501 kg ha^{-1}, 3,466 kg ha^{-1}, 3,428 kg ha^{-1} and 3,407 kg ha^{-1}, respectively. According to Carvalho et al. (2017), the search and demand for soybean genotypes are wide, especially when the subject is grain yield, with an extensive search of companies in search of information. Respectively, these genotypes are 5%, 4%, 3% and 2% above the national average (3,337 kg ha^{-1}) and 3.5%, 2.5%, 1.5% and 1% above the average of Rio Grande do Sul state (3,379 kg ha^{-1}), in the 2018/19 season (CONAB, 2022). However, the genotypes that presented the lowest grain yield were the BMX Potência RR (G_{42}), with a yield of 3,242 kg ha^{-1}, the AS 3610 IPRO (G_5), with a yield of 3,246 kg ha^{-1}, the BMX Turbo RR (G49), with a yield of 3,250 kg ha^{-1} and the SYN 1059 RR (G_{50}), with a yield of 3,253 kg ha^{-1}, respectively these genotypes are 3%, 2.8%, 2.6% and 2.5% lower than the national average and 4.2%, 4%, 4% and 3.9% lower than the state average. An explanation for the difference in grain yield may be related to the technologies used in each genotype, where the IPRO technology had significant increases in recent years, superior to the RR technology (DORNELES et al., 2020).

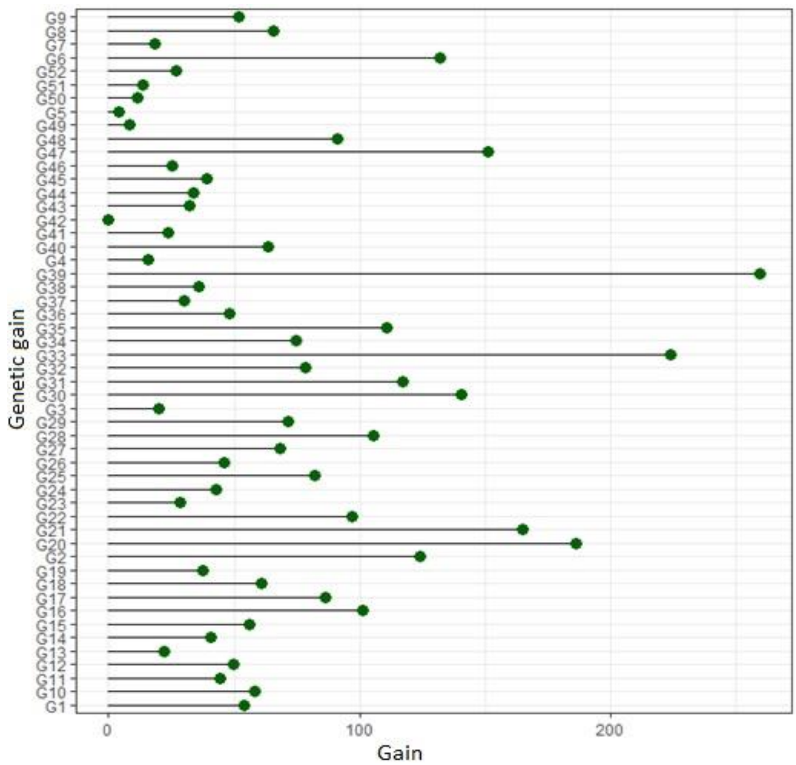

FIGURE 1 - Genetic gain in grain yield of the 52 genotypes regardless of the growing environment. NS 6909 RR (G_1), Don Mario 5.9 I RR (G_2), Don Mario 5.8 I RR (G_3), AS 3570 IPRO (G_4), AS 3610 IPRO (G_5), FPS Atalanta IPRO (G_6), BMX Ativa RR (G_7), BA 5770 Xi (G_8), BA 6011 Xi (G_9), BA 6230 Xi (G_{10}), BA 6380 Xi (G_{11}), BA 6525 Xi (G_{12}), Don Mario 5.9 I RR IPRO (G_{13}), 5855 RSF RR (G_{14}), Don Mario 70 I RR (G_{15}), 6863 RSF RR (G_{16}), BRS 5601 RR (G_{17}), BS 2606 IPRO (G_{18}), BS 2601 RR (G_{19}), DM 5958 IPRO (G_{20}), DM 6563 IPRO (G_{21}), 5855 RSF RR IPRO (G_{22}), BMX Força RR (G_{23}), FPS Antares RR (G_{24}), FPS Urano RR (G_{25}), IGRA RA 626 RR (G_{26}), FPS Júpiter RR (G_{27}), LG 60163 IPRO (G_{28}), M 5892 IPRO (G_{29}) M 5947 IPRO (G_{30}), M 6410 IPRO (G_{31}), NS 4823 RR (G_{32}), NS 5445 IPRO (G_{33}), NS 5909 RR (G_{34}), NS 5959 IPRO (G_{35}), NS 6006 IPRO (G_{36}), NS 6211 RR (G_{37}), NS 6906 IPRO (G_{38}), NS 6909 RR IPRO (G_{39}), NS 7237 IPRO (G_{40}), 7166 RSF IPRO (G_{41}), BMX Potência RR (G_{42}), PY 95R51 (G_{43}), SYN 1257 RR (G_{44}), TEC 6029 IPRO (G_{45}), TMG 7062 IPRO (G_{46}), TMG 7262 RR (G_{47}), 6863 RSF RR (G_{48}), BMX Turbo RR (G_{49}), SYN 1059 RR (G_{50}), 6968 RSF RR (G_{51}), 6160 RSF IPRO (G_{52}).

Furthermore, it can be observed that the vertical red line demonstrates the overall average yield of the experiment, which was 3242.4 kg ha^{-1}, it is observed that the growing environments Augusto Pestana (E1), Jóia (E2), Miraguaí (E3), Tenente Portela (E6), Três Passos (E7), Campo Novo (E9), Chiapetta (E10), Horizontina (E12), Humaitá (E13) and Ijuí (E14), to the left of the line had averages below the overall average of the experiment, consequently averages below the national and state average, demonstrating that these growing environments have low grain yield. The growing environments Nova Ramada (E4), Santo Augusto (E5), Bozano (E8), Doutor Maurício Cardoso (E11) and Independência (E15), on the right of the line, were the environments that presented values above the overall average of the experiment. Consequently, the averages of these environments are higher than the national and state averages, which shows these environments as having high grain productivity.

The model below (Figure 3) corresponds to the average effect of environments and grain yield (kg ha^{-1}) regardless of genotype. The environments with the greatest effects on grain yield were the county Doutor Maurício Cardoso (E11), with an average of 3,740 kg ha^{-1}, 11% higher than the national average (3,337 kg ha^{-1}) and 10% higher than the average yield of the state of Rio Grande do Sul (3,379 kg ha^{-1}) in the 2018/19 season (CONAB, 2022), after Nova Ramada (E4), with an average of 3,680 kg ha^{-1} 9% higher than the national average and 8% of the state and the growing environment of Independência (E15), with an average of 3,588 kg ha^{-1}, being 7% higher than the national average and 6% higher in the state.

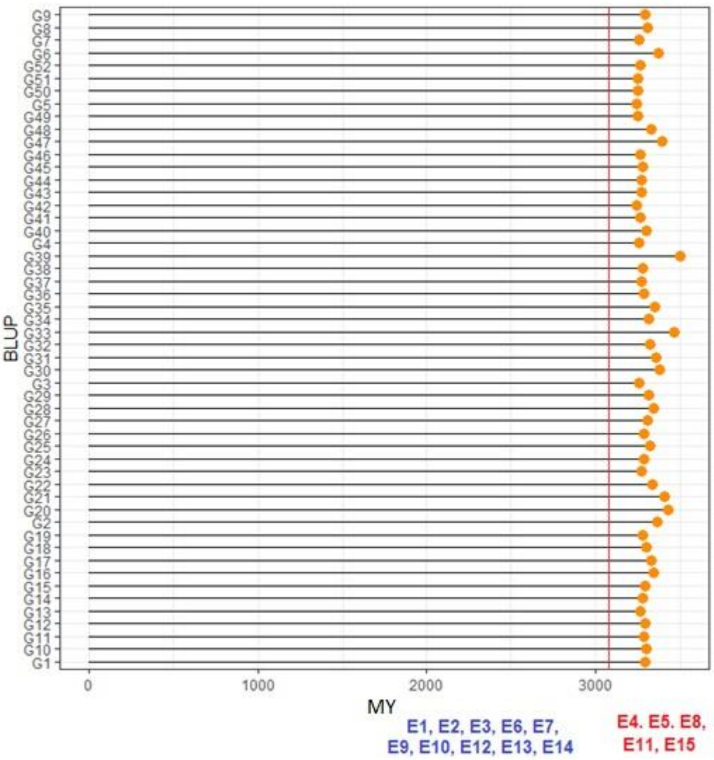

FIGURE 2 - Estimates of mean grain yield by BLUP of the 52 measured genotypes. NS 6909 RR (G_1), Don Mario 5.9 I RR (G_2), Don Mario 5.8 I RR (G_3), AS 3570 IPRO (G_4), AS 3610 IPRO (G_5), FPS Atalanta IPRO (G_6), BMX Ativa RR (G_7), BA 5770 Xi (G_8), BA 6011 Xi (G_9), BA 6230 Xi (G_{10}), BA 6380 Xi (G_{11}), BA 6525 Xi (G_{12}), Don Mario 5.9 I RR IPRO (G_{13}), 5855 RSF RR (G_{14}), Don Mario 70 I RR (G_{15}), 6863 RSF RR (G_{16}), BRS 5601 RR (G_{17}), BS 2606 IPRO (G_{18}), BS 2601 RR (G_{19}), DM 5958 IPRO (G_{20}), DM 6563 IPRO (G_{21}), 5855 RSF RR IPRO (G_{22}), BMX Força RR (G_{23}), FPS Antares RR (G_{24}), FPS Urano RR (G_{25}), IGRA RA 626 RR (G_{26}), FPS Júpiter RR (G_{27}), LG 60163 IPRO (G_{28}), M 5892 IPRO (G_{29}) M 5947 IPRO (G_{30}), M 6410 IPRO (G_{31}), NS 4823 RR (G_{32}), NS 5445 IPRO (G_{33}), NS 5909 RR (G_{34}), NS 5959 IPRO (G_{35}), NS 6006 IPRO (G_{36}), NS 6211 RR (G_{37}), NS 6906 IPRO (G_{38}), NS 6909 RR IPRO (G_{39}), NS 7237 IPRO (G_{40}), 7166 RSF IPRO (G_{41}), BMX Potência RR (G_{42}), PY 95R51 (G_{43}), SYN 1257 RR (G_{44}), TEC 6029 IPRO (G_{45}), TMG 7062 IPRO (G_{46}), TMG 7262 RR (G_{47}), 6863 RSF RR (G_{48}), BMX Turbo RR (G_{49}), SYN 1059 RR (G_{50}), 6968 RSF RR (G_{51}), 6160 RSF IPRO (G_{52}).

However, the environments with lesser effects on grain yield are Ijuí (E14) with an average of 2,599 kg ha^{-1}, with an average lower than the national one by 28% and 30% lower than the state, followed by Augusto Pestana (E1) with an average of 2,962 kg ha^{-1}, lower than the national average by 12% and 14% for the state and the growing environment of Chiapetta (E10) with an average of 2,973 kg ha^{-1}, lower than the national average by 12% and for the state in 13%.

These differences in grain yield can be explained, according to Carvalho et al. (2020), which found that grain yield, plant height, number of pods per plant and thousand grain mass, yield characteristics, are decisively influenced by the effect of the genotype x environment interaction. As well as the number of reproductive nodes and the branches that are intrinsic to the genotype, they are influenced by the growing environment they are positioned and the managements that are carried out (FERRARI et al., 2018).

However, the DM 6563 IPRO (G_{21}) genotype had the lowest yield, with characteristics of the cultivar with a RMG of 6.3, regular season, indeterminate growth, recommended for the southern region and frontier of RS, MS and PR, with an average of 2,600 kg ha^{-1}, with a result below the national and state average, 28% and 30%, respectively. The graph of averages (b) of the Jóia growing environment (E2) shows that the best genotype is 7166 RSF IPRO (G41), with characteristic of cultivar with GMR 6.6, regular season, indeterminate growth, recommended for the states of RS, SC, PR, SP and MS, with an average of 3,600 kg ha^{-1}, above the national and state average, 7% and 6% respectively. The genotype with the lowest yield is BMX Ativa RR (G_7), with RMG characteristics of 5.6, season and off-season, indeterminate growth, recommended for the northwest and north of RS, SC and PR, with an average of 2,442 kg ha^{-1}, income 36% lower than the national average and 38% lower than the state average.

The graph of averages (c) of the Miraguaí growing environment (E3), shows that the best genotype is NS 6909 RR IPRO (G_{39}), with characteristics of RMG 6.3, regular season, indeterminate growth, recommended for the states of RS, SC and PR, with an average of 3,555 kg ha^{-1}, 6% higher than the national average and 5% higher than the state average. For the same growing environment, the genotype with the lowest yield was BMX Turbo RR (G_{49}), with characteristics of GMR 5.8, season and off-season, indeterminate growth, recommended for RS, SC, PR, southern MS and SP, with average of 2,725 kg ha^{-1}, less than the national and state yields, 22% and 24%, respectively.

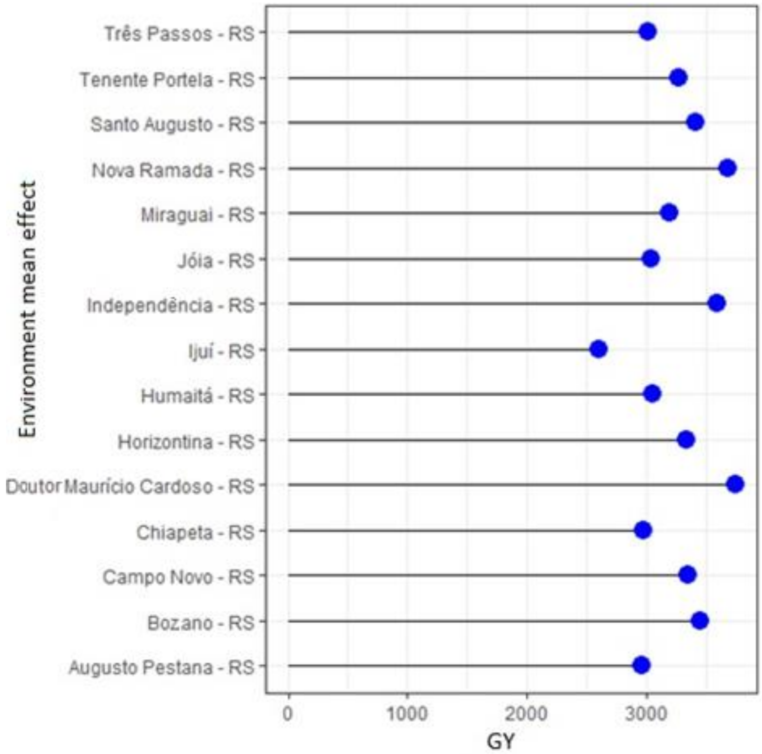

FIGURE 3 - Effect of environment on grain yield regardless of genotype used. GY = grain yield.

Figure 4 demonstrates the genotypes evaluated within each growing environment and their respective grain yield (kg ha^{-1}), the graph of means (a) of the Augusto Pestana growing environment (E1), shows that the best genotype is the NS 5909 RR (G_{34}), characterized by being a cultivar of the maturity group (RMG) of 6.2, used in the regular season, indeterminate growth habit, recommended for the regions of Rio Grande do Sul (RS), Santa Catarina (SC), Paraná (PR), Mato Grosso do Sul (MS) and São Paulo (SP), with an average of 3,350 kg ha^{-1}, with average productivity relatively similar to the national average (3,337 kg ha^{-1}) and the average of the state of Rio Grande do Sul (3,379 kg ha^{-1}), in the 2018/19 season (CONAB, 2022).

The graph of averages (d) characterizing the growing environment of Nova Ramada (E4), demonstrates that the best genotype is the NS 5959 IPRO (G_{35}), with characteristics of RMG 5.9, regular season, indeterminate growth, recommended for the northwest region of the RS, SC, PR, southern MS and SP, with a yield of 4,213 kg ha^{-1}, higher than the national and state yields, 26% and 24%, respectively. For this same environment, the genotype with the lowest yield was 6968 RSF RR (G_{51}), with characteristics of RMG 6.7, crop, indeterminate growth, recommended for the entire state of RS, SC, PR, southern MS and SP, with a yield of 2,600 kg ha^{-1}, lower than the national and state average, 28% and 30%, respectively.

The graph of averages (e) of the growing environment of Santo Augusto (E5) demonstrates that the best genotype is NS 5445 IPRO (G_{33}), with RMG characteristics of 5.4, season and off-season, indeterminate growth, recommended for the states from RS, SC and PR, with yield of 4,408 kg ha^{-1}, higher than the national and state average, 32% and 30%, respectively. For this same environment, the AS 3610 IPRO (G_5) genotype had the lowest yield, with characteristics of RMG 6.1, crop, indeterminate growth, being recommended for the states of MS, PR and SP, with a yield of 2,710 kg ha^{-1}, being lower than the national and state income, 23% and 24%, respectively.

The graph of averages (f) of the growing environment of Tenente Portela (E6), shows that the best genotypes are NS 5445 IPRO (G_{33}) and 6863 RSF RR (G16), being the first with characteristics already presented and the second with characteristics of RMG 6.2, regular season, indeterminate growth, recommended for the entire state of RS, southern MS, SP, SC and PR, with a yield of 3,800 kg ha^{-1}, higher than the national and state average, 14% and 12%, respectively. For the same environment, genotype 6563 IPRO (G_{21}) had the lowest yield, RMG of 6.3, regular season, indeterminate growth, recommended for the southern region and frontier of RS State, MS State and PR State, with an average of 2,900 kg ha^{-1}, lower than the national and state averages, 15% and 16%, respectively.

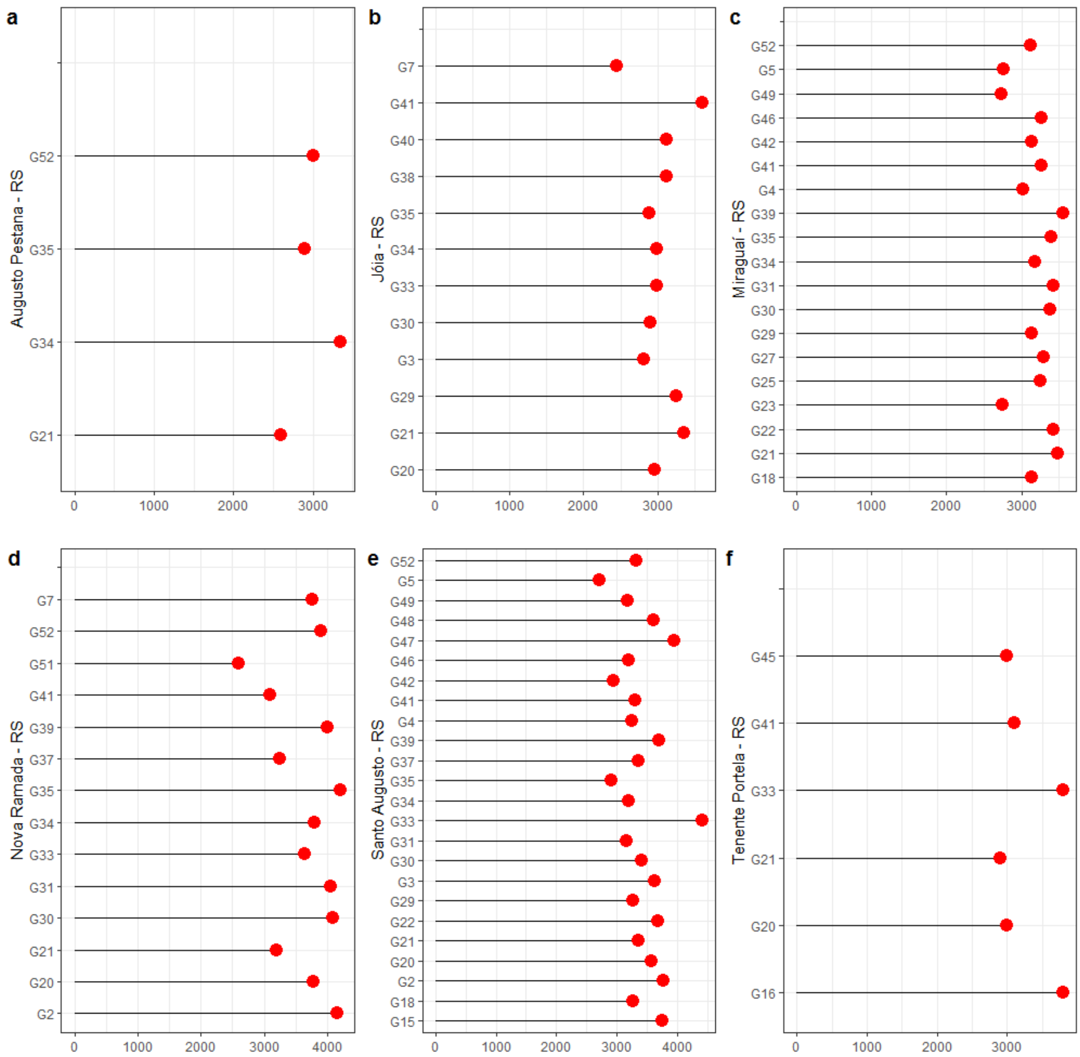

FIGURE 4 - Grain yield of the different genotypes in the growing environments: (a) Augusto Pestana - RS, (b) Jóia - RS, (c) Miraguaí - RS, (d) Nova Ramada - RS, (e) Santo Augusto and (f) Tenente Portela - RS. NS 6909 RR (G_1), Don Mario 5.9 I RR (G_2), Don Mario 5.8 I RR (G_3), AS 3570 IPRO (G_4), AS 3610 IPRO (G_5), FPS Atalanta IPRO (G_6), BMX Ativa RR (G_7), BA 5770 Xi (G_8), BA 6011 Xi (G_9), BA 6230 Xi (G_{10}), BA 6380 Xi (G_{11}), BA 6525 Xi (G_{12}), Don Mario 5.9 I RR IPRO (G_{13}), 5855 RSF RR (G_{14}), Don Mario 70 I RR (G_{15}), 6863 RSF RR (G_{16}), BRS 5601 RR (G_{17}), BS 2606 IPRO (G_{18}), BS 2601 RR (G_{19}), DM 5958 IPRO (G_{20}), DM 6563 IPRO (G_{21}), 5855 RSF RR IPRO (G_{22}), BMX Força RR (G_{23}), FPS Antares RR (G_{24}), FPS Urano RR (G_{25}), IGRA RA 626 RR (G_{26}), FPS Júpiter RR (G_{27}), LG 60163 IPRO (G_{28}), M 5892 IPRO (G_{29}) M 5947 IPRO (G_{30}), M 6410 IPRO (G_{31}), NS 4823 RR (G_{32}), NS 5445 IPRO (G_{33}), NS 5909 RR (G_{34}), NS 5959 IPRO (G_{35}), NS 6006 IPRO (G_{36}), NS 6211 RR (G_{37}), NS 6906 IPRO (G_{38}), NS 6909 RR IPRO (G_{39}), NS 7237 IPRO (G_{40}), 7166 RSF IPRO (G_{41}), BMX

Potência RR (G_{42}), PY 95R51 (G_{43}), SYN 1257 RR (G_{44}), TEC 6029 IPRO (G_{45}), TMG 7062 IPRO (G_{46}), TMG 7262 RR (G_{47}), 6863 RSF RR (G_{48}), BMX Turbo RR (G_{49}), SYN 1059 RR (G_{50}), 6968 RSF RR (G_{51}), 6160 RSF IPRO (G_{52}).

Figure 5 demonstrates the growing environments and genotypes evaluated by grain yield. The graph of means (a) of the Três Passos growing environment (E7) demonstrates that the genotype with the highest grain yield is NS 6909 RR IPRO (G_{39}), with characteristics already described with an average of 3400 kg ha^{-1}, with average yield respectively similar to the national and state averages. For the same graph, the NS 6211 RR (G_{37}) genotype had the lowest yield, this genotype has as characteristics a RMG of 6.2, crop, semi-determined growth, recommended for the states of RS, SC, PR, MS and SP, with yield of 2,775 kg ha^{-1}, lower than the national and state average, 20% and 21%, respectively.

For the mean graph (b) of the Bozano growing environment (E8), the DM 5958 IPRO (G_{20}) genotype had the highest yield, with characteristics RMG 5.8, regular season, indeterminate growth, recommended for the states of RS, SC, PR and SP, with a yield of 3,650 kg ha^{-1}, higher than the national and state average, 9% and 8%, respectively. The genotype 6563 IPRO (G_{21}) with characteristics already described and NS 6006 IPRO (G_{36}), with characteristics of RMG 5.7, season and off-season, indeterminate, recommended for the southern region of the country, both genotypes had a yield of 3,350 kg ha^{-1}, respectively, similar to the national and state averages.

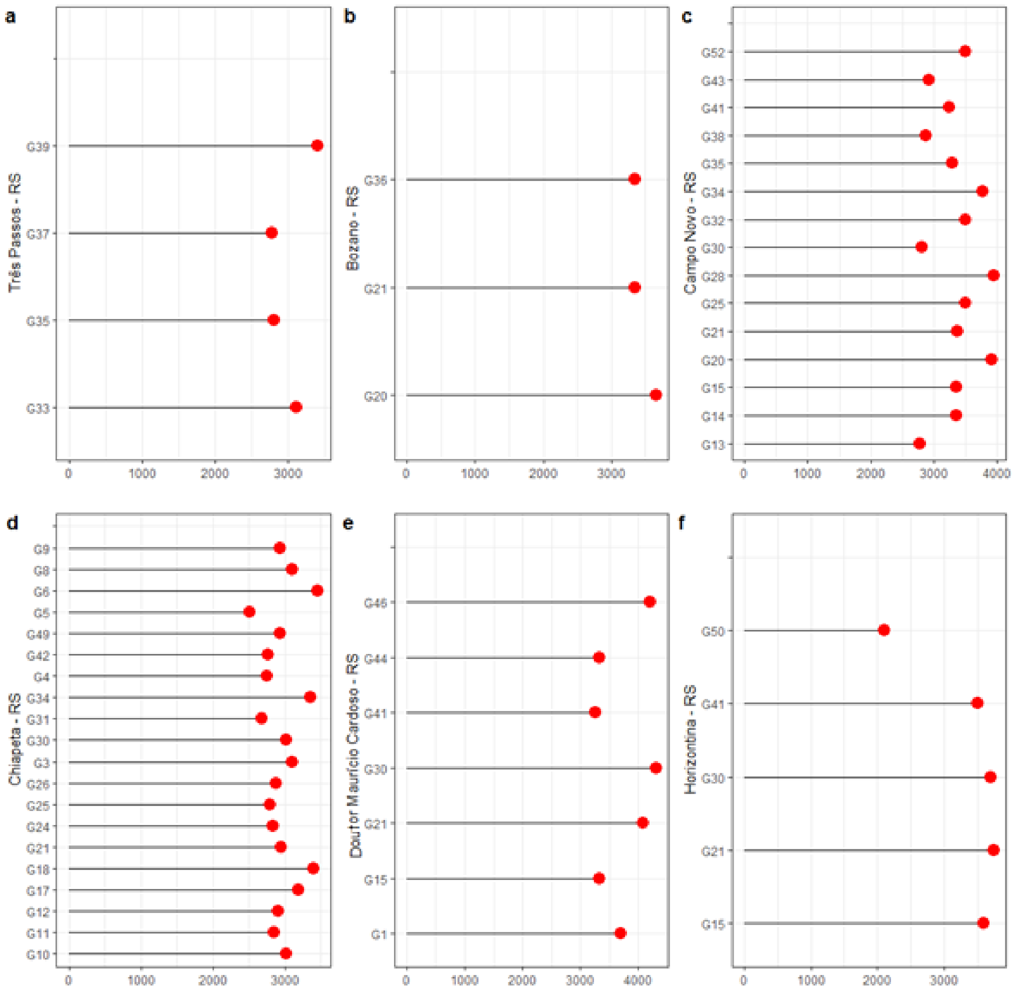

FIGURE 5 - Grain yield of the different genotypes in the growing environments: (a) Três Passos - RS, (b) Bozano - RS, (c) Campo Novo - RS, (d) Chiapeta - RS, (e) Doutor Maurício Cardoso e (f) Horizontina - RS. Rio do Grande de Sul State, Brazil. Don Mario 5.9 I RR (G_2), Don Mario 5.8 I RR (G_3), AS 3570 IPRO (G_4), AS 3610 IPRO (G_5), BMX Ativa RR (G_7), 5855 RSF RR (G_{14}), Don Mario 70 I RR (G_{15}), BS 2606 IPRO (G_{18}), BS 2601 RR (G_{19}), DM 5958 IPRO (G_{20}), DM 6563 IPRO (G_{21}), FPS Urano RR (G_{25}), M 5892 IPRO (G_{29}) M 5947 IPRO (G_{30}), M 6410 IPRO (G_{31}), NS 5445 IPRO (G_{33}), NS 5909 RR (G_{34}), NS 5959 IPRO (G_{35}), NS 6211 RR (G_{37}), NS 6909 RR IPRO (G_{39}), 7166 RSF IPRO (G_{41}), BMX Potência RR (G_{42}), TMG 7062 IPRO (G_{46}), BMX Turbo RR (G_{49}), 6160 RSF IPRO (G_{52}).

For the graph of means (c) of the Campo Novo growing environment (E9), the genotype with the highest yield was the LG 60163 IPRO (G_{28}), with characteristics of RMG 6.3, regular season, semi-determinate growth, recommended for the state of RS, PR, SC, MS, Goiás (GO), Federal District (DF) and Minas Gerais (MG), with a yield of 3,950 kg ha^{-1}, higher than the national and state average, 18% and 17%, respectively. For the same environment, the genotype Don Mario 5.9 I RR IPRO (G_{13}) had the lowest yield, with characteristics of RMG 5.9, regular season, indeterminate growth, recommended for the northwest of the state of RS, PR, SC and SP, with a yield of 2,785 kg ha^{-1}, mean lower than national and state, 20% and 21%, respectively.

For the mean graph (d) of the Chiapetta growing environment (E10), the FPS Atalanta IPRO (G_6) genotype obtained the highest yield, with characteristics of RMG 5.8, indeterminate growth, recommended for RS, SC and PR, with a yield of 3,461 kg ha^{-1}, mean respectively similar to the national and state mean. The AS 3610 IPRO (G_5) genotype had the lowest yield, with the characteristics already mentioned above, obtained a yield of 2,512 kg ha^{-1}, an average lower than the national and state, 33% and 34%, respectively.

For the graph of means (e) of the Doutor Maurício Cardoso (E11) growing environment, the genotype with the highest yield was the M 5947 IPRO (G_{30}), with characteristics of RMG 5.9, indeterminate growth, season and off-season, recommended for the states RS, GO, MG, SP SC, PR and MS, with yield of 4,300 kg ha^{-1}, higher than the national and state average, 29% and 27%, respectively. For the same graph, the genotype with the lowest yield was 7166 RSF IPRO (G_{41}), with characteristics previously described, with a yield of 3,250 kg ha^{-1}, yield similar to the national and state average.

The graph of means (f) of the Horizontina growing environment (E12) shows the highest yield with the 6563 IPRO (G_{21}) genotype, with characteristics previously described, with a yield of 3,750 kg ha^{-1}, higher than the national and state average, 12% and 11%, respectively. The genotype with the lowest yield was SYN 1059 RR (G_{50}), with characteristics of RMG 5.9, season and off-season, indeterminate growth, recommended for the northwest and north of RS, SC, PR, MS, MG, GO, MT and SP, with a yield of 2,100 kg ha^{-1}, much lower than the national and state average, 59% and 61%, respectively.

Figure 6 determines the grain yield for each genotype evaluated in each growing environment. As can be seen in the graph of averages (a), from the Humaitá environment (E13), the genotype that obtained the best result in yield was the Don Mario 70 I RR (G_{15}), with characteristics of RMG 6.2, regular season, indeterminate growth, recommended for RS, SC, PR, SP and MS, with a yield of 3,280 kg ha^{-1}, yield similar to the national and state average. The genotype Don Mario 5.9 I RR (G_2) was the one with the lowest yield for this growing environment, with the characteristics RMG 5.9, regular season, indeterminate growth, recommended for the northwest of the state of RS, PR, SC and SP, with a yield of 2,750 kg ha^{-1}, lower than the national and state average, 21% and 22%, respectively.

The graph of means (b) of the Ijuí growing environment (E14) shows that the genotype that obtained the highest yield was NS 6909 RR IPRO (G_{39}), with characteristics previously described, yielding 3,389 kg ha^{-1}, mean a little above the national and equal to the state average. For the same environment, the BMX Potência RR (G_{42}) genotype was the one with the lowest yield, with characteristics of RMG 6.7, regular season, indeterminate growth, recommended for the states of RS, SC, PR, SP and MS, with a yield of 1,736 kg ha^{-1}, below the national and state averages, 92% and 94%, respectively.

The graph of means (c) of the Independência growing environment (E15) showed that the genotype with the highest yield was the BMX Ativa RR (G_7), with characteristics previously described, with a yield of 4,050 kg ha^{-1}, average greater than the national and the state, 21% and 20%, respectively. For the same graph, the BMX Potência RR genotype (G_{42}), with characteristics previously described, was the one with the lowest yield with 3,063 kg ha^{-1}, lower than the national and state average yield, 9% and 10%, respectively.

The results observed in Figures 4, 5 and 6 had the same behavior of the genotypes observed in the study by Ferrari et al. (2016) and Carvalho et al. (2020), where different genotypes were placed in different growing environments and they presented different grain yield (kg ha^{-1}) for each environment. This can be explained by the study by Pires et al. (2012), where the behavior of soybean genotypes is different depending on the environment, characteristics that are specific to the environment, such as temperature, rainfall, altitude and soil characteristics, are decisive for the response that genotypes will deliver.

The estimation of genetic parameters of the soybean crop is substantial to promote the advance of the genetic gain of the crop. These parameters are influenced by the environments where the genotypes are evaluated, so it is necessary to cover new environments in future studies, as well as to develop and use methodologies that use environmental conditions to model the performance and genetic gains of the genotypes.

Understanding this genotype x environment interaction promotes the accurate identification of genotypes with genetic superiority and their responses to broad and specific environmental conditions. Associated with this, the stratification of similar environments reduces the need for investment in genetic improvement programs, as it is possible to form microregions and evidence genotypes with superior performance in these environments. Therefore, the present study generated information that meets this discussion and contributes strongly to the positioning of soybean genotypes in the southern region of the country.

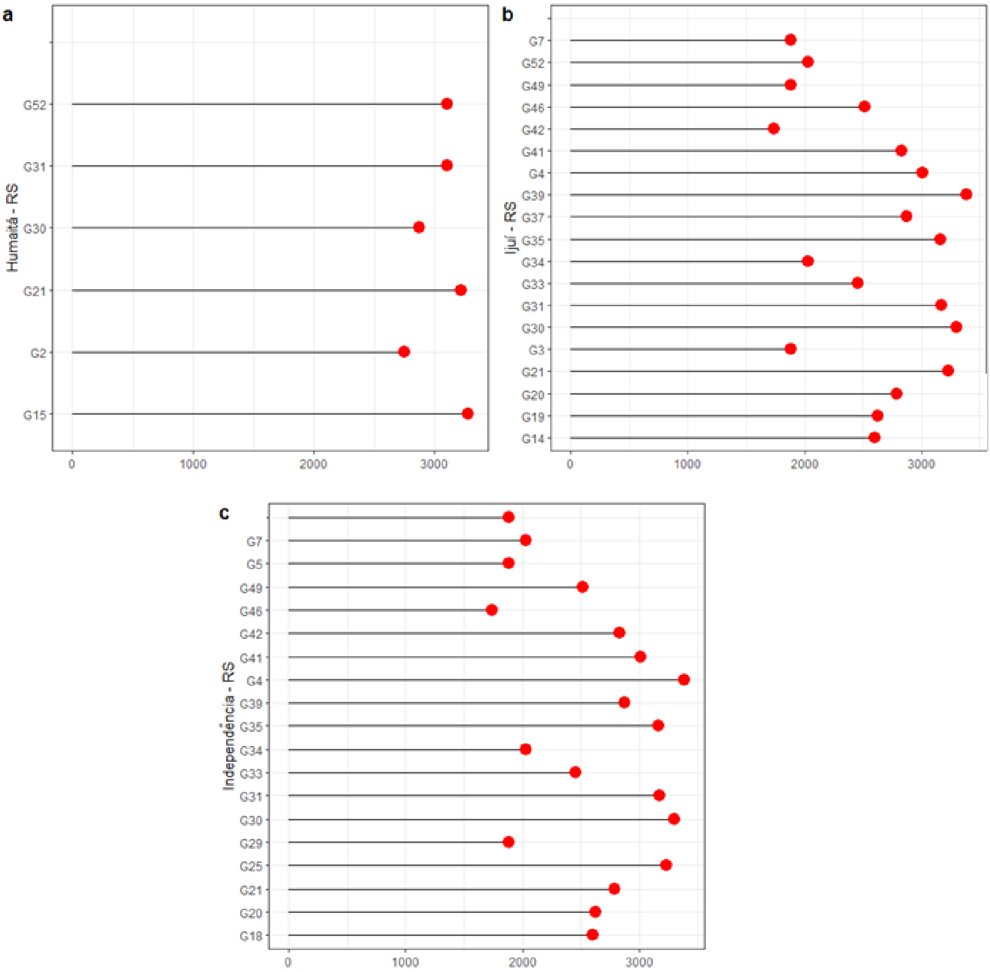

FIGURE 6 - Grain yield of the different genotypes in the growing environments: (a) Humaitá - RS, (b) Ijuí - RS, (c) Independência - RS. Rio do Grande do Sul State, Brazil. Don Mario 5.9 I RR (G_2), Don Mario 5.8 I RR (G_3), AS 3570 IPRO (G_4), AS 3610 IPRO (G_5), BMX Ativa RR (G_7), 5855 RSF RR (G_{14}), Don Mario 70 I RR (G_{15}), BS 2606 IPRO (G_{18}), BS 2601 RR (G_{19}), DM 5958 IPRO (G_{20}), DM 6563 IPRO (G_{21}), FPS Urano RR (G_{25}), M 5892 IPRO (G_{29}) M 5947 IPRO (G_{30}), M 6410 IPRO (G_{31}), NS 5445 IPRO (G_{33}), NS 5909 RR (G_{34}), NS 5959 IPRO (G_{35}), NS 6211 RR (G_{37}), NS 6909 RR IPRO (G_{39}), 7166 RSF IPRO (G_{41}), BMX Potência RR (G_{42}), TMG 7062 IPRO (G_{46}), BMX Turbo RR (G_{49}), 6160 RSF IPRO (G_{52}).

CONCLUSIONS

The phenotypic expression of grain yield is determined by 17% due to genetic effects and 83% by the environment.

The NS 6909 RR IPRO, NS 5445 IPRO, DM 5958 IPRO and DM 6563 IPRO genotypes showed greater genetic gains for grain yield.

The environments Doutor Maurício Cardoso (RS), Nova Ramada (RS) and Independência (RS) are characterized as favorable environments.

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