POSITIONING OF WHITE OAT CULTIVARS IN DIFFERENT ENVIRONMENTS FOR HIGH GRAIN PRODUCTIVITY IN ORGANIC SYSTEM †

[POSICIONAMIENTO DE CULTIVARES DE AVENA BLANCA EN DIFERENTES AMBIENTES PARA ALTA PRODUCTIVIDAD DE GRANO EN SISTEMA ORGÁNICO]

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SUMMARY

Background. White oat is a multifunctional species with significant benefits to human health, so the positioning of genotypes in the organic system is substantial to promote the expression of maximum productive potential. **Objective.** To select and identify the genotypes with greater stability and productive adaptability. **Methodology.** The study was carried out in 11 environments located in the countries of Brazil (states of Rio Grande do Sul and Paraná) and Paraguay (Itapúa) in 2019 and 2020, evaluating in each of them four genotypes of white oats (*Avena sativa*) (URS Corona, URS Brava, IPR Artemis and IPR Afrodite) each considered as treatments. The experimental design was randomized blocks with four replications per treatment. The variables analyzed were grain yield (GY, kg ha^{-1}) and the cycle in days from emergence to physiological maturity (PM). With the presence of G x E interaction, AMMI and GGE biometric methods were used to study adaptability and stability. **Results.** With the data obtained, it was possible to form three mega-environments with the identification of specifically adapted genotypes. The URS Brava genotype was characterized as the ideal genotype, with high stability and wide adaptability for grain yield, which can be positioned in all environments. High altitudes promoted a longer crop cycle and lower grain yield, while low altitudes induced a shorter cycle and grain yield maximization of white oat genotypes. **Implications.** The current results indicate that it is possible to position a single genotype within a region formed by similar environments, as well as it was identified that the crops should preferably be carried out in regions of lower altitudes. **Conclusion.** The URS Brava genotype is considered the ideal genotype with high potential for productivity at low altitudes.

Key words: *Avena sativa* L.; genotypes; stability; adaptability; *AMMI*; *GGE*.

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RESUMEN

Antecedentes. La avena blanca es una especie multifuncional con importantes beneficios para la salud humana, por lo que el posicionamiento de los genotipos en el sistema orgánico es sustancial para promover la expresión del máximo potencial productivo. **Objetivo. S**eleccionar e identificar los genotipos con mayor estabilidad y adaptabilidad productiva. **Metodologia.** El estudio se realizó en 11 ambientes ubicados en los países de Brasil (estados de Rio Grande do Sul y Paraná) y Paraguay (Itapúa) en 2019 y 2020, evaluando en cada uno de ellos cuatro genotipos de avena blanca (*Avena sativa*) (URS Corona, URS Brava, IPR Artemis and IPR Afrodite) considerados cada uno de ellos como tratamientos. El diseño experimental fue bloques al azar con cuatro repeticiones por tratamiento. Las variables analizadas fueron el rendimiento de grano (GY, kg ha^{-1}) y el ciclo en días desde la emergencia hasta la madurez fisiológica (PM). Con la presencia de interacción G x E, se utilizaron métodos biométricos AMMI y GGE para estudiar la adaptabilidad y la estabilidad. **Resultados.** Con los datos obtenidos fue posible formar tres megaambientes con la identificación de genotipos específicamente adaptados. El genotipo URS Brava se caracterizó por ser el genotipo ideal, con alta estabilidad y amplia adaptabilidad para rendimiento de grano, que puede posicionarse en todos los ambientes. Las altitudes elevadas promovieron una duración del ciclo más prolongada y un rendimiento de grano más bajo, mientras que a bajas altitudes mostraron una duración del ciclo más corta y una maximización del rendimiento de grano de los genotipos de avena blanca. **Implicaciones.** Los resultados actuales indican que es posible posicionar un solo genotipo dentro de una región formada por ambientes similares, así como también se identificó que los cultivos deben realizarse preferentemente en regiones de menor altitud. **Conclusión.** El genotipo URS Brava se considera el genotipo ideal con alto potencial de productividad a bajas altitudes.

Palabras clave: *Avena sativa* L.; genotipos; estabilidad; adaptabilidad; AMMI; GGE.

INTRODUCTION

The white oat (*Avena sativa* L.), over time started to play a prominent role in the world and national scenario, as one of the cereals with a wide range of uses, both for human and animal feed. Intended for the production of industrial quality grains, forage, hay and ground cover in the no-till system. It is a cereal of great nutritional quality for human consumption, as it has the beta-glucan compound in its chemical composition, which promotes the reduction of cholesterol levels, increasing its appreciation by society (Vetvicka et al., 2019).

Driven by the benefits and importance of white oat, world production was 21.83 million ton in the 2021/22 crop season in an area of 9.57 million ha (USDA, 2022). Brazil is the main producer of the crop in South America with 1.26 million ton in the 2022 harvest (Conab, 2022), meanwhile, Paraguay showed a production still below 0.03 million ha (USDA, 2022).

With the expansion of cultivation areas, because of the great demand for the cereal, the genetic improvement programs of white oat have the challenge of developing stable and adapted genotypes with high productive potential and, mainly, quality to meet the growing need for an increase in grain yield and dry matter. This demand is evidenced by the trends in the increase of production areas, mainly in Brazil, followed by the development of genetic improvement programs for plants that seek ideotypes for certain regions (Conab, 2022; Hawerroth *et al*., 2014).

For an ideal genotype of white oat, reduced plant stature is sought, with erect growth, resistant stem, smaller leaves with an erect disposition, in addition to a high harvest rate. The choice of genotypes with high agronomic performance is of great importance, however, the behavior of cultivars can be different in different regions, mainly influencing phenology and productive performance. Among the factors that affect the agronomic development of white oat is the positioning of genotypes with different characteristics and cultivation environments (Hawerroth *et al*., 2014).

The genotype x environments interaction is defined as the differential response of the genotypes as a function of the characteristics of the evaluated environments (Cruz *et al*., 2012; Carvalho *et al*., 2020). According to Neto *et al*. (2020), it can be defined biometrically as the difference between the values of phenotype, genotype and environment. The interaction genotype x environment in white oat exerts a great variation in the characters that express grain yield, which is one of the greatest difficulties faced in the positioning of cultivars. In corn, Carvalho *et al*. (2021) concluded that the characters plant height, cob insertion height, thousand grain weight and grain yield are significantly influenced by the genotype x environment interaction.

Some recent research has focused on the study of the interaction between genotype x environment in white oat (Rother *et al*., 2019; Corazza *et al*., 2021; Moura *et al*., 2021), promoting proper positioning in the evaluated environments and evidencing the significant effects of the interaction, mainly, on grain yield. Therefore, it is necessary constant research advancement in the area, in order to maximize the performance of genotypes by targeting them to specific micro regions.

The identification of genotypes with greater stability and grain yield adaptability in different environments helps to promote a better positioning of cultivars, which guarantees better responses to grain yield. In this context, this work aims to select and identify the genotypes of white oat with greater stability and productive adaptability.

MATERIALS AND METHODS

The investigation was carried out in eleven environments located between the states of Rio Grande do Sul (RS), Paraná (PR) in Brazil and one environment (Itapúa) in Paraguay (PY). For the environments, the soil type was characterized as Dystrophic Red Latosol and the climate, according to the Köppen classification, is subtropical *Cfa* type.

The experimental design used was randomized blocks, with four genotypes of white oat (URS Corona, URS Brava, IPR Artemis and IPR Afrodite) being evaluated in 11 environments located in Brazil and Paraguay: C2019 (Candói - PR), ERS2020 (Entre Rios - PR), I2020 (Ijuí -RS), I2019 (Itapúa - PY), L2020 (Londrina - PR), M2020 (Mangueirinha - PR), P2019 (Palotina - PR), PF2020 (Passo Fundo - RS), SAP2020 (Santo Antônio do Palma - RS), TP2020 (Três Passos - RS) and TP2019 (Três Passos - RS) with treatments arranged in four replications in each environment. The experimental units consisted of 18 lines of five meters in length and three meters in width, spaced at 0.17 meters. Sowing was carried out with a density of 300 seeds per square meter. Both fertilization, pest and disease control was carried out ensuring organic cultivation.

The harvest was carried out manually and the grain yield (GY, kg ha^{-1}) was evaluated by weighing the samples and stipulating per hectare, while the cycle (CY, days) was obtained by observing the emergence period until physiological maturity. The data were subjected to analysis of variance at 5% probability by the F test, which verified the assumptions of the mathematical model, model additivity, normality of residuals, and homogeneity of residual variances (Ramalho *et al*., 2000). Subsequently, the interaction between genotype x environment was identified at 5% probability. In the presence of significant G x E interaction, the Additive Main Effects and Multiplicative Interaction Analysis (*AMMI*) and Genotype and Genotype-Environment Interaction (*GGE*) models were used, which combine the main additive effects of genotypes and environments with the multiplicative effects of the interaction (G x E), which later, the obtained scores were represented in *BIPLOT* graphs through the multivariate methodology of the principal components (Zobel *et al*., 1988).

The altitude data of the environments, grain yield (kg ha^{-1}), and the duration of the genotype cycle (CY, days) were submitted to regression analysis to analyze the correlation between them. The meteorological information, medium temperature (Tmed, °C) and the accumulated precipitation (Prec, mm), were expressed in order to better understand the results obtained (Nasa Power, 2021).

RESULTS AND DISCUSSION

The cultivation of white oat does not require a large amount of water during the development cycle, having minimum requirements for its development, where the most critical period for grain yield refers to the reproductive period of flowering and grain filling that demand greater amounts of water. Flower infertility and even reduction in grain weight can occur under low humidity conditions, combined with high air temperatures, which directly impairs grain production and quality (Castro *et al*., 2012).

The accumulated precipitation in the different environments (Figure 1) of Brazil and Paraguay, showed that in May, in which the experiment was sown, both environments presented precipitation greater than 100 mm, where for this period the need for water was smaller. The environments SAP2020, TP2020, PF2020, P2019, and C2019 expressed the lowest precipitation for May, June, July, and August, the period between emergence and grain filling, where the accumulated precipitation in some years for these environments is from 20 to 150 mm per month.

The highest averages in precipitation were obtained in the environments IJ2020, L2020, IT2019, M2020, C2019 and ERS2020, but with some variation from year to year, however, in the last three environments mentioned, July and January had the lowest accumulation. L2020 and M2020 in the state of Paraná proved to be the environments of greater precipitation instability, where some months had a large accumulation of precipitation, and for other years low accumulation.

During the period of maturation and harvesting, high rainfall can impair the quality of the grains and cause productivity losses due to lodging and a decrease in the hectoliter grain weight. It is observed that for September and October for the environments of TP, PF and SAP, there were precipitation accumulations greater than 300 mm.

The average ambient temperature (Figure 2), obtained in each environment for a period of three years, showed a behavior of a subtropical climate, that is, with well-defined seasons (fall, winter, spring and summer), in general for regions with a subtropical climate, average air temperatures tend to be milder in the middle of the fall season, that is, in the second half of May. The recommended sowing time for white oats is from May 20th for regions with a subtropical climate, where air temperatures are expected to gradually decrease from that date.

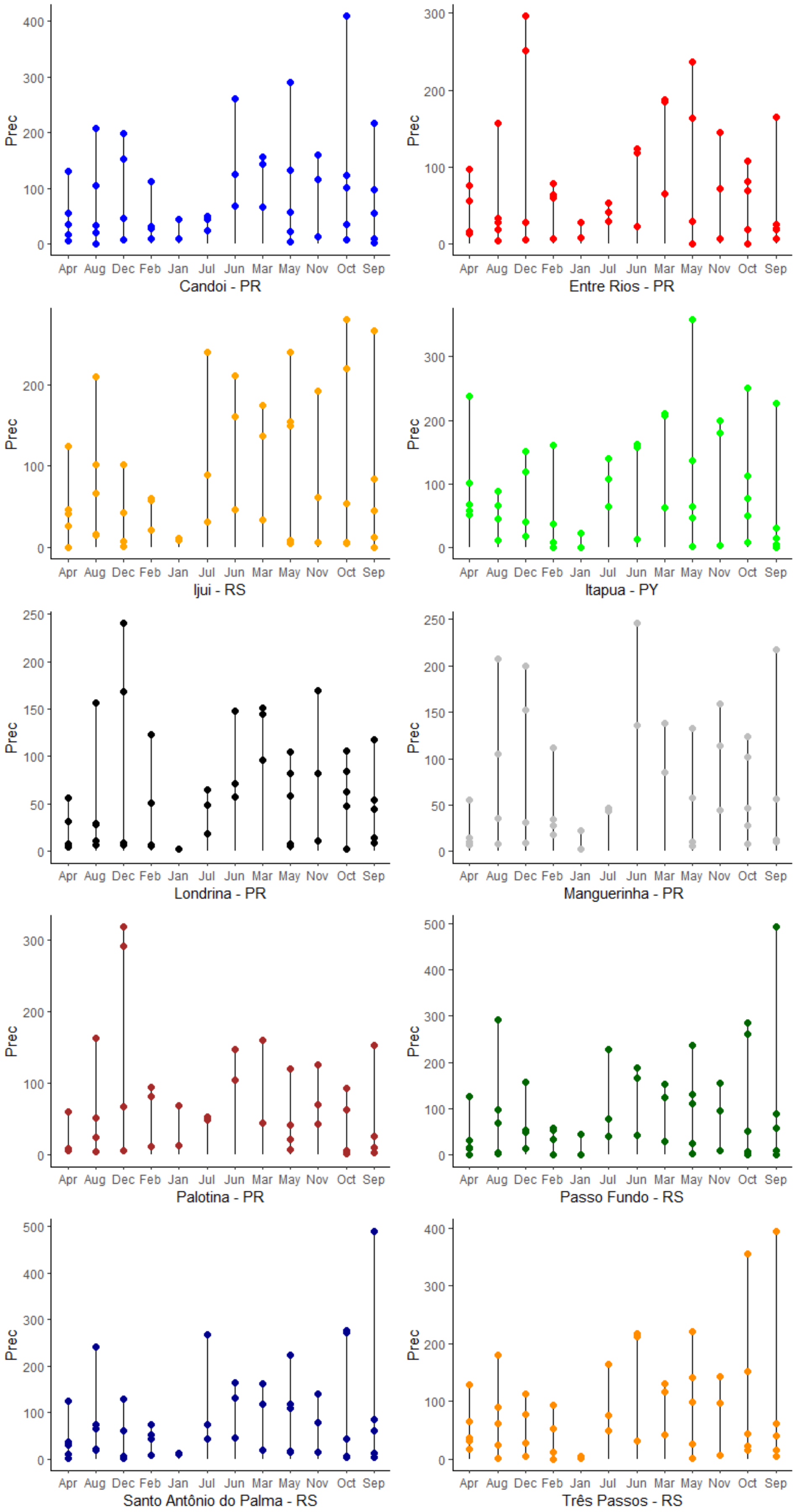

Figure 1. Accumulated precipitation (Prec, mm) for the environments Candói - PR, Entre Rios - PR, Ijuí - RS, Itapúa - PY, Londrina - PR, Mangueirinha - PR, Palotina - PR, Passo Fundo - RS, Santo Antônio do Palma - RS and Três Passos - RS.

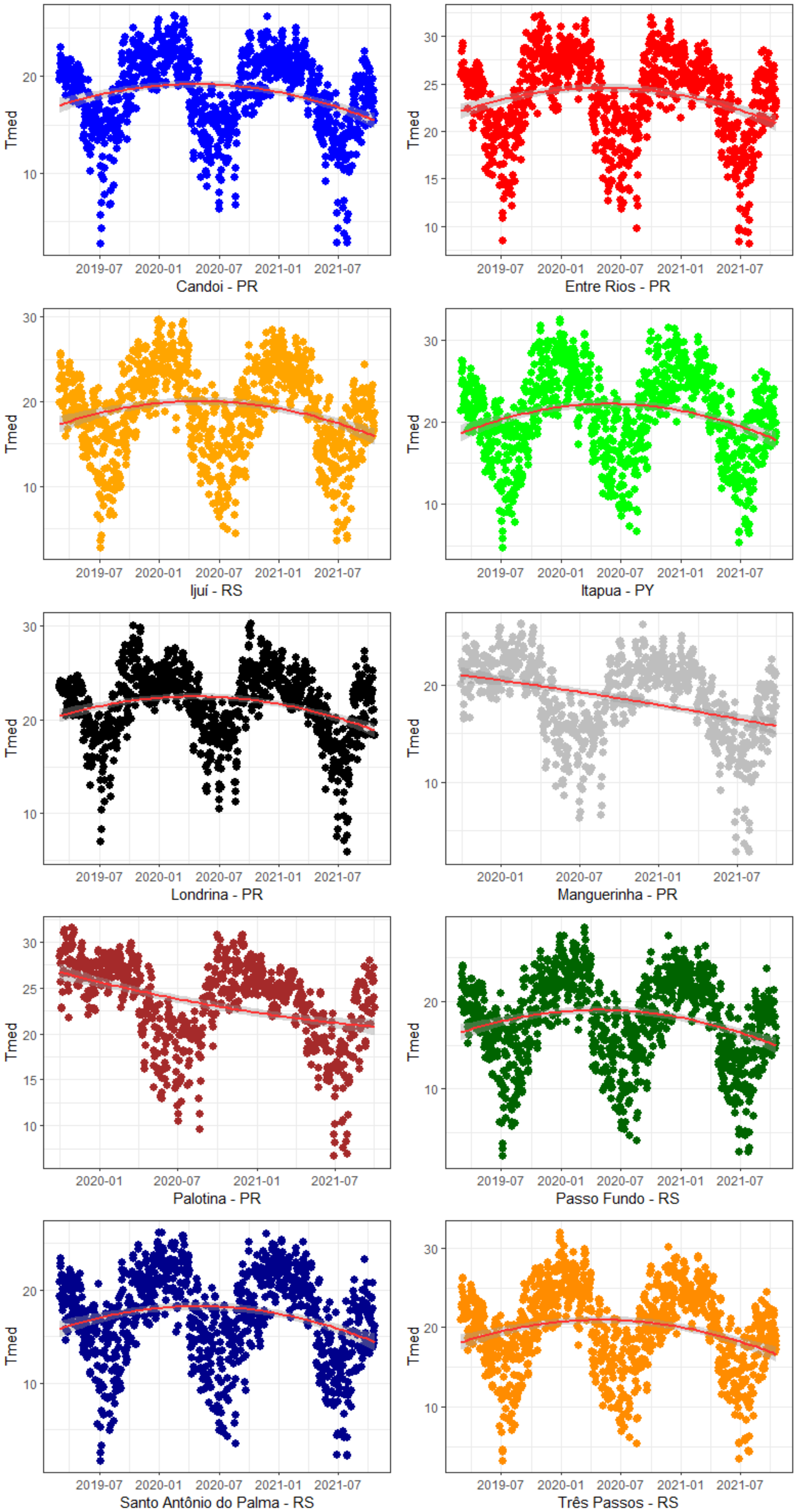

Figure 2. Average air temperatures (Tmed, °C) for the eleven environments evaluated, Candói - PR, Entre Rios - PR, Ijuí - RS, Itapúa - PY, Londrina - PR, Mangueirinha - PR, Palotina - PR, Passo Fundo - RS, Santo Antônio do Palma - RS and Três Passos – RS (2019 and 2020).

It is observed that the environments of IJ2020, PF2020, TP2019, TP2020 and P2019, have an average air temperature of 20 to 23°C in the period of three years. The period from winter to spring, the highest proportion of averages is between 10 and 20 °C, while the months from November to May represent a period where average air temperatures are higher, above 25 °C.

For most annual grasses, the relationship between net photosynthesis and air temperature shows a wide optimal range, from 10 to 25 °C, with high rates of photosynthesis maintained at temperatures below this range, but greatly decreasing in warmer conditions (Castro, *et al*., 2012). White oat develops optimally when the vegetative stage receives relatively low air temperatures that are not harmful to plants, however, in the reproductive stage, temperatures below 2ºC and 3ºC can cause damage to leaves and stems and, mainly, sterility of flowers (Castro *et al*., 2012).

The months of September and October correspond to the period of grain filling and the end of the cycle of the white oat crop, sown in the second half of May and early June, in this period all environments evaluated begin to have an increase in average air temperatures which influence the increase in respiration rate and reduction in the rate of photo assimilates production, limiting the accumulation of plant reserves (Fontaneli and Santos, 2012).

The relationship between altitude and air temperature is relevant for tropical and subtropical regions where a difference of hundreds of meters causes sensitive changes in the environment and adaptation of the biota (Pacheco *et al*., 2012). SAP2020, PF2020 and C2019 are environments with altitudes above 700 meters and presented average temperature below 20°C, considering that in the winter season (June to September) the average is concentrated in greater proportion at 15°C, but in extreme periods it can be lower than 5°C.

For most annual grasses, the relationship between net photosynthesis and air temperature shows a wide optimal range from 10 to 25°C, with high rates of photosynthesis maintained at air temperatures below this range, but with a drastic reduction in warmer conditions (Castro *et al*., 2012). The environments of ERS2020 and IT2019 have the highest average close to 25°C and also show more defined seasons, that is, lower average air temperature in the cold season and higher in the hot season, possibly referring to altitudes of 350 and 200 m above the sea level, respectively.

Analysis of variance (Table 1) revealed a significant interaction between crop environments x white oat genotypes for grain yield at 5% probability, which indicates the presence of variability between genotypes and between environments used, and the occurrence of differential response of the genotypes to the environments, evidences the need to carry out stability and adaptability analyses.

AMMI analysis is one of the most used methodologies in the area of genotype selection due to the ease of interpretation of results. Its application includes several crops such as soybean (*Glycine max* (L.) Merrill) (Carvalho *et al*., 2021), wheat (*Triticum aestivum* L.) (Schneider *et al*., 2021, Szareski *et al*., 2021), however these cited studies showed explanations by the principal components inferior to the present study. The first main component was responsible for representing 68.1% of the general effects attributed to the G x E interaction and the second 26.3%.

Thus, the first two main components explain 94.4% of the interaction effects (Figure 3 A and B). It is observed that the environments SAP2020, TP2019, IT2019 and I2020, arranged above the horizontal line and in the right quadrant are classified as favorable environments for grain yield, but showed low stability (Figure 3A). The cultivar IPR Artemis still has a higher average for grain yield, but it is considered a genotype of low stability for the variable, with a position far from the horizontal line. The cultivar URS Brava showed high stability for all environments, however with a lower average grain yield when compared to the IPR Artemis genotype.

Table 1. Analysis of variance (ANOVA) for white oat grain yield, adaptability and multivariate stability (AMMI) scores, for four cultivars in eleven environments in the states of Rio Grande do Sul and Paraná in Brazil, and Itapúa in Paraguay.

SV	DF	SS	MS	Value F	Pr >F	Percent	Accumulation
ENV (E)	10	34444207.5	3444420.75	29.5803451	2,2204E-16	.	.
REP (ENV)	44	5123486.98	116442.886	0.49907262	0.99523373	.	.
GEN (G)	3	858148.011	286049.337	1.22600355	0.30309579	.	.
G X E	30	37154998.1	1238499.94	5.30819382	1.2755E-11	.	.
PC1	12	25516818.1	2126401.51	9.11	0	68.1	68.1
PC2	10	9851514.09	985151.409	4.22	0	26.3	94.4
PC3	8	2081332.85	260166.606	1.12	0.3543	5.6	100
RESIDUES	126	29398133.8	233318.522	0	0	.	.
Total	243	144428639	594356.541	0	0	0	0

SV: Source of Variation, ENV: Environments, REP (ENV): Repetition (Environment), GEN: Genotypes, PC: Principal Component, DF: Degrees of Freedom, SS: Sum of Squares, MS: Mean Square.

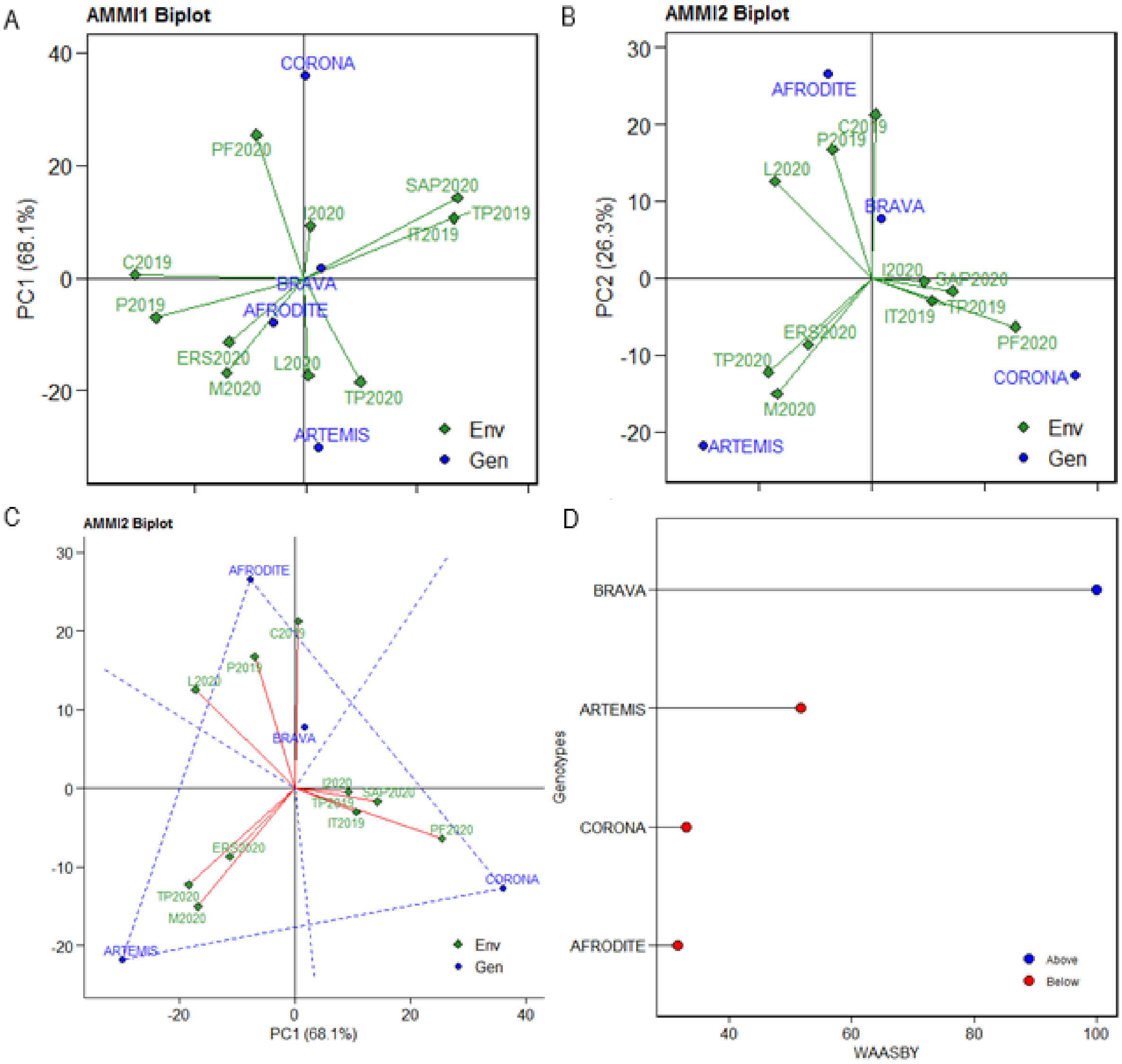

Figure 3. Plotting the PC1 and PC2 main component scores for the AMMI method and genotype selection by the WASSBY index, referring to the interaction genotypes x environments obtained by the AMMI method for grain yield of white oat, for four genotypes, (IPR Afrodite), (IPR Artemis), (URS Brava) and (URS Corona); Env: Environments, IT2019 (Itapúa - PY), P2019 (Palotina - PR), C2019 (Candói - PR), L2020 (Londrina - PR), TP2019 (Três Passos - RS), TP2020 (Três Passos - RS), PF2020 (Passo Fundo), SAP2020 (Santo Antônio do Palma - RS), I2020 (Ijuí - RS), M2020 (Mangueirinha-PR) and ERS2020 (Entre Rios - PR).

The C2019 environment showed stability, but with low representation in grain yield compared to favorable environments and less stability. The environments, P2019, ERS2020 and M2020, arranged in the lower left quadrant, are characterized as environments of low stability and low expressiveness in average grain yield for the four genotypes, thus considered as unfavorable environments. TP2020 and P2020 are characterized as high-yield unstable environments and are representative of the IPR Artemis and URS Corona genotypes, respectively (Figure 3B). The PF2020 environment was not considered favorable in AMMI1, but in Figure 3B, it expresses high grain yield for the URS Corona genotype.

Grain yield (Figure 3C) is only evaluated for the specific genotype with greater representation for each environment, in this way it is possible to group the environments and indicate which genotypes express higher grain yield. Detailing the graph, we can see the formation of three mega environments, being the mega environment I, composed of PF2020, TP2019, IT2019, SAP2020 and I2020 for these the genotype URS Corona expresses greater adaptability and grain yield.

The environments L2020, P2019 and C2019 (Figure 4C), form the mega environment II with greater expressiveness for the genotypes IPR Afrodite and URS Brava. Mega environment III is composed of TP2020, M2020 and ERS2020, with better performance for the IPR Artemis genotype. For both environments, the URS Brava genotype has adaptability and productive stability with a productivity similar to the superior genotype.

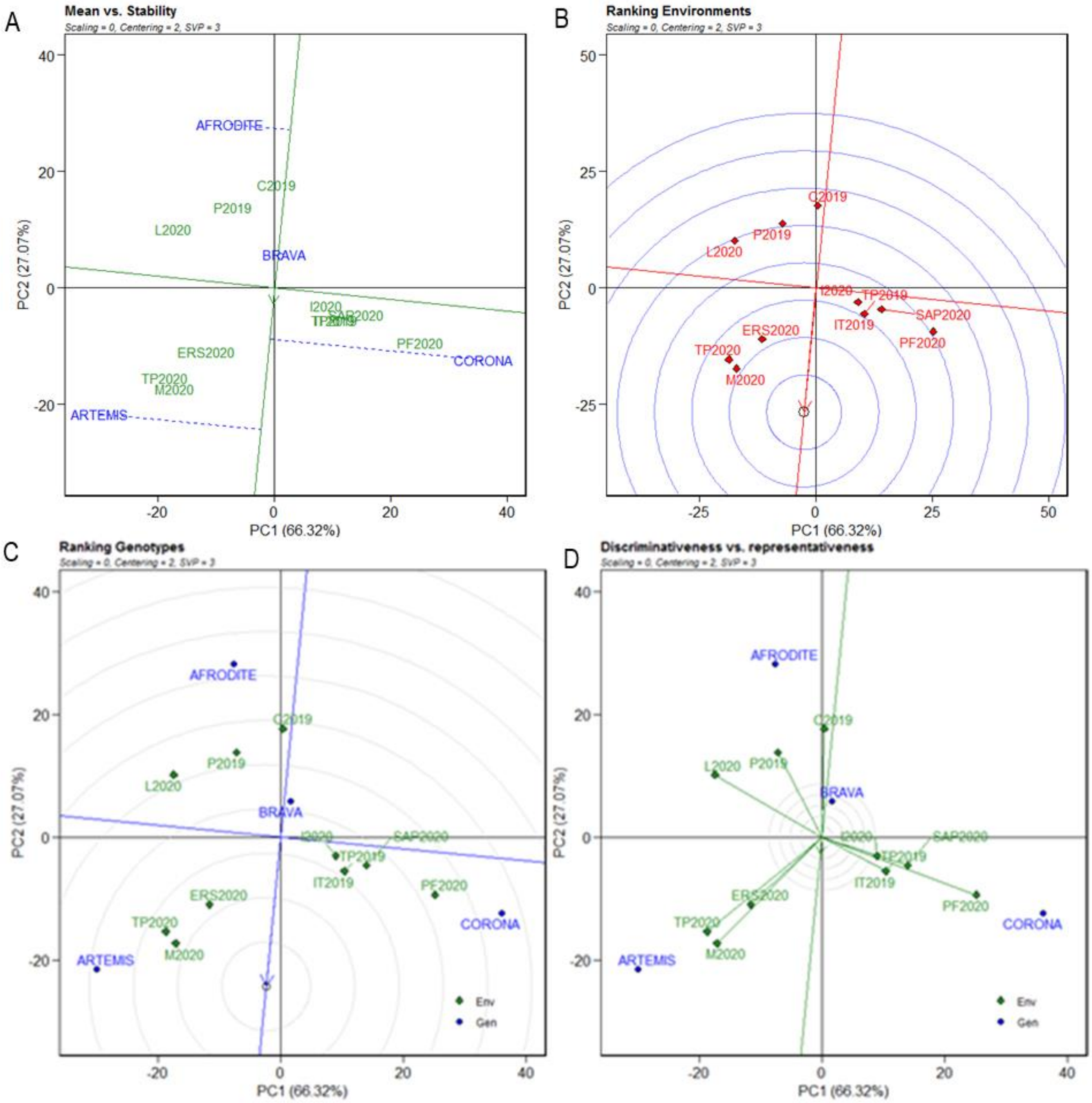

Figure 4. Mean vs stability (A), ranking of environments (B), ranking genotypes (C), and discriminativeness vs. Representativeness (D) for genotypes (IPR Afrodite), (IPR Artemis), (URS Brava) and (URS Corona); Env: Environments; IT2019 (Itapúa - PY), P2019 (Palotina - PR), C2019 (Candói - PR), L2020 (Londrina - PR), TP2019 (Três Passos - RS), TP2020 (Três Passos - RS), PF2020 (Passo Fundo - RS), SAP2020 (Santo Antônio do Palma - RS), I2020 (Ijuí - RS), M2020 (Mangueirinha - PR) and ERS2020 (Entre Rios - PR).

Thus, by evaluating the averages of the genotypes in each environment, it was possible to list the ideal genotype, characterized by the cultivar URS Brava, since it showed great stability and adaptability to the variable grain yield, while grain yield is lower to the other genotypes in both environments. This reference gives the assumption that the genotype has high stability in grain yield in different variations of environment, being able to be used in multiple locations, guaranteeing that the genotype would deliver a similar result.

The environment of TP2019 and TP2020, had an influence on the agricultural year since there was a difference in grain yield for both genotypes, which probably had an influence on meteorological variations. The environment in 2019, (TP2019) resembled the environments of PF2020, IT2019, SAP2020 and I2020 already for the year 2020, (TP2020) resembled M2020 and ERS2020 under the character of grain yield, thus considered as an environment unpredictable for this variable.

The selection of promising genotypes was aided by the use of the superiority index (WAASBY) which is the simultaneous use of yield and stability by variable weighting of the yield and stability of genotypes (Olivoto *et al*., 2019). The WAASBY index (Figure 4D) makes it possible to identify genotypes that express high adaptability and phenotypic stability (Olivoto *et al*., 2019). In this way, it was verified that the genotype URS Brava presents greater stability and adaptability in relation to the environments, followed by the genotypes IPR Artemis, URS Corona, and IPR Afrodite with less stability.

The evaluation of phenotypic stability for the *GGE* method reflects on the possibility of predicting possible responses in the next crops, since it indicates the predictability of the response of a given genotype under those cultivation conditions. These estimates showed that the method allowed (PC I: 66.32% and PC II: 27.07%) to represent 93.39% of the interaction effects on the grain yield variable.

Thus, the multivariate definitions of the *GGE* method make it possible to classify the genotypes of high and low stability based on the approximation with the vertical line and the point of greatest stability. It is evident that the genotype URS Brava is the closest to this, since it showed excellent stability for the variable grain yield (Figure 4A). The cultivar IPR Afrodite, on the other hand, showed stability in representativeness when compared to the averages, however with low expressiveness for grain yield.

The genotypes URS Corona and IPR Artemis demonstrate phenotypic instability, but with good performance in grain yield. In the lower right half of the graph, the environments closer to the vertical line are more stable and more predictable for grain yield. The greater the equidistance of the line, the lower the stability and the greater the representativeness of the environment with the specific genotype.

In the classification of environments, in contrast to the similarity between them (Figure 4B), the environments are inserted according to the genotype that presents greater adaptability and grain yield. In the second curvature of the graph, the environments M2020, TP2020 and ERS2020 are inserted, which had the highest grain yield with the URS Artemis genotype and for this reason are closer of the highest average point. The IT2019, SAP2020, TP2019 and I2020 environments form a second group of environments where they are similar and express greater productivity of grains for the URS Corona genotype. L2020, differs a little from the P2019 and C2019 environments because it presents predictability for the IPR Afrodite and IPR Artemis genotypes, thus being more distant from the other environments.

The representativeness of the mean in the grain yield of the eleven environments (Figure 4C), where the higher the mean, the greater the proximity of the genotype to the center of the circle. Thus, the IPR Artemis genotype is the closest to the highest average point for grain yield in the sum of the eleven evaluated environments, taking into account the distance from the horizontal line that represents the stability of the genotype. The cultivar URS Brava is in second place where it has medium productivity and high stability and URS Corona in the average of the eleven environments is in third place in grain productivity, but with low stability, and IPR Afrodite is stable with low productivity.

It is observed that the genotypes present distinction in relation to grain yield (Figure 4D), that is, there was no similarity in the behavior of grain production among cultivars. Only the URS Brava genotype was located near the data source. This indicates that the URS Brava genotype is the closest to the ideotype, since it is stable in the tested environments.

The regression analysis for altitude in the different environments and the cycle of genotypes, indicates that its influence is evident (Figure 5A). Furthermore, it can be correlated with air temperature since this factor normally decreases with the altitude in a proportion of approximately 1ºC/100m (dry air adiabatic gradient). This cooling rate occurs because a rising dry air mass is subjected to less pressure, expanding its volume and decreasing the air temperature, that is, transforming thermal energy into potential energy (Fritzsons *et al*., 2016).

White oat, as well as grasses in general, is a species responsive to ambient air temperature since there is an accumulation of degrees per day for the development of the physiological stages, mainly in the vegetative period. The presence of an inverse relationship between air temperature and the duration of the vegetative phase indicates that the higher the average air temperature, the shorter the duration of this phase. Thus, when the altitude of the environments increases, the duration of the cycle tends to be longer.

The regression analysis for the correlation between altitude and cycle of genotypes indicates that there is a positive relationship (Figure 5A). Thus, the equation shows that for each meter added to altitude (m) under the X axis, there is an increase of 0.045 days in the genotype cycle (Y axis), this equation allowed an applicability of 45% under the effects of regression.

It can be observed that the lower altitude environments, IT2019 and P2019 with 200 and 300 m, presented an average cycle of 89.2 and 94.2 days, respectively, whereas the environments with an average altitude close to 400 m, with the exception of TP2019, had a cycle on days of 110 and 125 days. Similarly, the environments of SAP2020, M2020, and C2019 with 700, 800, and 962 m of altitude, respectively, presented a cycle from 125 to 136 days in an increasing manner relative to the altitude of the environment, indicating the increase in days required to reach physiological maturity.

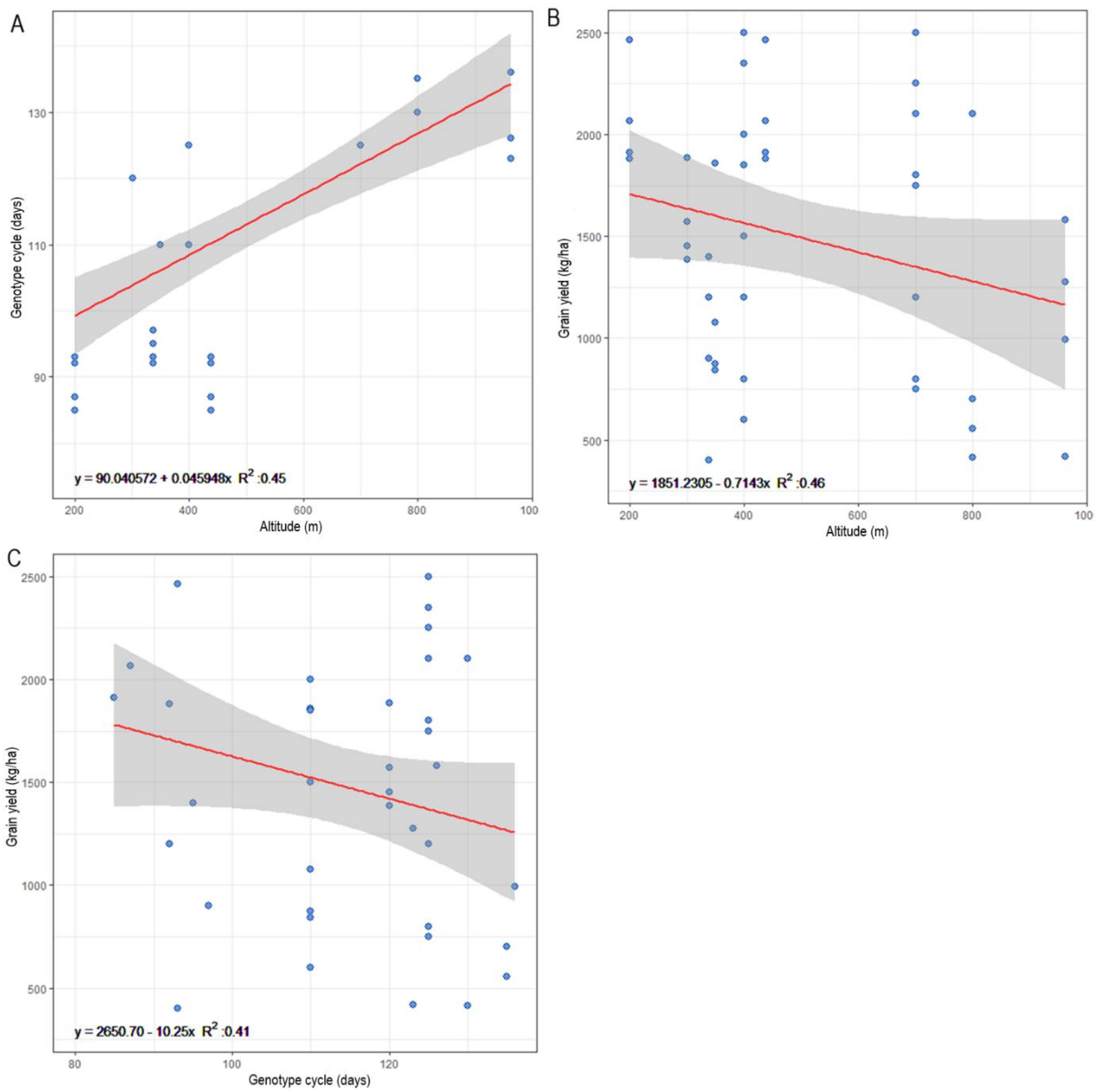

Figure 5. Regression analysis for altitude and cycle of genotypes (A), grain yield and altitude of environments (B), and between grain yield and cycle in days until physiological maturity (C) cultivated in eleven environments.

The regression analysis shows that there is a negative relationship between the variables altitude (m) and grain yield (kg ha^{-1}) and presents 46% of the explainability (Figure 5B). The equation allowed interaction where each species from the X axis (altitude) represents -0.713(kg ha^{-1}) in the Y axis to (grain yield). In other words, for each meter added over altitude, there is a reduction of 0.713 (kg ha^{-1}) in grain yield.

When comparing the two environments with the highest average in kg ha^{-1} of grains, there is a great difference in terms of altitude in which the municipality of IT2019 has 200 meters, whereas the municipality of SAP2020 has an altitude of 700 meters in relation to sea level, this difference between the environments caused the genotype cycle to increase by 35 days in relation to the lower altitude environment. In the same way as the cycle, altitude reflects on grain yield, since the largest proportion of environments are at an altitude of 301 to 400 meters, grain yield declines when altitude is raised to the 800 and 962 meters, that this is the case of the environments, M2020 and C2019 in the state of Paraná.

The environment of TP2019 and TP2020 showed differences in the behavior of the genotypes in relation to the duration of the cycle. Although it is the same environment, for 2019 the genotypes IPR Artemis, URS Brava, IPR Afrodite, and URS Corona had cycles of 85, 87, 92, and 93 days, respectively; in 2020 the cycle was 125 days for both genotypes. This difference in the behavior of the cycles is due to variations in abiotic factors such as levels of precipitation, solar radiation, and air temperature.

Regression analysis for correlation between grain yield and genotype cycle duration indicates that there is a negative relationship between the variables (Figure 5C). It displays 41% of the explanation of this correlation. The equation allowed interaction where for each species of the X axis (cycle in days) there is a reduction of 10.25 (kg ha^{-1}) in grain yield.

Although most genotypes have a cycle of 110 to 125 days, Figure 5C shows a decreasing linear regression in relation to grain yield when advancing on the X axis (cycle in days), where the environments that provided the shortening of the cycle of the genotypes showed higher grain yield, with the exception of P2019, which showed a reduction in the cycle of both genotypes and showed the lowest averages for grain yield. For the environments of SAP2020 and TP2020, all genotypes had a cycle of 125 days and presented average grain yield above 2000 kg ha^{-1}.

CONCLUSION

It was possible to form three mega environments with the identification of specifically adapted genotypes.
The URS Brava genotype is characterized as the ideal genotype, with high stability and predictability for grain yield, which can be positioned in all environments.

High altitudes promote longer cycle duration and lower grain yield, while at low altitudes there is shorter cycle duration and maximization of grain yield of white oat genotypes.

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