Revista Thema
v.23 | n.2 | 2024
p.532-544

DOI: http://dx.doi.org/10.15536/thema.V23.2024.532-544.3621
ISSN: 2177-2894 (online)

CIÊNCIAS AGRÁRIAS

Relationships between agronomic traits and characterization of the white oat ideotype for cultivation with and without chemical fertilization

Relações entre caracteres agronômicos e caracterização do ideótipo de aveia branca para cultivo com e sem adubação química

Murilo Vieira Loro[1]
https://orcid.org/0000-0003-0241-4226 http://lattes.cnpq.br/0597180308983982

Ivan Carvalho[2]
https://orcid.org/0000-0001-7947-4900 http://lattes.cnpq.br/7945266734797620

Genesio Luiz Meggiolaro Junior[3]
https://orcid.org/0009-0007-3347-579X http://lattes.cnpq.br/9527885142332784

Leonardo Cesar Pradebon[4]
https://orcid.org/0000-0001-7827-6312 http://lattes.cnpq.br/1412832919433642

Jaqueline Piesanti Sangiovo[5]
https://orcid.org/0000-0002-7599-9926 http://lattes.cnpq.br/1950235586584863

João Pedro Dalla Roza[6]
https://orcid.org/0000-0001-6902-0454 http://lattes.cnpq.br/2392328923118575

Willyan Júnior Adorian Bandeira[7]
https://orcid.org/0000-0002-9430-3664 http://lattes.cnpq.br/3996028237275274

ABSTRACT

This paper aimed to characterize and verify whether the linear relationships between agronomic traits of white oat are different between crops with and without chemical fertilization; and identify the agronomic ideotype that enhances the agronomic performance of white oats. Two uniformity tests were carried out with and without chemical fertilization in the 2020 harvest. In each trial, on 285 plants, agronomic traits were measured. Pearson's linear correlation coefficients and the direct and indirect effects of the trial analysis were calculated. The regression tree algorithm and Kohonen map neural network were used to identify the

[1] Universidade Federal de Santa Maria – UFSM, Santa Maria/RS – Brasil. E-mail: muriloloro@gmail.com
[2] E-mail: carvalho.ircii@gmail.com
[3] E-mail: junio@gmail.com
[4] E-mail: pradebon_leo@gmail.com
[5] E-mail: sangiovo_jaque@gmail.com
[6] E-mail: roza_pedroj@gmail.com
[7] E-mail: bandeira.wjab@gmail.com

agronomic ideotype. The linear relationships between agronomic characters of white oat are similar between crops with and without chemical fertilization. White oat genotypes with greater panicle grain weight can be selected indirectly by panicle weight, regardless of cultivation with or without fertilization. White oat genotypes measuring 114.57 cm in height, 97.41 cm in panicle insertion, 18.11 cm in panicle length, 1.31 g in panicle weight and 27.92 grains in the panicle characterize the agronomic ideotype that maximizes panicle grain weight.

Palavras-chave: *Avena sativa*; correlation; path analysis; regression tree; Kohonen map.

RESUMO

Os objetivos deste trabalho foram caracterizar e verificar se as relações lineares entre caracteres agronômicos da aveia branca são distintas entre cultivos com e sem adubação química; e identificar o ideótipo agronômico que potencializa o desempenho agronômico da aveia branca. Realizaram-se dois ensaios de uniformidade com e sem adubação química na safra de 2020. Em cada ensaio, em 285 plantas, mensuraram-se os caracteres agronômicos. Calcularam-se os coeficientes de correlação linear de Pearson e os efeitos diretos e indiretos da análise de trilha. O algoritmo de árvore de regressão e a rede neural de mapas de Kohonen foram utilizadas para identificar o ideótipo agronômico. As relações lineares entre caracteres agronômicos da aveia branca são similares entre cultivos com e sem adubação química. Os genótipos de aveia branca com maior massa de grãos da panícula podem ser selecionados indiretamente pela massa da panícula, independentemente do cultivo com ou sem adubação. Os genótipos de aveia branca com 114.57 cm de altura, 97.41 cm de inserção da panícula, 18.11 cm de comprimento da panícula, 1.31 g de massa da panícula e 27.92 grãos na panícula caracterizam o ideótipo agronômico que maximiza a massa de grãos da panícula.

Keywords: *Avena sativa; correlação; análise de trilha; árvore de regressão; mapa de Kohonen.*

1. INTRODUCTION

The development and selection of high-performance genotypes is a priority in white oat breeding programs (Azevedo *et al*., 2022). However, this characteristic is complex in nature, which makes it difficult to select individuals with high productive potential (Corazza *et al*., 2021; Berlezi *et al*., 2023). Secondary traits that generally present greater heritability and are correlated with grain productivity have been identified for indirect selection of white oat genotypes with high productive potential (Loro *et al*., 2022; Schimidt *et al*., 2023; Treter *et al*., 2023).

Linear correlation allows the study of associations between pairs of characters and makes it possible to infer the existence of a correlation between characters. In genetic improvement, this information allows the development of indirect selection strategies. However, the relationships between characters may not be cause and effect. Therefore, it is possible to break down the linear correlation coefficients into direct and indirect effects through trial analysis (Cruz; Carneiro; Regazzi, 2014). Studies have used these methodologies to identify relationships between characters in white oats (Meira *et al*., 2019; Mantai *et al*., 2020; Schimidt *et al*., 2023; Treter *et al*., 2023). The results indicate that white oat plants with higher grain productivity can be selected indirectly by the weight and number of grains in the panicle (Schimidt *et al*., 2023; Treter *et al*., 2023).

Although understanding the relationships between characters is important for indirect selection strategies, it is necessary to know the plant ideotype, that is, the set of characters that maximizes the productive response of plants subjected to different environmental conditions (Barbosa *et al*., 2021; Kehl *et al*., 2022; Carvalho *et al*., 2016). To this end, through the application of machine learning algorithms and neural networks, it is possible to identify patterns and magnitudes of phenotypic characters associated with greater expression of grain productivity (Silva Júnior *et al*., 2023). Therefore, based on the phenotypic evaluation of plants, it is possible to employ algorithms such as the regression tree and Kohonen maps (Kohonen, 2001) to recognize character patterns among the plants evaluated. This makes it possible to identify the values of a set of characters that enhance the productive response. This approach directly contributes to characterizing the plant ideotype to be selected in genetic improvement programs, according to different environmental conditions.

The genotype x environment interaction alters the linear relationships between traits and the agronomic ideotype. For example, in maize the relationships between phenological characters and grain yield are different in irrigated and rainfed conditions (Melo *et al*., 2018), consequently there is a specific ideotype for each environment. This reveals factors such as fertilization, sowing dates and weather conditions determine the expression and relationships between traits (Sah *et al*., 2020). In white oat, studies have focused on the selection and positioning of genotypes for cultivation in an organic system, without the use of chemical fertilizer (Loro *et al*., 2022; Schimidt *et al*., 2023; Treter *et al*., 2023). Therefore, the relationships between characters and ideotype characterization in organic environments, with less use of resources, and in high investment environments must be investigated.

Therefore, understanding whether there are changes in the relationships and characterization of the agronomic ideotype is essential for the development of selection strategies for specific growing conditions. In this sense, the objectives of this work were to characterize and verify whether the linear relationships between agronomic traits of white oat are different between crops with and without chemical fertilization; and identify the agronomic ideotype that enhances the agronomic performance of white oats.

2. MATERIAL AND METHODS

Two uniformity tests were carried out in the same area in the 2020 harvest in the municipality of Catuípe, RS, Brazil (28º 20’ 14’’S, 54º 07’ 12’W, 270 m altitude). In one of the tests, basic chemical fertilization was carried out with 250 kg ha^{-1} of fertilizer 05-20-20 (N-P-K) and in the other test, white oat was cultivated without the use of fertilizer. Each test consisted of 19 basic experimental units, totaling 56,525 m^2. The basic experimental units consisted of 7 rows of 2.50 m in length spaced 0.17 cm apart, totaling 2.975 m^2. White oat (cv. URS Taura) was sown on April 15th, 2020. Nitrogen top dressing was not used in both trials. Phytosanitary management was carried out to minimize abiotic effects (pests and diseases) on plant development.

At full physiological maturity, in 15 plants from each UEB (total of 285 plants per trial), collected randomly, the following characters were measured: plant height (PH, cm), considering the distance between the soil surface and the extremity of the topmost branch; height insertion of the panicle (HIP, cm), considered the distance between the soil surface and the panicle insertion; panicle length (PL, cm); panicle weight (PW, g); number of grains per panicle (NGP, unit); and panicle grain weight (PGW, g).

Principal component analysis was applied in order to verify data variability and possible formation of groups of individuals between trials with and without fertilization. For each test (with and without chemical fertilization), Pearson's linear correlation coefficients were calculated between pairs of characters, forming two correlation matrices. The significance of the correlation coefficients was verified using the *Student* t test at 5% probability. Then, to verify whether the linear relationships between the characters in the tests with and without fertilization are different, the intraclass correlation coefficient was calculated (between the two correlation matrices). With the similarity of the linear relationships between the characters in the two environments, the correlation coefficients between pairs of characters were calculated jointly, that is, considering all observations from the two tests. Next, the PGW character was considered as dependent and the other characters (PH, HIP, PL, PW and NGP) as independent.

Multicollinearity diagnosis was carried out in each of the three matrices (with, without and joint) of independent characters (PH, HIP, PL, PW and NGP), considering the condition number (CN). In the absence of multicollinearity, three trial analyzes were carried out (with, without and joint), calculating the direct and indirect effects of the independent characters on the dependent character. To confirm the similarity of the linear relationships between the characters in the two tests (with and without), the correlation of the direct and indirect effects between the tests with and without fertilization was calculated. Based on the evidence of similarity of linear relationships, the remaining analyzes were carried out with all observations, regardless of the use or not of fertilizer.

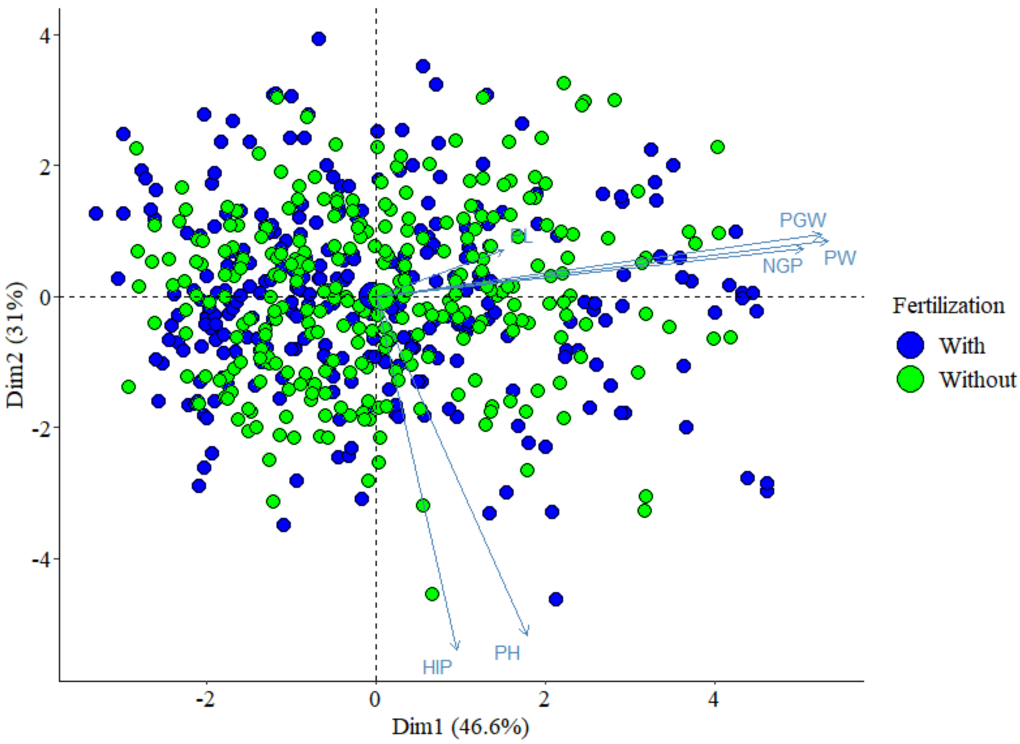
To identify the characteristics of the plant ideotype with high productive performance, the parameters of the regression tree algorithm were estimated, considering PGW as a dependent character and the other characters as independent (PH, HIP, PL, PW and NGP). Kohonen's self-organizing map (Kohonen, 2001) was used as an approach to identify the plant ideotype of white oat. For this, a 3 × 3 neural structure was used, accounting for a total of nine neurons. Hexagonal topology was used for the configuration, and data organization was performed over 3,000 iterations. During this process, the initial learning rate of 0.05 was gradually reduced linearly until it reached a value of 0.01. Then, the Euclidean distances between each neuron were calculated, in order to verify the similarity between the neurons. All analyzes were performed using the R software (R CORE TEAM, 2023) through the packages *ggplot2* (Wickham, 2016), *AgroR* (Shimizu; Marubayashi; Goncalves, 2023), *kohonen* (Wehrens; Kruisselbrink, 2018), *rpart* (Therneau; Atkinson, 2022) and *rpart.plot* (Milborrow, 2022).

3. RESULTS AND DISCUSSION

In the principal component analysis carried out for the two trials (with and without fertilization), it was observed that the first two principal components explained 77.60% of the total variation in the data (Figure 1). Observations from each trial were colored distinctly. The distribution of observations revealed the absence of group formation. This indicates that the tests with or without fertilization did not influence differently the relationship and expression of the evaluated characters.

In the two correlation matrices (with and without fertilization), the coefficients (r) between pairs of characters ranged from -0.112 (HIP *vs* PGW) to 0.968 (PW *vs* PGW) (Figure 2). In both tests, positive coefficients of high magnitude were observed between PGW with PW and NG (r ≥ 0.768). These results are consistent with the results reported by Schmidt *et al*. (2023) and Treter *et al*. (2023), who observed a correlation coefficient of 0.68 and 0.64, respectively, between the number of grains and the panicle grain weight in an organic cultivation system. Mantai *et al*. (2020) reported a positive correlation (r = 0.35) between panicle weight and oat grain productivity when using 30 and 60 kg ha^{-1} of N, in cultivation after soybean. This indicates the possibility of carrying out indirect selection of plants with higher PGW through PW and NG.

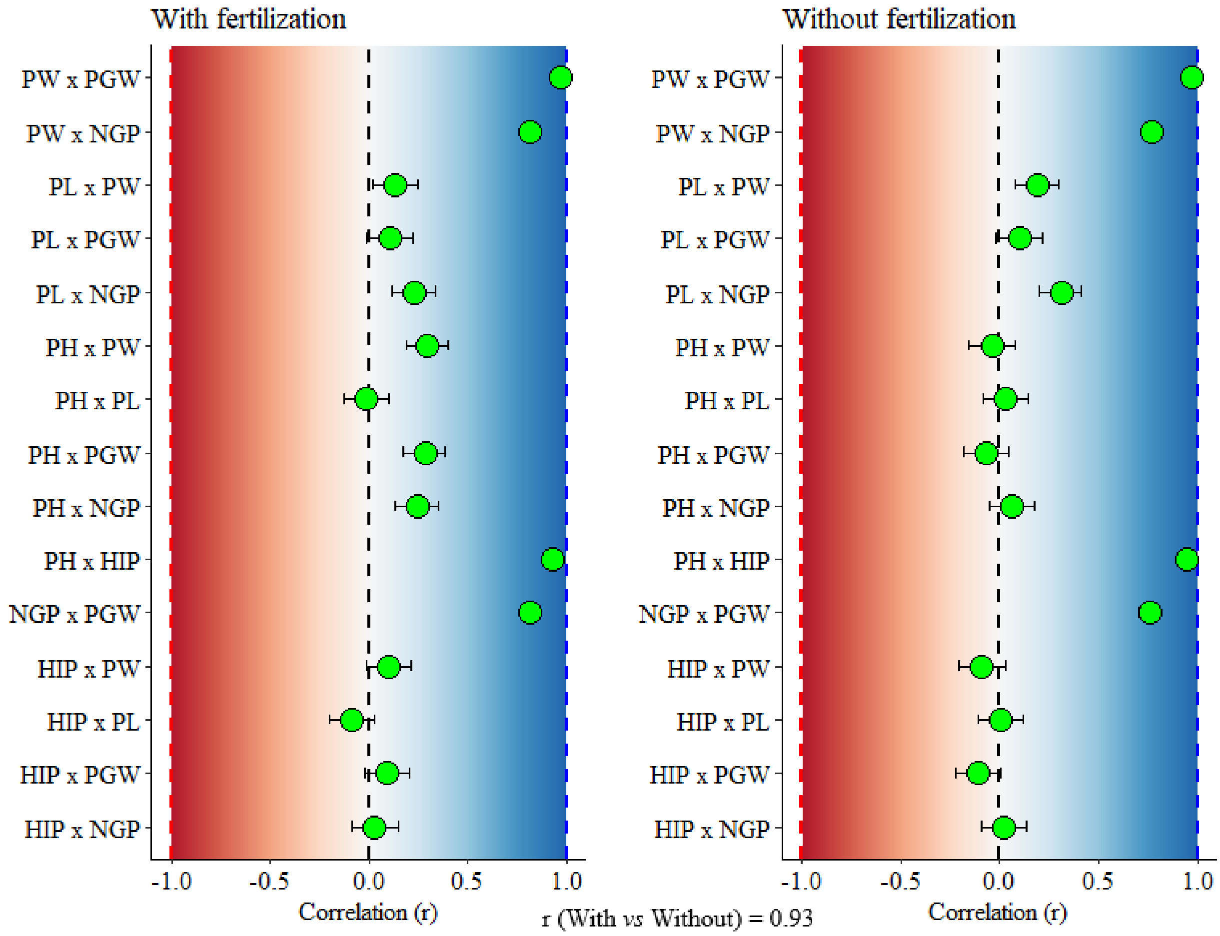
Figure 1 – Total variability of white oat data evaluated in trials with and without fertilization represented by two main components. Characters: plant height (PH, cm), height insertion of the panicle (HIP, cm), panicle length (PL, cm); panicle weight (PW, g); number of grains per panicle (NGP, unit) and panicle grain weight (PGW, g).



Font: authors.

In both tests, at least 60% of the explanatory characters were positively correlated with PGW. In organic system Schmidt *et al*. (2023) and Treter *et al*. (2023) found that the grain weight of the white oat panicle correlated with 50% of the explanatory characters. These results highlight the complex nature of the interactions present in the evaluated characters, which, in turn, complicates the task of indirect selection, as it makes discerning the most relevant characters more challenging. Therefore, the correlation coefficients were decomposed into direct and indirect effects, with the aim of allowing the assessment of the individual importance of each explanatory character in the expression of the dependent character (Cruz; Carneiro; Regazzi, 2014). The correlation coefficient (r) between the correlation matrices of the two trials n = 15 pairs of characters in each matrix) was 0.93 (Figure 2).

Figure 2 – Pearson's correlation coefficients (r) between the traits plant height (PH, cm), height insertion of the panicle (HIP, cm), panicle length (PL, cm); panicle weight (PW, g); number of grains per panicle (NGP, unit) and panicle grain weight (PGW, g) of white oats in trials with fertilization and without fertilization.
r (With *vs* Without): correlation coefficient between the
correlation matrix of the test with fertilization vs without fertilization.



Font: authors.

The correlation between the direct effects of independent traits on panicle grain weight of the two trials was 0.95 (With *vs* Without) (Table 1). Thus, it can be inferred that the linear relationships between pairs of characters are similar between trials with and without fertilization. Cultivation of white oat under contrasting fungicide management conditions did not modify trait relationships (Berlezi *et al*., 2023). While Mantai *et al*. (2020), observed variations in the linear relationships between white oat characters under different doses of nitrogen. In maze, Melo *et al*. (2018) observed that the cultivation environment modified the relationships between pairs of characters, requiring specific selection for each environment. However, this phenomenon was not observed in this study, indicating the possibility of using PM for indirect selection of plants with higher PGW, regardless of the environment with or without the use of fertilization. Therefore, trail analysis, regression tree and Kohonen maps were carried out, jointly considering all observations from the two tests.

The condition number ranged from 23.72 to 44.15, indicating low collinearity in the correlation matrices (Table 1). A high coefficient of determination ($R^2 \geq 0.94$) was observed, indicating a high explanation of PGW through independent characters. Path analysis revealed a greater direct effect of PW on PGW. Furthermore, the correlation of NGP with PGW is explained by the indirect effects of panicle weight. Thus, it can be inferred that PW can be used to indirectly select white oat plants with higher PGW, regardless of cultivation with or without fertilization (N-P-K). Mantai *et al*. (2020) also reported a high magnitude of direct effects of panicle weight on white oat grain yield. The number of grains per panicle had the greatest direct effect on grain productivity, according to Meira *et al*. (2019), however, the authors did not consider panicle grain weight in the analysis. The advantage of using PW as a selection criterion is that it is not necessary to thresh the panicle grains, which facilitates the process of identifying plants with higher PGW.

It was possible to identify values of independent characters that were associated with the highest average PGW of white oats (Figure 3). PW was the main division node in the regression tree, suggesting that this character determines the expression of PGW in white oat plants. The highest average PGW (1.09 g) corresponded to panicles with a weight greater than 1.19 g, representing 8.9% of observations. Panicles with a weight greater than 0.787 g but less than 1.19 g had a PGW of 0.735 g (22.3% of observations). The results confirm that PW was the main predictive trait of PGW. Consequently, in genetic improvement programs, the selection of genotypes with higher PGW can be carried out simply by weighing the PW. This approach provides greater efficiency and precision in the selection of superior genotypes, using directly measured traits, without the need to thresh the panicles. In rice, the use of machine learning techniques also efficiently quantified the importance of independent variables in predicting productivity (SILVA JÚNIOR *et al*., 2023).

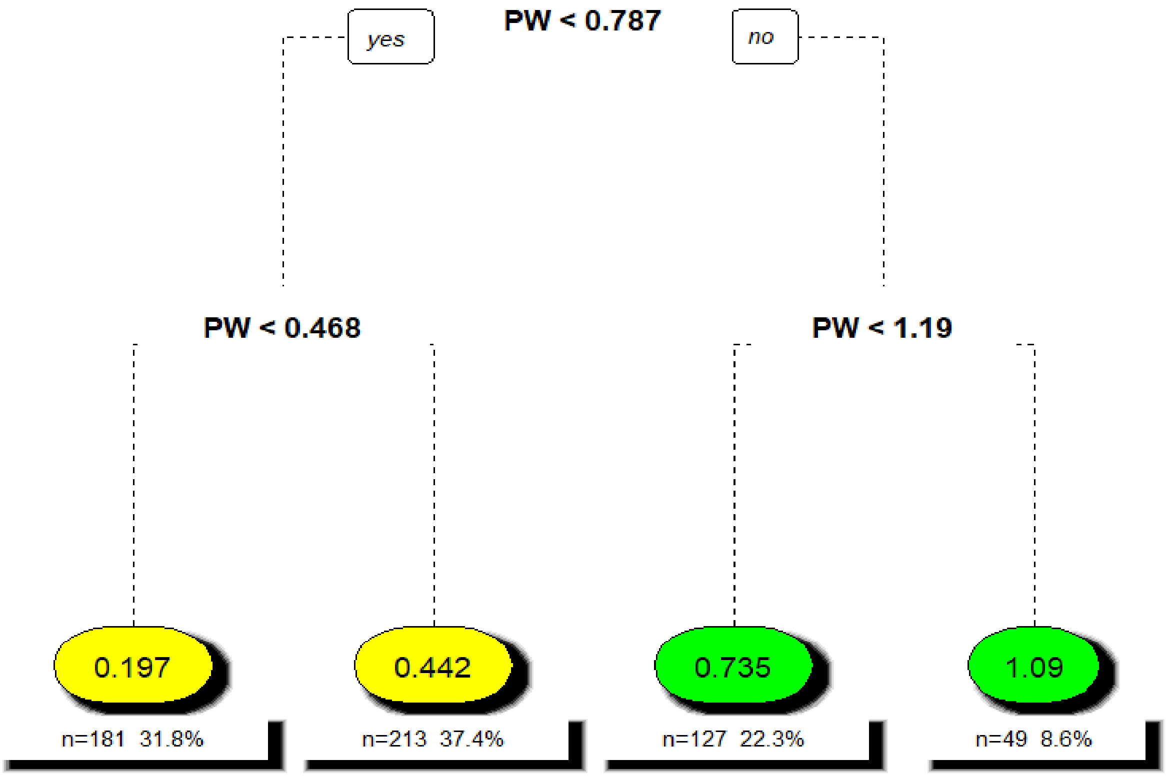
Table 1 – Estimates of Pearson's linear correlation coefficients and the direct and indirect effects of the trial analysis of the characters plant height (PH, cm), height insertion of the panicle (HIP, cm), panicle length (PL, cm); panicle weight (PW, g) and number of grains per panicle (NGP, unit) panicle grain weight (PGW, g) of white oat in trials with fertilization, without fertilization and general.

Effect	**With**	**Without**	**General**
Direct from PH over PGW	-0.03	-0.08	-0.11
Indirect via HIP	0.03	0.04	0.07
Indirect via PL	0.00	0.00	0.00
Indirect via PW	0.26	-0.04	0.14
Indirect via NGP	0.03	0.01	0.02
Pearson's Correlation	0.28	-0.07	0.12
Direct from HIP over PGW	0.03	0.05	0.08
Indirect via PH	-0.03	-0.08	-0.10
Indirect via PL	0.00	0.00	0.00
Indirect via PW	0.09	-0.08	0.01
Indirect via NGP	0.00	0.00	0.00
Pearson's Correlation	0.09	-0.11	0.01
Direct from PL over PGW	-0.04	-0.10	-0.07
Indirect via PH	0.00	0.00	0.00
Indirect via HIP	0.00	0.00	-0.01
Indirect via PW	0.12	0.17	0.14
Indirect via NGP	0.03	0.03	0.03
Pearson's Correlation	0.10	0.10	0.09
Direct from PW over PGW	0.88	0.92	0.91
Indirect via PH	-0.01	0.00	-0.02
Indirect via HIP	0.00	0.00	0.00
Indirect via PL Thema - Corpo do texto	0.00	-0.02	-0.01
Indirect via NGP	0.09	0.07	0.08
Pearson's Correlation	0.97	0.97	0.97
Direct from NGP over PGW	0.11	0.09	0.10
Indirect via PH	-0.01	-0.01	-0.02
Indirect via HIP	0.00	0.00	0.00
Indirect via PL	-0.01	-0.03	-0.02
Indirect via PW	0.72	0.71	0.72
Pearson's Correlation	0.82	0.76	0.78
Determination coefficient (R^2)	0.94	0.95	0.94
Effect of residual variable	0.06	0.05	0.06
Condition number	44.15	40.01	23.72
r (With *vs* Without)	0.95	-	-

r (With *vs* Without): intraclass correlation (correlation coefficient between the matrix of direct and indirect effects of the test with fertilization vs the matrix of direct and indirect effects of the test without fertilization.

Font: authors.

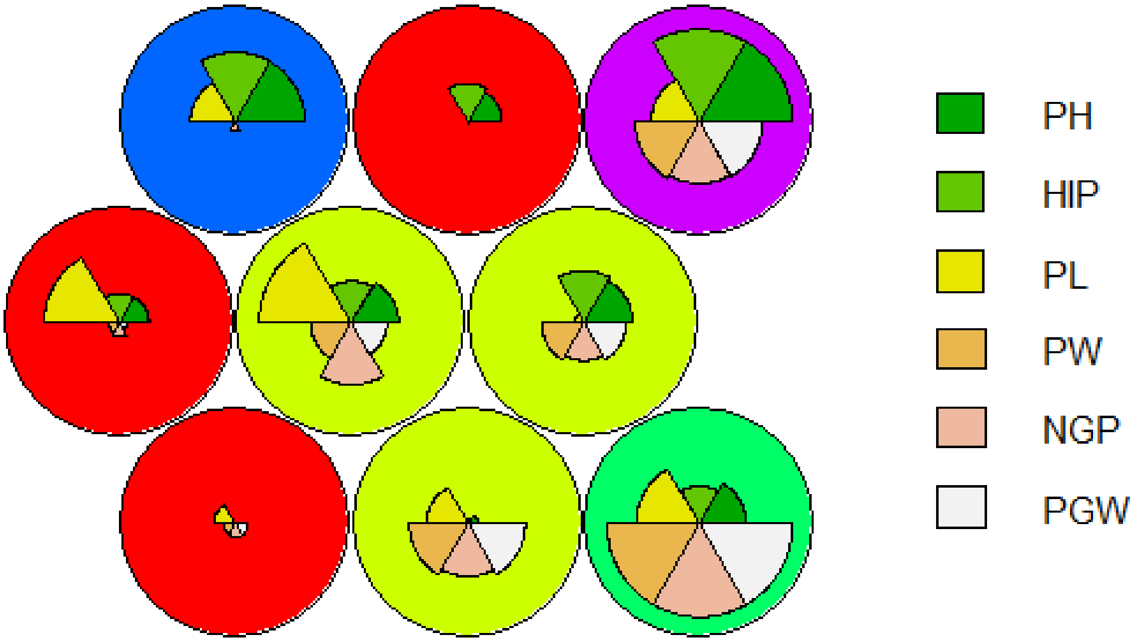
Figure 3 – Graphical representation of the regression tree for predicting panicle grain weight (PGW, g) of white oat, through plant height (PH, cm), height insertion of the panicle (HIP, cm), panicle length (PL, cm); panicle weight (PW, g); number of grains per panicle (NGP, unit); and panicle grain weight (PGW, g) (n = 570 observations).



Font: authors.

The 570 observations (plants) were grouped into nine neurons, made up of plants that showed similarity in the magnitude of the evaluated characters (Figure 4). Neurons with the same colors had the smallest Euclidean distances between them. Thus, it was possible to identify five plant ideotypes with distinct characteristics. The desired agronomic ideotype consists of plants with greater productive performance, that is, greater panicle grain weight. This ideotype was identified in the third neuron (green), since there is a greater magnitude of PGW expression.

Figure 4 – Unsupervised learning through neural network by Kohonen Map algorithm. Each colored dot on the graph represents a code neuron and reflects the similarities between input patterns. The arrangement of points reveals the topology of the original data and helps identify groupings and trends. Characters: plant height (PH, cm), height insertion of the panicle (HIP, cm), panicle length (PL, cm); panicle weight (PW, g); number of grains per panicle (NGP, unit) and panicle grain weight (PGW, g). Circles with equal colors represent the same group formed by Euclidean distance.



Font: authors.

Thus, based on the third neuron, the ideotype of white oat was characterized, with the largest panicle grain weight (1.08 g), with plants measuring 114.57 cm in height, 97.41 cm in panicle insertion, 18.11 cm in panicle length, 1.31 g of panicle weight and 27.92 grains in the panicle (Table 2). The results indicate that white oat plants with greater panicle length are not necessarily associated with greater panicle grain weight. This relationship was also observed by Mantai *et al*. (2020), in which panicle length showed a negative correlation with the productivity and industrial quality of white oat grains. Meira *et al*. (2019) observed that panicle length had a negative relationship with the number of grain in the panicle.

Although there are studies focused on identifying agronomic ideotypes, primarily in soybean crops (Barbosa *et al*., 2021; Kehl *et al*., 2022), there is a lack of research on the agronomic ideotype of white oats and the necessary character magnitudes to achieve high productivity. Thus, the present study gathered valuable information on the linear relationships between characters and characterized the agronomic ideotype of white oat plants, with the magnitude of the characters, for environments with and without the use of fertilization. This ideotype can be used as a reference standard for genotype selection, through selection indices based on multi-traits. This allows guiding the selection of genotypes, thus improving the efficiency of the process of selecting high-performance plants.

Table 2 – Average values of the characters plant height (PH, cm), height insertion of the panicle (HIP, cm), panicle length (PL, cm); panicle weight (PW, g); number of grains per panicle (NGP, unit) and panicle grain weight (PGW, g) of neurons identified by the Kohonen map.

Neurons	PH	HIP	PL	PW	NGP	PGW
N1	103.42	88.97	16.14	0.50	9.93	0.36
N2	105.88	90.19	17.06	0.96	18.76	0.76
N3	114.57	97.41	18.11	1.31	27.92	1.08
N4	110.46	95.55	18.68	0.49	10.14	0.31
N5	114.66	98.23	19.48	0.79	20.86	0.56
N6	115.13	100.62	15.56	0.80	15.45	0.63
N7	119.98	104.51	17.25	0.40	9.12	0.24
N8	111.62	97.56	15.10	0.38	7.03	0.25
N9	125.64	109.57	17.41	1.02	20.83	0.81

N1: neuron 1; N2: neuron 2; N3: neuron 3; N4: neuron 4; N5: neuron 5; N6: neuron 6; N7: neuron 7; N8: neuron 8; and N9: neuron 9.

Font: authors.

4. FINAL CONSIDERATIONS

The linear relationships between agronomic characters of white oat are similar between crops with and without chemical fertilization.

White oat genotypes with greater panicle grain weight can be selected indirectly by panicle weight, regardless of cultivation with or without fertilization (N-P-K), without the need to destroy the plant.

White oat genotypes measuring 114.57 cm in height, 97.41 cm in panicle insertion, 18.11 cm in panicle length, 1.31 g in panicle weight and 27.92 grains in the panicle characterize the agronomic ideotype that maximizes panicle grain weight.

5. REFERENCES

AZEVEDO, C. F. *et al*. Updated knowledge in the estimation of genetics parameters: a Bayesian approach in white oat (*Avena sativa* L.). **Euphytica**, v. 218, n. 4, p. 43, 2022.

BARBOSA, M. H. *et al*. Contribution of the additive genetic effects in soybean breeding aiming at the agronomic ideotype. **Functional Plant Breeding Journal**, v. 3, n. 1, 2021.

BERLEZI, J. D. *et al*. Selection of white oat genotypes for contrasting fungicide management conditions. **Brazilian Agricultural Research**, v. 58, p. e03084, 2023.

CORAZZA, T. *et al*. Genetic parameters and multi-trait selection of white oats for forage. **Genetics and Molecular Research**, v. 20, p. 1, 2021.

CRUZ, C. D.; CARNEIRO, P. C. S.; REGAZZI, A. J. **Biometric Models applied to genetic improvement**. 3. ed. Viçosa: UFV, 2014. p. 688.

KEHL, K. *et al*. Strategic positioning of soybean based on the agronomic ideotype and on fixed and mixed multivariate models. **Brazilian Agricultural Research**, v. 57, e02702, 2022.

KOHONEN, T. **Self-organizing maps. Number 30 in springer series in information sciences**. 3. ed. Berlin: Springer-Verlag, 2001.

LORO, M. V. *et al*. Strategic positioning of white oat genotypes in the organic system. **Scientia Agraria Paranaensis**, p. 336-345, 2021.

LORO, M. V. *et al*. Decomposition of white oat phenotypic variability by environmental covariates. **Brazilian Journal of Agriculture**, v. 97, n. 3, p. 279-302, 2022.

MANTAI, R. D. *et al*. Nitrogen management in the relationships between oat inflorescence components and productivity. **Brazilian Journal of Agricultural and Environmental Engineering**, v. 24, p. 385-393, 2020.

MEIRA, D. *et al*. Multivariate analysis revealed genetic divergence and promising traits for indirect selection in black oat. **Brazilian Journal of Agricultural Sciences**, v. 14, n. 4, p. 1-7, 2019.

MELO, A. V. *et al*. Agronomic performance of maze genotypes subjected to water stress in the south of the state of Tocantins. **Brazilian Maze and Sorghum Magazine**, v. 17, n. 2, p. 177-189.

MILBORROW, S. **rpart.plot: Plot 'rpart' models**: an enhanced version of 'plot.rpart'. R package version 3.1.1, 2022. Available in: https://CRAN.R-project.org/package= rpart.plot. Access in: 31 out. 2023.

R CORE TEAM. **R**: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2023. Available in: https://www.R-project.org. Access in: 31 out. 2023.

SAH, R. P. *et al*. Impact of water deficit stress in maize: phenology and yield components. **Scientific Reports**, v. 10, n. 2944, p. 1-15, 2020.

SCHMIDT, A. L. *et al*. Organic system and reflections on white oat grain productivity components. **Agronomy Science and Biotechnology**, v. 9, p. 1-12, 2023.

SILVA JÚNIOR, A. C. D. *et al*. Computational intelligence to study the importance of characteristics in flood-irrigated rice. **Acta Scientiarum. Agronomy**, v. 45, 2023.

SHIMIZU, G.; MARUBAYASHI, R.; GONCALVES, L. **AgroR**: experimental statistics and graphics for agricultural sciences. R package version 1.3.5, 2023. Available in: https://CRAN.R-project.org/package=AgroR. Access in: 31 out. 2023.

THERNEAU, T.; ATKINSON, B. **rpart**: recursive partitioning and regression trees. R package version 4.1.19, 2022. Available in: https://CRAN.R-project.org/package=rpart. Access in: 31 out. 2023.

TRETER, R. J. R. *et al*. Agronomic performance of white oats in organic system in the northwest region of Rio Grande do Sul. **Agronomy Science and Biotechnology**, v. 9, n. 1, p. 1-11, 2023.

WEHRENS, R.; KRUISSELBRINK, J. Flexible self-organizing maps in Kohonen 3.0. **Journal of Statistical Software**, v. 87, n. 7, p. 1-18, 2018.

WICKHAM, H. **ggplot2**: elegant graphics for data analysis. New York: Springer-Verlag, 2016.

* Revisão de Língua Inglesa: Carina Coelho[8]
http://lattes.cnpq.br/5071919170716761

Submetido em: **31/10/2023**

Aceito em: **08/07/2024**

[8] E-mail: carinacoelho89@gmail.com