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Prediction of grain diameter and grain mass in white oat using morphological and phytosanitary variables

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ABSTRACT

This study aimed to evaluate the possibility of predicting grain diameter and grain mass in white oat using morphological and phytosanitary variables. A total of 478 white oat lines were evaluated in the municipality of Augusto Pestana, Rio Grande do Sul, Brazil. The lines were sown on April 23, 2023, using an augmented block design. After flowering, leaf rust (LR, %), stem rust (SR, %), and leaf spot (LS, %) were assessed. At physiological maturity, lodging (LOD, %) was evaluated, and ten plants were collected to measure plant height (PH, cm), grain diameter (GD, mm), hundred grain mass (HGM, g), and grain mass (GM, g). Pearson correlation coefficients were calculated, with significance determined by Student's *t*-test at the 5% level, and a correlation network was constructed. Regression tree analysis was used to predict GD and GM. The results indicated that these variables can be predicted based on morphological traits. Hundred grain mass was the main determinant of grain diameter, whereas plant height and hundred grain mass determined grain mass. Phytosanitary variables showed low predictive contribution in the models used, reinforcing the importance of selecting more efficient and productive genotypes under field conditions.

Keywords: *Avena sativa* L; machine learning; regression tree; indirect selection.

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INTRODUCTION

White oat (*Avena sativa* L.) is a cereal of considerable importance in both human and animal nutrition, recognized for its nutritional and agronomic properties. This grass species is valued for its high content of fiber, protein, and phenolic compounds, which may promote cardiovascular health, aid in the regulation of cholesterol levels and diabetes, and contribute to intestinal health.[1] From an agronomic perspective, white oat stands out for its versatility of uses and its tolerance to acidic soils, while also contributing to improvements in soil quality.[2]

White oat production in Brazil increased from 376,841 hectares cultivated in 2017 to 545,402 hectares in 2024.[3] Despite a significant 144.7% increase in production, productivity remains limited, mainly due to disease incidence. In addition, according to the Brazilian Oat Research Commission (CBPA), the industrial quality of the grains is directly related to the percentage of those with a thickness greater than 2 mm; it is recommended that at least 75% of the grains meet this specification to satisfy industry requirements.[4]

Breeding programs in Brazil have focused on increasing yield potential, improving oat grain quality, and enhancing disease tolerance.[5] To achieve this, it is necessary to identify the main morphological and phytosanitary variables that determine grain diameter and grain mass. This enables the development of strategies for indirect selection and the creation of new genotypes that meet the established ideotype. The study of these relationships requires the use of predictive statistical methodologies, such as linear correlation and regression tree algorithms.

In white oat, positive correlations have been observed between plant height and grain yield components, suggesting that taller plants tend to exhibit greater yield potential.[6] Lodging is associated with reduced grain yield.[7] Stem rust, leaf rust, and leaf spot are the main diseases affecting white oat. Studies have reported substantial grain yield losses, ranging from 10 to 50%, due to the severity of leaf rust,[8-10] leaf spot,[11] and stem rust.[12] Understanding the relationships among these variables can provide a basis for the indirect selection of genotypes with higher grain quality and yield potential. In this context, this study aimed to evaluate whether it is possible to predict grain diameter and grain mass in white oat using morphological and phytosanitary variables.

MATERIAL AND METHODS

A total of 478 white oat lines were evaluated in the municipality of Augusto Pestana, located at geographic coordinates 28°00′14″ S and 52°00′22″ W, in the state of Rio Grande do Sul, Brazil. The experimental area is characterized predominantly by a typical Dystroferric Red Latosol.[13] The white oat lines were sown on April 23, 2023, and the experiment was conducted using an augmented block design. The cultivars URS Olada, URS Altaneira, and IPR Artêmis were included as checks, each with four replications, distributed in the experiment to allow comparison with the evaluated lines.

The experimental plots consisted of five rows, each 5 m in length, spaced 0.18 m apart, totaling a usable area of 4.50 m^2 per plot. Sowing was performed at a density of 50 viable seeds per linear meter. Basal fertilization consisted of the application of 300 kg ha^{-1} of the formulated fertilizer 05-20-20 (N-P-K) at sowing. Nitrogen topdressing was carried out with the application of 200 kg ha^{-1} of urea (45% N) at the beginning of plant tillering. Phytosanitary management was conducted through the application of insecticides in all plots to minimize pest effects and ensure greater reliability of the experimental results. The crop was cultivated without the application of fungicides.

After flowering, the following phytosanitary variables were evaluated: leaf rust (LR, %), stem rust (SR, %), and leaf spot (LS, %). These variables were assessed by assigning scores on a numerical scale ranging from 0 to 10, which were subsequently converted into percentage values. This procedure is widely used in visual assessments of phenotypic variables, as it allows for the standardization of estimates and facilitates data interpretation and statistical analysis, as described for diagrammatic scales such as the Horsfall-Barratt et al.[14] scale.

At physiological maturity, the percentage of lodging (LOD, %) was evaluated. Lodging was assessed by assigning scores on a numerical scale ranging from 0 to 10, which were subsequently converted into percentage values. Subsequently, ten plants per plot were randomly collected to evaluate plant height (PH, cm), grain diameter (GD, mm), hundred grain mass (HGM, g), and grain mass (GM, g).

Tertiles were calculated for the variables GD and GM. Initially, the mean values of PH, LR, SR, LS, LOD, HGM, and GM were computed for the lines belonging to the first

and third tertiles of GD. Subsequently, the same approach was applied to PH, LR, SR, LS, LOD, GD, and HGM, considering the tertiles corresponding to GM. To compare the means between the first and third tertiles, Student's *t*-test at the 5% significance level was used for each variable.

Based on the evaluated phytosanitary and morphological variables, Pearson's linear correlation coefficients were calculated for all pairs of variables, with significance assessed using Student's *t*-test at the 5% level. Subsequently, a correlation network was constructed among the variables. A regression tree algorithm was used to predict GD (y) as a function of PH, LR, SR, LS, LOD, HGM, and GM, and to predict GM (y) as a function of PH, LR, SR, LS, LOD, GD, and HGM. Predictions were made using the CART algorithm with a regression tree approach. All analyses were performed using R software.[15] The rpart, rpart.plot, and caret packages were used.

RESULTS AND DISCUSSION

The comparison between the low and high GD groups indicated a significant difference for GD ($\Delta = 0.665$; $p < 0.05$), confirming adequate stratification (Table 1). Among the remaining variables, significant differences were observed for LR ($\Delta = 1.647$; $p < 0.05$) and HGM ($\Delta = 0.296$; $p < 0.05$), both showing higher mean values in the high GD group. For PH, SR, LS, LOD, and GM, no statistically significant differences were observed ($p > 0.05$), although PH showed a reduction in the high GD group ($p = 0.091$). Thus, higher GD values were associated with increases in LR and HGM, without consistent changes in the other evaluated variables. The positive association between GD and HGM reinforces the importance of components related to grain filling, which are key determinants of oat industrial quality, as highlighted by the Brazilian Oat Research Commission,[4] which establishes minimum thickness criteria for industrial acceptance.

The comparison between the low and high GM groups showed a significant difference only for GM itself ($\Delta = 0.758$; $p < 0.05$), confirming adequate group separation. For the remaining variables (PH, LR, SR, LS, LOD, GD, and HGM), no statistically significant differences were observed ($p > 0.05$). Although HGM showed a tendency toward a higher mean in the high GM group ($p = 0.075$), this difference was not statistically confirmed. Thus, contrasting levels of GM did not result in consistent changes in the other evaluated variables.

Table 1. Comparison of the analyzed means between the groups corresponding to the first [(P)] and third [(T)] tertiles of the variables grain diameter (GD, mm) and grain mass (GM, g), including the mean difference (Δ), *p*-value from Student's *t*-test, and significance (sig) for the comparison between groups of white oat lines from the F6 generation

Variables[(1)]	GD[(P)]	GD[(T)]	Δ	p-value	sig
GD	2.633	3.298	0.665	0.000	*
PH	101.966	100.128	-1.838	0.091	ns
LR	0.472	2.119	1.647	0.002	*
SR	0.155	0.194	0.038	0.699	ns
LS	6.239	5.256	-0.983	0.165	ns
LOD	3.245	2.938	-0.308	0.760	ns
HGM	3.036	3.332	0.296	0.000	*
GM	1.065	1.000	-0.065	0.157	ns
Variables	**GM[(P)]**	**GM[(T)]**	**Δ**	**p-value**	**sig**
GM	0.680	1.438	0.758	0.000	*
PH	101.755	100.598	-1.157	0.305	ns
LR	1.683	1.131	-0.552	0.322	ns
SR	0.149	0.356	0.207	0.233	ns
LS	5.211	5.253	0.042	0.951	ns
LOD	2.795	4.578	1.783	0.113	ns
GD	2.976	2.943	-0.033	0.396	ns
HGM	3.139	3.236	0.098	0.075	ns

[(1)] Plant height (PH, cm), leaf rust (LR, %), stem rust (SR, %), leaf spot (LS, %), lodging (LOD, %), and hundred-grain mass (HGM, g).

The results of Pearson's linear correlation indicated that GD was positively correlated with HGM and negatively correlated with PH and LS (Figure 1). This indicates that an increase in HGM promotes an increase in GD, whereas taller plants and those with higher LS incidence exhibit reduced GD. These findings are consistent with previous studies reporting associations between morphological traits and yield components, such as Kebede et al.[6] who observed a positive relationship between plant height and productive traits; however, in the present study, the relationship with GD was negative, Brunava et al.,[16] also observed that taller plants do not necessarily exhibit higher productive performance.

The GM showed a positive relationship with HGM and LOD and a negative relationship with PH and LS. This suggests that plants with higher HGM and lower PH and LS tend to exhibit greater productive performance. Therefore, among the phytosanitary variables, LS can be considered the main disease associated with the reduction of GD and GM. These results are consistent with the findings of Berlezzi et al.[17] who reported that leaf rust reduces grain yield in white oat.

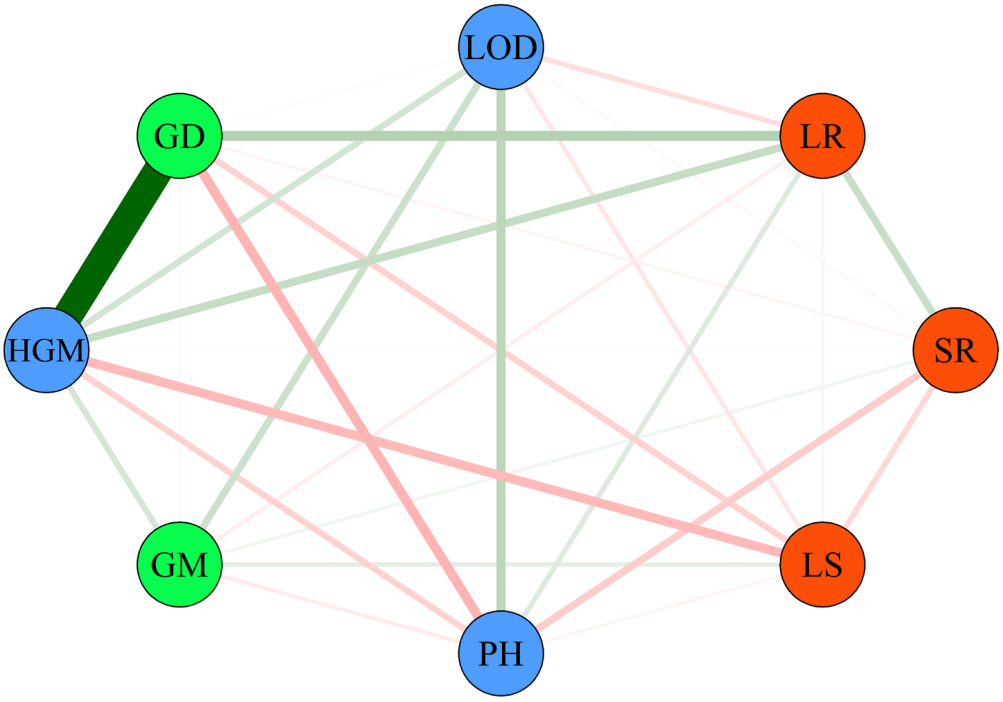


Figure 1. Pearson's linear correlation network among the variables plant height (PH, cm), leaf rust (LR, %), stem rust (SR, %), leaf spot (LS, %), lodging (LOD, %), grain diameter (GD, mm), hundred grain mass (HGM, g), and grain mass (GM, g), evaluated 478 from the F6 generation lines and three white oat check cultivars. The red lines represent negative linear correlations between the traits, while the green lines represent positive linear correlations. Line thickness reflects the magnitude of the coefficients: thin lines correspond to weaker correlations, whereas thicker lines indicate stronger correlations.

The variables HGM, GM, and PH, in this order, showed the greatest importance for predicting GD, whereas PH and HGM, in this order, were the most important for predicting GM (Figure 2). These results reinforce the importance of morphological traits as indirect selection criteria.[5] This indicates that, when selecting white oat genotypes for greater GD, HGM should be considered simultaneously. Similarly, to develop genotypes with higher GM, PH should be considered indirectly.

When HGM was lower than 2.2 g, GD values were reduced, with an overall mean of 2.28 mm (Figure 3). At this node, GM exerted an additional influence, such that GM values lower than 0.621 g resulted in the lowest observed mean GD (1.84 mm), whereas GM values equal to or greater than 0.621 g increased the mean GD to 2.52 mm. When HGM was equal to or greater than 2.2 g, the values of the response variable increased substantially. At this node, HGM values lower than 2.91 g resulted in a mean GD of 2.79 mm, whereas HGM values equal to or greater than 2.91 g showed the highest observed mean GD (3.04 mm). These results indicate that higher HGM values are associated with consistent increases in GD, whereas GM has a secondary effect, acting only under conditions of low HGM. The association between GD and HGW was expected, given that greater starch accumulation in the grains tends to promote higher HGW and, consequently, higher GD. The mean squared error of the GD prediction was 0.27 mm, and that of the leave-one-out cross-validation was 0.29 mm.

The PH was the most relevant variable in the first split of the model (Figure 4). Shorter plants showed greater productive performance, which may be related to lower susceptibility to lodging, as discussed by Liu et al.[7] who demonstrated the influence of lodging on oat yield. The plants with the highest GM (1.61 g) were those with PH lower than 118 cm and HGM greater than 4.03 g. It was observed that PH values equal to or greater than 118 cm resulted in the lowest GM values (0.756 g). When PH was lower than 118 cm, HGM began to influence the response variable. Thus, HGM values lower than 4.03 g were associated with a mean GM of 1.04 g. In contrast, HGM values equal to or greater than 4.03 g resulted in the highest observed mean (1.61 g). These results indicate that, under conditions of lower PH, increases in HGM are associated with substantial increases in GM. The root mean square error for GM prediction was 0.39 g, and that of the leave-one-out cross-validation was 0.42 g.

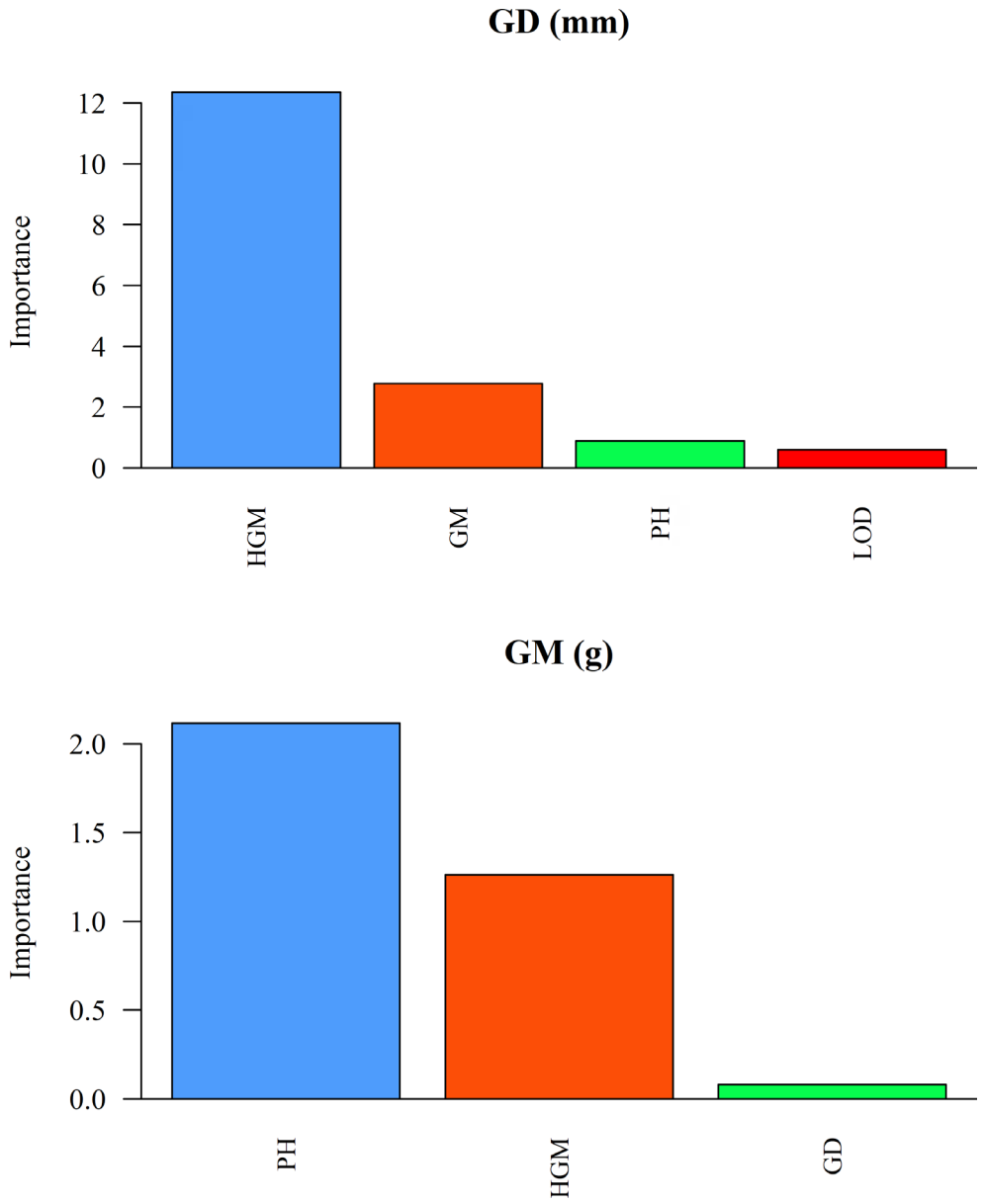


Figure 2. Relative importance of the variables plant height (PH, cm), leaf rust (LR, %), stem rust (SR, %), leaf spot (LS, %), lodging (LOD, %), grain diameter (GD, mm), hundred-grain mass (HGM, g), and grain mass (GM, g) for predicting grain diameter (GD, mm) and grain mass (GM, g), evaluated 478 from the F6 generation lines and three white oat check cultivars.

The results obtained have relevant implications for white oat breeding, particularly in defining criteria for the indirect selection of superior genotypes. The strong association between grain diameter and hundred grain mass indicates that this variable can be used to indirectly select plants with higher industrial quality. Plant height proved to be a determinant for predicting grain mass, indicating that shorter genotypes tend to exhibit greater productive performance and lower susceptibility to lodging, the results corroborate the study by Kaspary et al.[18]

Phytosanitary variables showed a low contribution to the prediction of grain diameter and grain mass. However, leaf spot stood out as the main factor associated with the reduction of these variables, highlighting its negative effect on productive performance. This result reinforces the importance of both phytosanitary management and the selection of genotypes with greater disease tolerance.[8-12] Therefore, these findings enable a more efficient and targeted selection process.

CONCLUSION

Grain diameter and grain mass in white oat can be predicted based on morphological variables.

Hundred grain mass is the main variable determining grain diameter. Plant height and hundred grain mass are the main variables determining grain mass.

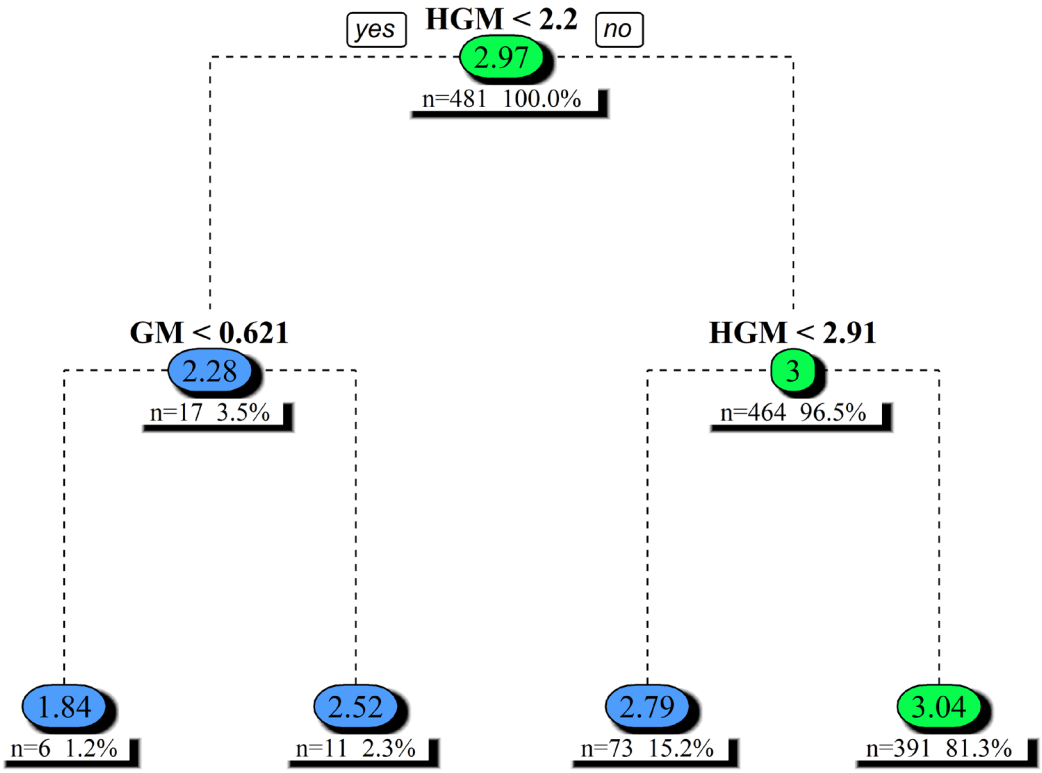


Figure 3. Regression tree algorithm for predicting grain diameter using the variables plant height (PH, cm), leaf rust (LR, %), stem rust (SR, %), leaf spot (LS, %), lodging (LOD, %), hundred grain mass (HGM, g), and grain mass (GM, g), evaluated 478 from the F6 generation lines and three white oat check cultivars.

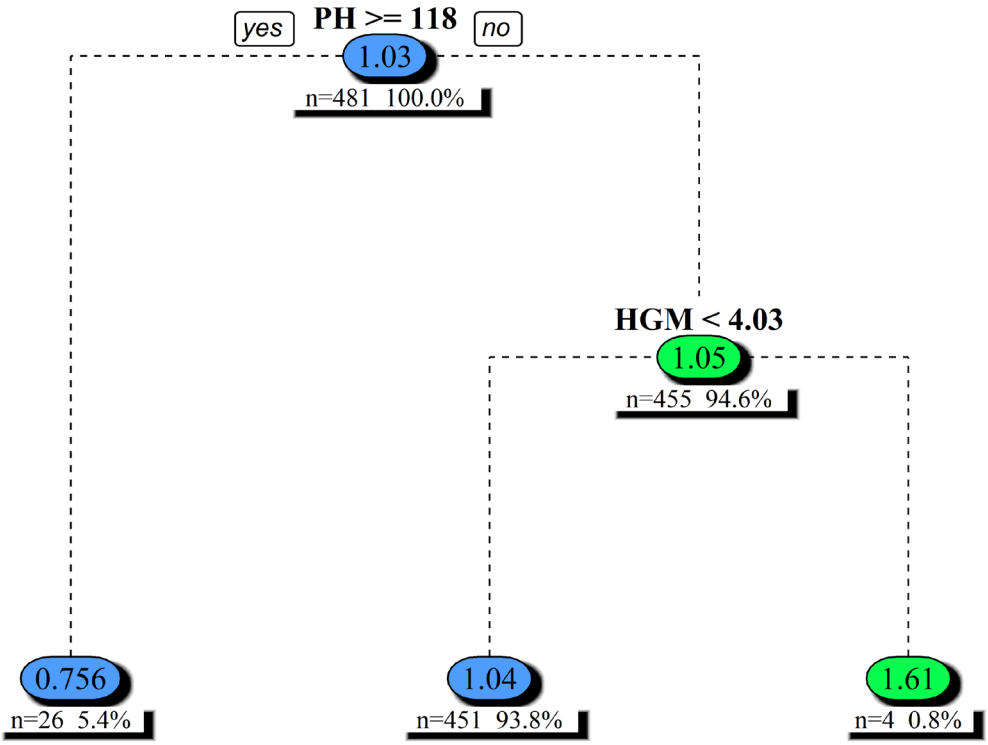


Figure 4. Regression tree algorithm for predicting grain mass (GM) using the variables plant height (PH, cm), leaf rust (LR, %), stem rust (SR, %), leaf spot (LS, %), lodging (LOD, %), grain diameter (GD, mm), and hundred-grain mass (HGM, g), evaluated 478 from the F6 generation lines and three white oat check cultivars.

Phytosanitary variables showed low contribution to the prediction of grain diameter and grain mass.

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The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

All datasets supporting the conclusions of this study are available upon request to the corresponding author.

AUTHOR CONTRIBUTIONS

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Project administration: Ivan Ricardo Carvalho.

Software: Murilo Vieira Loro, Ivan Ricardo Carvalho.

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