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Anatomical traits and structural components of peduncle associated with lodging in *Avena sativa* L.

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Abstract. Lodging dramatically reduces the yield of cereals and increases the difficulty of mechanical harvesting. Because it is a complex phenomenon, new cultivars with genetic resistance to lodging is a sustainable alternative in agricultural production systems. This resistance is associated with a combination of factors, such as stem thickness and stiffness, being closely linked to anatomical traits and structural carbohydrates present in the stem. In the present study we compared, under field conditions, eight contrasting oat cultivars in terms of lodging resistance. Our aim in this study was to investigate the association of anatomical traits and structural components of the peduncle with resistance to lodging, aiming to assist in the plant selection process. In addition, a second objective was to understand the genetic dissimilarity among oat cultivars according to the characters studied. Some characteristics for potential indirect selection were studied in this work and if correlated with lodging can be used to identify superior genotypes. From the anatomical point of view, the correlation obtained between the internal vascular bundle and the lodging resistance factor allowed us to confirm that this trait can be used in indirect selection to lodging resistance. The structural components of peduncle, in the two ways explored in the present study, comparison of mean and correlation, did not demonstrate the potential to be used exclusively as plant selection characters traits for lodging resistance. There is noticeable variability in oat cultivars for most stem traits.

Key words: cereal, indirect selection, genetic variability, oat.

INTRODUCTION

In agricultural production of cereals, lodging is a serious problem, and can drastically reduce yield, cause decreased qualitative parameters and increase difficulty of mechanical grain harvesting (Packa et al., 2015). Lodging is defined as the displacement of the stem from its vertical position (Pinthus, 1974).

The effects of lodging are increased by environment and mannagement, such as rain, strong winds, high levels of fertilization (mainly nitrogen) (Kangor et al., 2010), population densities of plants above the recommendation, intrinsic characteristics of the genotypes, as well the stage of development of the plant when subjected to lodging stress (Khobra et al., 2019). The lodging generates unfavorable conditions for plant growth, limiting the plant's access to light and air, obstructing photoassimilation and respiration, and contributing to the proliferation of pathogens (Ingver et al., 2010; Packa et al., 2015). In severe cases, lodging can block the transport of water, minerals and photoassimilates, leading to declines in grain yield (Berry & Spink, 2012; Mulsanti et al., 2018). Furthermore, lodging reduces quality of cereals produced (Berry et al., 2004; Shah et al., 2017).

Lodging resistance is associated with a combination of thickness and stiffness of stem (Ookawa et al., 2010). In this sense, morphological, anatomical traits and structural components of the stem, with emphasis on weight and diameter, concomitantly with short stature, thick walls and a high number of vascular bundles, are characteristics of cultivars with more resistance to lodging (Zuber et al., 1999). Nevertheless, it has been reported that stem stiffness is related to the main cellular components, such as cellulose, hemicellulose, lignin, silica and starch (Sato, 1957; Li et al., 2008). The lack of general associations of anatomical characters of the stem with lodging, confirms the complex nature of this phenomenon (Kelbert et al., 2004). Production of oats as well as production of other cereal grains such as wheat and barley serving as human food and animal feed are affected by lodging.

In the present study, conducted under field conditions, we compared the anatomical and structural of the stem of eight oat cultivars differing in resistance to lodging. Our objective in this study was to investigate the association of anatomical characters and structural components of the peduncle with resistance to lodging, aiming to assist in the process of plant selection.

MATERIALS AND METHODS

Plant material

Eight oats (*Avena sativa* L.) cultivars were evaluated for lodging resistance (Table 1). The data presented were obtained from the Brazilian Commission for Oat Research (2017), on average from 18 sites in the states of Rio Grande do Sul, Santa Catarina and Paraná (Brazil).

Table 1. Agronomy characters of cultivars of oats used in the study of lodging resistance

Cultivar	Height (cm)	Cycle[2] (days)	LO[3] (%)
FAEM 5 Chiarasul	117	128	42
UPFA Gaudéria	117	129	39
FAEM 4 Carlasul	117	129	39
Brisasul	110	133	33
URS Brava	127	130	31
IPR Afrodite	114	133	25
URS Altiva	120	128	15
URS Taura	101	128	15

Fonte: Lângaro et al. (2017); [2]Time from emergence to maturation; [3]Lodging occurence.

Experiment site

The experiment was conducted in the experimental field of the Faculty of Agronomy and Veterinary Medicine

(FAMV) of the University of Passo Fundo (UPF), in the municipality of Passo Fundo / RS (28º 15 '46 ”S, 52º 24' 24” W), from May to November 2018. The soil of the region is classified as humic dystrophic Red Latosol (Santos et al., 2018). The soil samples from the study site were collected from 0–20 cm depth and have the following chemical characteristics: clay = 45%; pH (H_2O) = 5.2; pH SMP = 5.6; P (mg dm^{-3}) = 29.8; K (mg dm^{-3}) = 182; organic matter = 2.9%.

The climate is humid subtropical according to the Köppen-Geiger classification (Moreno, 1961), with an average annual rainfall of 1,746 mm and temperature of 20 °C. Precipitation and wind speed for the period of the experiment were obtained from the experimental station of the Brazilian Agricultural Research Corporation (Embrapa), National Wheat Research Center, Passo Fundo, Rio Grande do Sul, Brazil (Fig. 1).

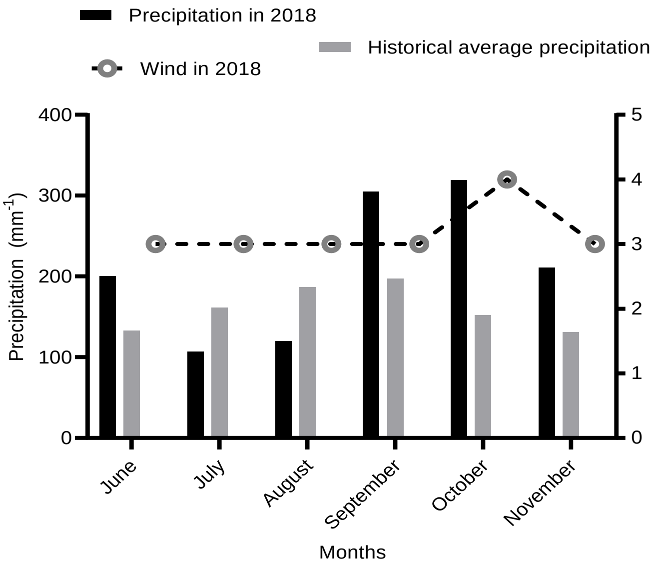

Figure 1. Monthly rainfall and average wind speed in the experimental period and climatological normals. Passo Fundo, Rio Grande do Sul, Brazil, 2020.
Source: Embrapa Wheat.

Experimental design

The treatments were eight cultivars of oats (Table 1), arranged in a randomized complete block design, with three replications. The experimental units consisted of plots of five rows and five meters in length, with a spacing of 0.17 m between rows and 0.40 m between plots.

Procedure

The site was desiccated fifteen days before the sowing of the experiment with 2 L ha^{-1} of glyphosate (Roundup Original®) + 1.5 L ha^{-1} of 2,4-D (Aminol®) + 0.5 L ha^{-1} of clethodim (Select 240®) and two days before sowing 2 L ha^{-1} of paraquat (Gramoxone). The experiment was conducted in a field with soybean [*Glycine max* (L.) Merr.] as the previous crop. The sowing rate was 300 seeds m^{-2}. Cultural treatments were carried out with reference to the phenological stages of oats (Zadoks et al., 1974). The fertilization used at sowing was 10 kg ha^{-1} N, 40 kg ha^{-1} P_2O_5, and 40 kg ha^{-1} K_2O. Nitrogen (N) was applied in the form of urea at growth stage 25 (30 kg N ha^{-1}) and at the beginning of stage 31 (15 kg N ha^{-1}). At the end of growth stage 25, 1.5 L ha^{-1} of 2,4-D (Aminol®) was used for weed control. The plots were treated with 0.8 L ha^{-1} of epoxiconazole + fluxapyroxad + pyraclostrobin (Ativum®), at growth stages 41, 61 and 70 (Zadoks et al., 1974) to control *Puccinia coronata* var. *avenae*, *Drechslera avenae* and *Puccinia graminis* f. sp. *Avenae*.

Anatomical characters and structural components of peduncle

The evaluations of peduncle characteristics occurred at the phenological stage 70 (Zadoks et al., 1974). For the evaluations, ten main stems of each cultivar cultivar were evaluated from each replication. Six anatomical traits and four structural components of peduncle and resistance to lodging were evaluated: a) neutral detergent fiber; b) acid detergent fiber; c) hemicellulose; d) lignin; e) length of the sclerenchyma over the internal vascular bundle; f) length of the sclerenchyma over the external vascular bundle; g) external vascular bundle; h) parenchyma; i) internal vascular bundle; j) sclerenchyma up to the medullary cavity.

For the evaluation of the structural components of the peduncle wall, an analysis of the neutral detergent fiber (NDF) and acid detergent fiber (ADF) content was obtained by the methods of Van Soest et al. (1991). Hemicellulose (HEM) was obtained through a difference between the levels of NDF and ADF. The determination of the lignin content (LIG) was determined by the sequential method of Van Soest (1991), in ten stems of the main stem for each cultivar.

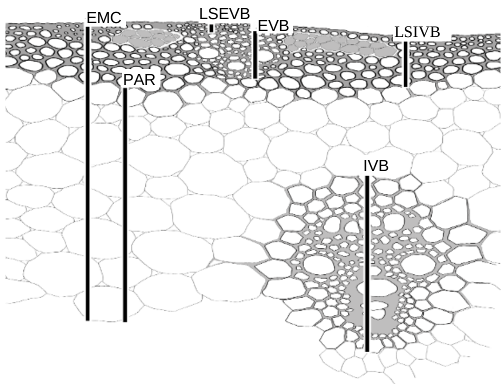

Figure 2. Scheme of the cross section of a oat stem and measured anatomical traits. Passo Fundo, Rio Grande do Sul, Brazil, 2020.

*LSIVB: length of sclerenchyma over the internal vascular bundle; LSEVB: length of sclerenchyma over the external vascular bundle; EVB: external vascular bundle; PAR: parenchyma; IVB: internal vascular bundle; EMC: sclerenchyma up to the medullary cavity.

To observe the anatomical structure inside the peduncle (Fig. 2), the middle portions of the stem tissue were used. After collecting the peduncles, they were immediately fixed in FAA (formaldehyde = 5 mL; acetic acid = 5 mL; ethyl alcohol = 90 mL). 70 for 48 h and, subsequently, preserved in 70° GL ethanol (Johansen, 1940). Anatomical cuts were made freehand, transversely from the median portion of the peduncle, later stained with a combination of fuchsin and alcian blue (Luque et al., 1996) and assembled with 50% glycerin.

Resistance of stem to lodging

To evaluate the stem resistance, the main stem was evaluated for lodging resistance factor (cLr): it was determined by the formula proposed by Grafius & Brown (1954):

$$cLr = \frac{F}{b}$$

where ‘F’ is the weight in grams, of the part that was suspended, of a chain with 0.5 g per link, with two links per centimeter, attached at the base of the panicle and ‘b’ is the height of the stem (cm), measured from the base of the plant to the base of the panicle.

The number of links was defined as the point at which the stem interrupted its downward movement, thus establishing a balance between resistance to torque and the torque that tended to cause lodging. In order to reach the value of the coefficient of stem resistance to lodging, the number of links in the chain was counted and multiplied by the weight of the links. Subsequently, the stem length was measured. In this index, the weight of the stem, leaves and panicle are excluded by deposition, since the plant under field conditions is fully capable of supporting its own weight.

Statistical analysis

Analysis of variance (ANOVA) was used, and in case of significant difference, the Tukey test was applied at 5% probability of error for comparisons between means. The normality and homogeneity of variances of the data were verified by the Shapiro-Wilk and the Bartlett test, with no need to transform the data for the variables under study. The data were submitted to Pearson's correlation analysis. The magnitudes of correlation coefficients were classified as $r = 0$ was considered null; $r = 0$ to 0.30 was considered weak; $r = 0.30$ to 0.60 was considered average; $r = 0.60$ to 0.90 was considered strong; $r = 0.90$ to 1 was considered very strong and $r = 1$ was considered perfect.

The cluster analyses used to assess genetic variability were performed using the hierarchical clustering methods. The analysis was performed for the anatomical traits and structural components of the peduncle, by generating the Mahalanobis distance matrix (D^2). The illustration of the (dis)similarity among cultivars was performed using a dendrogram. The number of groups was defined by the Mojena (1977) procedure, based on the relative size of distances in the dendrogram. For the variables, the relative contribution of the characters to genetic divergence was obtained, by the method of Singh (1981). For data analysis, the statistical program GENES (Cruz, 2016) was used.

RESULTS AND DISCUSSION

There was a significant difference ($p < 0.05$) among cultivars for 10 of 11 characters. The variation coefficients were low, showing an acceptable experimental error (Table 2).

The lodging resistance factor was the index used to determine the resistance among cultivars (Figs 3, 4 and 5). This index is a predictor of the strength that the stem can support until the moment of flexion (Grafius & Brown, 1954; Kashiwagi et al., 2007). Over the years, studies with oats, wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) have demonstrated the reliability of the stem resistance coefficient as a means of indirect assessment of resistance to lodging (Norden & Frey, 1959; Cruz et al., 2001; Cruz et al., 2004; Hirano et al., 2017). For this index, the highest lodging resistance factor was demonstrated by cultivar URS Taura (0.34 g cm^{-1}); and, the lowest resistance was observed in the FAEM 4 Carlasul (0.18 g cm^{-1}), FAEM 5 Chiarasul (0.18 g cm^{-1}) and URS Brava (0.17 g cm^{-1}).

Table 2. Analysis of variance for the characters studied in eight cultivars of oats (*Avena sativa* L.). Passo Fundo, Rio Grande do Sul, Brazil, 2020

Source	DF	Mean square						
		NDF	ADF	HEM	LIG	LSIVB	LSEVB	EVB
Block	2	24.54	65.86	10.18	0.01	1,298.73	234.97	568.90
Cultivar	7	38.47*	104.18*	28.25*	2.58*	8,682.24*	559.38^{ns}	4,141.19*
Error	14	8.16	6.73	4.07	0.18	1,156.55	275.06	984.78
Average	-	69.23	40.42	28.81	6.38	284.02	158.21	468.95
CV (%)	-	4.13	6.42	7.00	6.59	11.97	10.48	6.69

Source	DF	Mean square			
		PAR	IVB	EMC	cLr
Block	2	116,805.62	4,435.91	100,026.47	0.00
Cultivar	7	1,308,605.02*	162,244.90*	1,418,488.03*	0.01*
Error	14	60,842.66	4714.18	49,891.42	0.00
Average	-	1,786.95	1,244.90	2,278.00	0.23
CV (%)	-	13.80	5.52	9.81	13.27

*significant at 5% probability by the F test. ns = not significant. NDF: neutral detergent fiber; ADF: acid detergent fiber; HEM: hemicellulose; LIG: lignin; LSIVB: length of sclerenchyma over the internal vascular bundle; LSEVB: length of sclerenchyma over the external vascular bundle; EVB: external vascular bundle; PAR: parenchyma; IVB: internal vascular bundle; EMC: sclerenchyma up to the medullary cavity; cLr: lodging resistance factor.

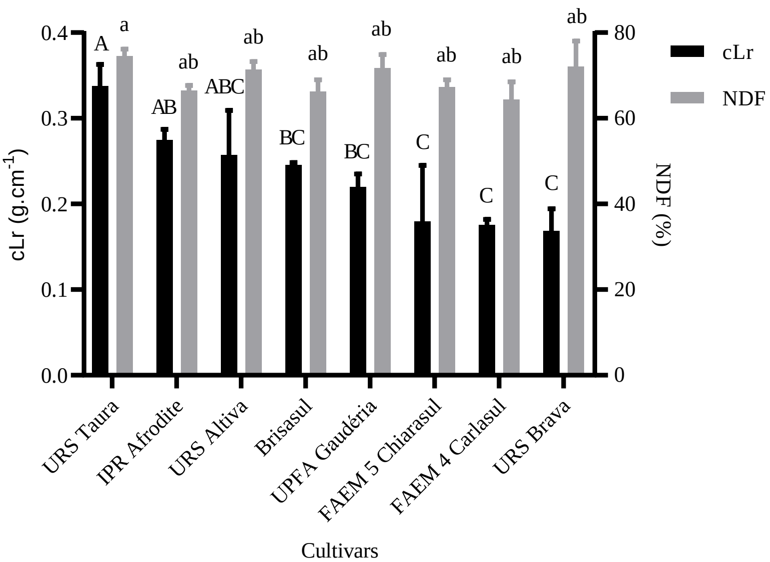

Figure 3. Structural components (cellulose + hemicellulose + lignin) through neutral detergent fiber of peduncle and lodging resistance factor. Passo Fundo, Rio Grande do Sul, Brazil, 2020.
*cLr: lodging resistance factor; NDF: neutral detergent fiber.

There are many analytical methods for measuring specific components of the cell wall (Jung, 1997). The structural components are made up of neutral detergent fiber (NDF) and acid detergent fiber (ADF). The NDF comprises the fraction composed of cellulose + hemicellulose + lignin (Fig. 3); the ADF is composed of cellulose + lignin (Fig. 4) (Van Soest, 1991). Hemicellulose, on the other hand, is obtained from the difference between the NDF and ADF fractions. In this sense, URS Taura presented greater resistance in relation to the other cultivars, as well as higher content of NDF and ADF, with 74.45 and 46.41% (Figs 3 and 4), respectively. For these structural components, the lowest levels were obtained for FAEM 4 Carlasul and FAEM 5 Chiarasul, 64.33% and 31.10%, respectively. Both cultivars showed low resistance to lodging (0.18 g cm^{-1}). The structural components of the peduncle do not prove to be parameters for identifying genotypes in terms of lodging resistance.

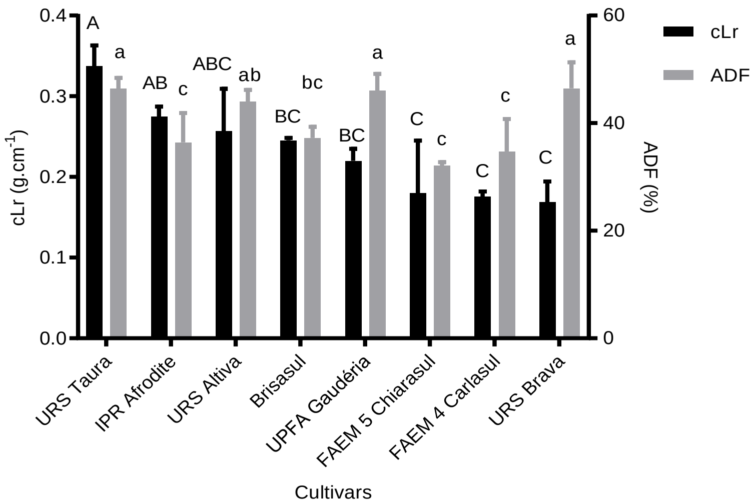

Figura 4. Structural components (cellulose + lignin) through the acid detergent fiber in the peduncle and lodging resistance factor. Passo Fundo, Rio Grande do Sul, Brazil, 2020.
*cLr: lodging resistance factor; ADF: acid detergent fiber.

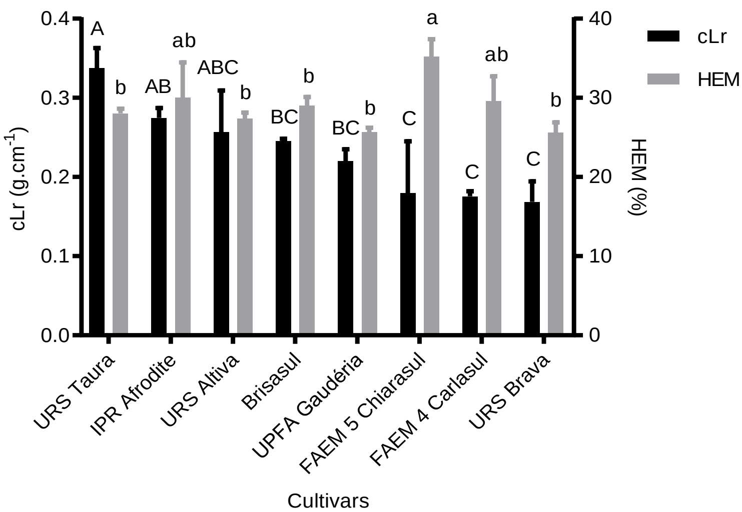

Figure 5. Peduncle hemicellulose and lodging resistance factor. Passo Fundo, Rio Grande do Sul, Brazil, 2020.
*cLr: lodging resistance factor; HEM: hemicellulose.

For the hemicellulose character the cultivar URS Taura show a distinct tendency (Fig. 5) than for ADF and NDF. The cultivar FAEM 5 Chiarasul showed higher levels for this character (35.20%), in addition to low lodging resistance. The lowest content of this character was obtained with URS Brava (25.58%), concomitant with the lowest lodging resistance factor (0.17 g cm^{-1}). The structural components of the stem are formed by cellulose, hemicellulose and lignin that play a significant role in stem resistance to lodging, as they constitute the cell wall of vegetables (Wang et al., 2006; Kong et al., 2013). In wheat, higher levels of lignin and hemicellulose increased stem resistance and reducing lodging (Berry et al., 2003). In contrast, in this study, the levels of hemicellulose (Fig. 5) and lignin (Fig. 6) were higher for cultivar FAEM 5 Carlasul and its lodging resistance factor was lower than other cultivars.

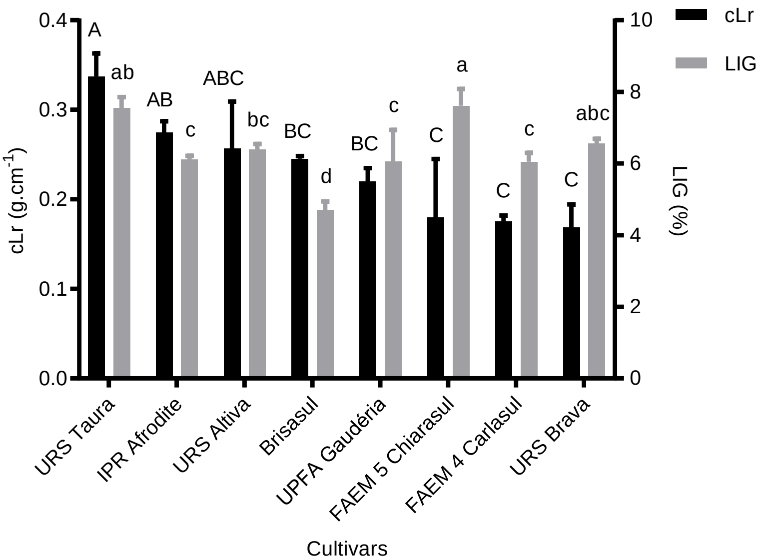

Figure 6. Peduncle lignin content and lodging resistance factor. Passo Fundo, Rio Grande do Sul, Brazil, 2020.

*cLr: lodging resistance factor; LIG: lignin.

For lignin (Fig. 6), cultivars FAEM 5 Chiarasul, URS Taura and URS Brava presented the highest levels with values of 7.61%, 7.55% and 6.56%, respectively; already, the lowest value was obtained for the cultivar Brisasul (4.70%). The lignin content showed a negative correlation with the sclerenchyma length over the internal vascular bundle (Table 4). In wheat, lignin was strongly correlated with stem diameter, wall thickness and stem lodging resistance index (Kamran et al., 2018). This reinforces the idea that the lignin content is correlated with the resistance to lodging, as it provides rigidity and mechanical support determining the stem physical strength; low levels of these components weaken it (Berry et al., 2003; Ookawa et al., 2014; Dorairaj & Ismail, 2017). The correlation between stem strength and lignin suggests that genotypes with greater lignin accumulation can be used in breeding programs in order to develop cultivars that are more resistant to lodging (Peng et al., 2014; Shah et al., 2017). However, in the present study, the highest levels of lignin did not show an association with the lodging resistance factor (Fig. 6). The results obtained corroborate a study conducted on rice, in which the highest lodging resistance factor was not always obtained in cultivars with a higher lignin content (Okuno et al., 2014). Furthermore, in another study, with barley, it was shown that lignin and hemicellulose may also not be associated with resistance to lodging (Stanca et al., 1979). According to Ma (2009) the role of lignin and cellulose in resistance to lodging is not yet consistent for use in indirect selection for resistance to lodging.

The correlations between the evaluated characteristics are shown in Table 3. Among the evaluated traits, only the internal vascular bundle showed a significant correlation coefficient with the coefficient of stiff resistance to lodging (Table 3). In work with barley and wheat, there was no evidence of a correlation in the number of vascular bundles of basal internodes and resistance to lodging (Stanca et al., 1979; Zuber et al., 1999; Kong et al., 2013). Also in wheat, it was shown that large proportions of sclerenchymatic tissue are correlated with resistance to lodging (Wang et al., 2006). More recently, in rice, there was a positive correlation between internal and external vascular bundles and resistance to lodging (Zhang et al., 2016). Differences in correlations among characters can be attributed to the variability between cultivars used. Therefore, for each set of cultivars, an appropriate selection strategy must be chosen (Lúcio et al., 2013).

Table 3. Correlation coefficient among anatomical traits, structural components of peduncle and lodging resistance factor. Passo Fundo, Rio Grande do Sul, Brazil, 2020

	NDF	ADF	HEM	LIG	LSIVB	EVB	IVB	PAR	EMC
NDF	1								
ADF	0.90**	1							
HEM	-0.57	-0.87**	1						
LIG	0.46	0.11	0.33	1					
LSIVB	-0.21	0.00	-0.25	-0.78**	1				
EVB	0.01	-0.19	0.37	0.53	-0.11	1			
IVB	0.22	0.19	-0.11	0.05	0.53	0.68	1		
PAR	0.06	0.25	-0.41	-0.59	0.88**	-0.04	0.59	1	
EMC	0.12	0.30	-0.44	-0.55	0.87**	0.00	0.63	1.00**	1
cLr	0.42	0.34	-0.16	0.10	0.43	0.30	0.76*	0.35	0.40

** and * significant at 1 and 5% probability by t test.

*ADF: acid detergent fiber; HEM: hemicellulose; LIG: lignin; LSIVB: length of sclerenchyma over the internal vascular bundle; EVB: external vascular bundle; PAR: parenchyma; IVB: internal vascular bundle; EMC: sclerenchyma up to the medullary cavity; cLr: lodging resistance factor.

Based on the correlations obtained (Table 3), the internal vascular bundles of the peduncle are indicated for indirect selection aiming at lodging resistance. In addition, cultivars that are more resistant to lodging presented greater internal vascular bundle length compared to the most susceptible cultivars (Fig. 7). For this character, the cultivars URS Taura, IPR Afrodite and UPFA Gaudéria showed the highest thickness with values of 1,617.74 μm, 1,443.94 μm and 1,425.65 μm, respectively; already, the smaller thickness of the internal vascular bundles was found in URS Brava (954.92 μm).

Estimates of the relative contribution of the ten anatomical characters and structural components of peduncle to the genetic dissimilarity among the eight cultivars of oats were evaluated by the method of Singh (1981) and are shown in Table 4. The traits that contributed most to genetic divergence were neutral detergent fiber and hemicellulose totaling 89.37% of the genetic divergence among oats cultivars. Otherwise, the characters with the least contribution to genetic dissimilarity were sclerenchyma, lignin, length of sclerenchyma over the internal vascular bundle, internal vascular bundle, and lodging resistance factor, acid detergent fiber, external vascular bundle and parenchyma. The selection of genotypes for breeding based only on genetic divergence, without considering their traits of interest, can be an inefficient strategy in a breeding program (Carpentieri-Pípolo et al., 2000). Thus, in addition to the genetic dissimilarity for identifying parents, their performance *per see*, in specific environments, deserves greater attention (Nardino et al., 2017).

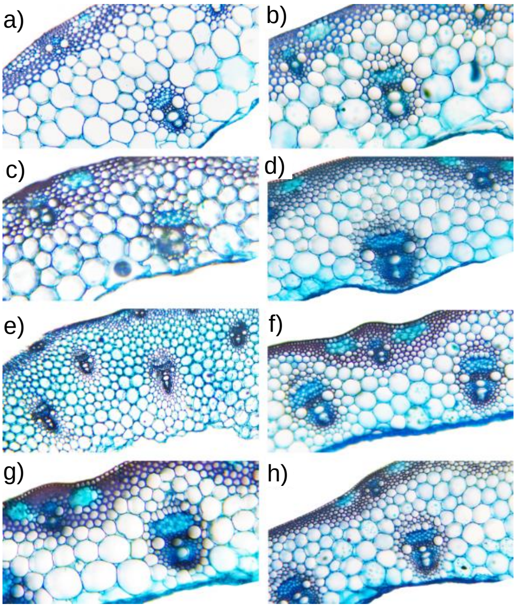

Figure 7. Cross section of the stem of eight cultivars of oats. Passo Fundo, Rio Grande do Sul, Brazil, 2020.

*a) Brisasul; b) FAEM 4 Carlasul; c) FAEM 5 Chiarasul; d) IPR Afrodite; e) UPFA Gaudéria; f) URS Altiva; g) URS Brava; h) URS Taura.

Tabela 4. Relative contribution of structural and anatomical components of peduncle to genetic dissimilarity (RCGD) among eight cultivars of oats, in decreasing order of importance by the method of Singh (1981), based on the values of Sj. Passo Fundo, Rio Grande do Sul, Brazil, 2020

Caractere[1]	Sj	RCGD (%)
NDF	50,984.69	65.22
HEM	18,881.30	24.15
EMC	3,190.62	4.08
LIG	2,601.77	3.33
LSIVB	1,819.55	2.3275
IVB	560.47	0.72
cLr	136.89	0.18
ADF	0	0
EVB	0	0
PAR	0	0

*NDF: neutral detergent fiber; HEM: hemicellulose; EMC: sclerenchyma up to the medullary cavity; LIG: lignin; LSIVB: length of sclerenchyma over the internal vascular bundle; IVB: internal vascular bundle; cLr: lodging resistance factor; ADF: acid detergent fiber; EVB: external vascular bundle; PAR: parenchyma.

Through hierarchical methods, it is possible to illustrate the formation of groups by means of dendrograms (Fig. 8). The Mahalanobis distance matrix (data not shown) revealed high amplitude in this measure of dissimilarity, between 37.17 to 949.37. The cultivars Brisasul and URS Taura were the most dissimilar (D^2 = 949.37), whereas FAEM 4 Carlasul and IPR Aphrodite were the most similar (D^2 = 37.17). The cofenetic correlation coefficient, which estimates the representativeness of data from the dendrogram dissimilarity matrix, revealed a magnitude of 0.72, which indicates that the the data of matrix showed a satisfactory adjustment in the graphical representation presented by the dendrogram (Fig. 8). The cofenetic correlation index, when greater than 0.70, indicates the adequacy of the method to the adopted dissimilarity matrix (Streck et al., 2017).

The UPGMA grouping method, using the averages of the distances between all pairs of cultivars for the formation of each group, allowed the formation of two distinct groups, with a higher concentration of cultivars in group I (75%), which were: group 1 (FAEM 4 Carlasul; IPR Aphrodite; URS Brava; URS Altiva; FAEM 5 Chiarasul; URS Taura); group 2 (UPFA Gaudéria; Brisasul). This type of distribution portrays the high similarity between genotypes (Kaur et al., 2018).

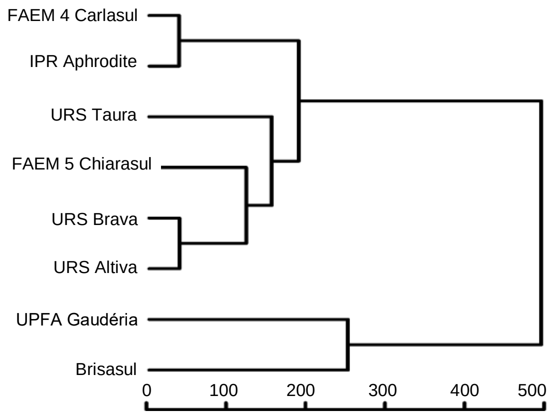

Figure 8. Dendrogram obtained by the hierarchical grouping method UPGMA, based on the Mahalanobis distance (D^2) from the characters studied in eight cultivars of oats. Passo Fundo, Rio Grande do Sul, Brazil, 2020.

In the dendrogram (Fig. 8), group 1 was formed by six cultivars, due to the higher levels of neutral detergent fiber (average = 69.32%) and hemicellulose (average = 29.30%) in relation to group 2. Regarding the characters of lower relative contribution (Table 4), group 1 had a higher lignin content (mean = 6.71%), shorter sclerenchyma length over the internal vascular bundle (mean = 261.47 µm) and internal vascular bundle (mean = 1,213.51 µm) in relation to group 2. The resistance to lodging was measured through the lodging resistance factor, considered as the main parameter to predict the physical strength that the stem can support. Despite presenting a low relative contribution to genetic divergence (Table 4), among the eight cultivars of oats studied, the groups had the same average value of 0.23 g cm^{-1}.

Rapid investigations based on morphological, anatomical and structural components of plants are frequently considered in the literature. It was expected that cultivars with higher stem resistance to lodging had higher levels of structural components, such as neutral detergent fiber, acid detergent fiber, hemicellulose and lignin. This was not observed for all cultivars studied. The anatomical components, for cultivars with greater stem resistance to lodging, presented higher sclerenchyma values over the internal and external vascular bundle, internal and external vascular bundle and sclerenchyma compared to the cultivars most susceptible to lodging. In this sense, the number of vascular bundles in combination with the lignin content can confer resistance to lodging (Stanca et al., 1979; Kong et al., 2013). However, some authors report that, in anatomical terms, no feature was found associated with lodging and, therefore, not useful for indirect selection in breeding programs (Kelbert et al., 2004). Thus, in cereals, the selection of plants with resistance to lodging, should not be made based only on anatomical characters and structural components of stem. In addition, traits used to select superior genotypes in terms of lodging resistance should be: 1) fast, easy and stable to measure; 2) strongly inheritable; and 3) be strongly correlated with resistance to lodging (Shah et al., 2017).

Some characteristics, possible for selection were studied in this work and can be used to identify of superior genotypes in terms of lodging resistance. There is noticeable variability in oat cultivars for most stem traits. In addition to visual assessments of lodging, the lodging resistance factor is the most used test, as it is a predictor of the strength that the stem can withstand. Finally, the peduncle structural components, in the two ways explored in the present study, did not demonstrate a concise result to be used exclusively as plant selection characters to lodging resistance. The correlation obtained between the internal vascular bundle and the lodging resistance factor allowed us to confirm that this character can be used in indirect selection aiming to lodging resistance.

CONCLUSIONS

Variability in stem characters was observed among the eight whit oat cultivars studied. Of the anatomical characters, the internal vascular bundles were associated with resistance to lodging, allowing to identify it as a possible character of selection of plants. For the structural components of the stem, there was no significant association with resistance to lodging. The lodging resistance factor is an important tool for assessing stem resistance to lodging in oats.

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