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Effect of induced lodging on grain yield and quality of brewing barley

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ABSTRACT - *Lodging is one of the main factors of constraint to grain yield stability in barley. The objective of this study was to evaluate the effects of lodging on agronomic and qualitative traits, when induced at different stages of the crop development. The trial was carried out in Victor Graeff, RS, using a randomized complete block design with four replications and 3 factors: year, lodging date and lodging intensity. The analyzed parameters were grain yield (GY), kernel plumpness (KP), germination (G), and score of lodging at harvest (SLH). No significant interaction was observed for GY and G. The effects of induced lodging at the booting and physiologic maturity stages were distinct for GY, KP and G. Unlike G, the variables GY and KP were not significantly affected by lodging intensity. Quantitative and qualitative losses in barley can be predicted based on lodging.*

Key words: *Hordeum vulgare*, management, cereal.

INTRODUCTION

Since the first studies on genetic improvement of barley in Brazil, the area of this cereal has grown considerably and, today, it covers a stable 140.000 ha (FAO 2005). Lodging, be it a consequence of the use of tall varieties, of inadequate nitrogen management or of unfavorable climate conditions is one of the main barriers on the way to higher mean yields and an enhanced quality of cereal crops (Floss 2004). According to Berry et al. (2004) it is a problem that limits the production, in developed as much as in developing countries, especially in barley (Stanca et al. 1979). In an analysis of the impact of this physical/physiological effect on barley grain yield, different authors reported varied levels of damage: 20% (Briggs 1990), 30% (Pinthus 1973), 40% (Eassen et al. 1993) and up to 66% (Berry et al. 2003), depending on the crop development stage at the date of lodging and on the intensity of the phenomenon. When lodging occurs at the beginning of the development of the crop, before full elongation, plants are able to recover their original position, differently from when it occurs after heading (Manitoba 2004).

In Brazil, the consequences of lodging for quality are weightier, since nearly the entire barley production is destined for beer brewing, opposite to the global situation, where approximately 95% of the product is destined for the forage market (FAO 2005). In view of the qualitative aspects (fundamental to determine the use of the cereal for beer brewing) and quantitative criterion (indispensable for the agronomic viability of the crop), lodging is one of the issues most intensely

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studied by barley researchers, from the viewpoint of genetics as much as management, and is the focus of numerous revisions in all the world. Two forms of lodging in cereals are known worldwide: the first caused by stem fragility and the second by poor root development, which indicates the factors that need to be adjusted (Ennos 1991).

Of the 10 barley cultivars presently raised on an industrial scale in Brazil only one denominated BRS 195, developed by the Embrapa and released in 2002, presents genetic resistance to lodging, conveyed by dwarfing genes. The lodging management in the others is based on fertilization control, caution in the application of N top-dressing and the application of growth regulators. In France, Germany and England, for example, growth regulators are used on 70% of the areas planted with wheat, in contrast to the Brazilian reality. While research is done along these lines (of genetics and management), insights on lodging-related effects on the crop as a possibility of predicting damages in the short term are fundamental, since the market price for barley that does not meet brewing standards is substantially lower (around U$ 25.00 to U$ 35.00 ton^{-1}) than for brewing barley (which requires over 95% germination - MAPA 1996). Estimates of losses can also be of help when deciding on a possible application of fungicides and/or insecticides, considering the cost/benefit in view of the situation of the crop. Several authors have used observations of field and experimental work to create mathematical models of prevision of the damage done by lodging to barley yield and quality, among them Baker et al. (1998), Berry et al. (2003) and Sterling et al. (2003).

To analyze the impact of lodging on barley yield and quality, the induction or simulation of this effect seems to the best option, especially because the natural occurrence of the phenomenon is irregular and depends on the interaction of different factors (Kelbert et al. 2004). In 1950, Harrington and Waywell already studied the effects of induced lodging, using wind (controlled) as inducing agent. This method was later also used by Lekes and Zenisceva (1962), cited by Pinthus (1973). In 1967, Udagawa and Oda, also cited by Pinthus (1973), described a mobile wind tunnel as induction method to detail the information available. The plants were even sprayed with several types of auxins after anthesis to induce lodging in 1964 by Petinov and Urmanstsev, cited by Pinthus (1973). In this context of techniques and methods to simulate lodging of barley plants and to predict the effects, Sisler and Olson (1951) developed a simple technique, used later by Day (1957). The system consists in overlaying the barley plots horizontally with a framework that consists of a vertical bar and horizontally arranged laths, fixed to the ground with iron pegs. According to these authors, the advantage of the method is that it allows lodging induction at different intensities and development stages of barley, while a control can be maintained at normal conditions; the disadvantages include possible damages to the plot and their effects on the yield, besides the difficulties of application of the technique on larger areas.

The objective of the was to the determine the effect of induced lodging in barley on distinct agronomic and quality traits at different growth and reproductive development stages.

MATERIAL AND METHODS

The trial was conducted in the experimental field of Cia. Brasileira de Bebidas (AmBev), in Victor Graeff, state of Rio Grande do Sul, in the growing seasons of 2002 and 2003. The county has a characteristically clayey, dystrophic, dark-red soil, lies at a altitude of 450 m and is representative of the climate conditions of the largest barley-producing area of the state, which allows significant inferences of the obtained data. Three factors were tested, in a randomized block design with 4 replications, arranged in a 2 x 4 x 2 + 1 factorial scheme: a) year, with 2 levels – 2002 and 2003, b) Date of lodging induction, with 4 levels – booting, heading (100% of the spikes outside the sheath), grain filling (soft kernels) and ripening (mature grain – point of harvest), and c) Intensity of lodging induction, with 2 levels – 50 % (plants inclined approximately 45°) and 100% (plants inclined approximately 90°). An additional treatment without lodging induction was included as control, to monitor the occurrence of lodging under normal conditions. The test cultivar was MN 698, chosen for its susceptibility to lodging. Each experimental unit consisted of 12 rows, each 5 m long, covering a useful area of 10.5 m². The levels of factor B were parametrized according to the phenological development scale of Zadoks et al. (1974), which is best fit for the study of winter cereals (Floss 2004), in the respective stages 45, 58.59, 83 and 92. For factor C, the intensity was defined according to the pressure of the artificial structure exerted on the plot, expressed by the angle the plants were subjected to, that is, partially lodged (50% or 45° - level 1) and completely lodged (100% or 90° - level 2). The induction method was adapted from the one proposed by Sisler and Olson (1951), as described below:

Structure

Frames of braided bamboo were constructed for lodging induction on the plots, in similar dimensions to the experimental unit (2 x 5m). The bamboos were spaced 20 cm, in the vertical as well as horizontal direction, and tied to each other. Eight frames were assembled, as required to induce lodging in the 4 treatment replications, at both intensities.

Procedure

According to the date of induction determined by the treatments and on the four corresponding replications, the previously constructed frames were installed on a plot with sideways movement, so that all plants of the plot were subjected to the weight of the framework (Figure 1a and 1b). Depending on the level of the factor Intensity, the structure was pressed with more or with less intensity, pressing the plants to an angle of approximately 45° in the case of an intensity of 50%, and to 90° in the case of 100% intensity (Figure 1b). After adjusting the intensity level, the frame was pinned to the soil with iron pegs, able to support the ascending pressure of the plants. Twenty-four hours after the installation the frame was removed from the plot, in order to simulate lodging as it occurs under the influence of wind and rain and the reestablishment of the normal development conditions thereafter. The same structures were used to induce lodging at booting and the other stages of crop development.

All cultural practices required for the development of barley, such as application of fertilizers, fungicides and insecticides were performed in compliance with the recommendations of the Barley Research Committee in effect (Reunião 2005). The following aspects were evaluated: a) Score of Lodging at Harvest (SLH): determined at the moment of the harvest, through visual scores expressed in percentage; b) Kernel Plumpness (KP): determination of the kernel size based on the the segmentation of 100 g of barley, in a specific device, expressed in class 1 (fraction of over 2.5 mm) and class 2 (fraction of over 2.2 and smaller than 2.5 mm) and waste (fraction with sizes of less than 2.2 mm); c) Grain yield (GY): in kg ha^{-1}, based on the weight of each plot; and d) Germination (G): determined according to grain germination and expressed in percentage of living grains. The results were analyzed by F test, and the means of the significant factors compared by Duncan's comparison tests (5%). Analyses of linear correlation between the responses of the most important variables were performed as well, by Pearson's method (Steel and Torrie 1980).

RESULTS AND DISCUSSION

The analysis of variance (Table 1) presented distinct results regarding the effects of induced lodging on the responses of the variables SLH, GY, KP and G, so they were classified in three groups: 1) SLH: significant triple interaction, requering the decomposition into main effects for each factor necessary; 2) GY and KP: without any significant interaction between the factors (performed similarly) presenting significant differences for the factors Year and Time, by Duncan's mean comparison test; 3) G: significance for the Year x Intensity interaction and for all factors individually, in a mixed analysis, by partitioning the main effects for the factors involved in the interaction and an individual evaluation of the factor Date.

Effect of induced lodging on grain yield

The absence of significant interaction between the factors for the variables grain yield and kernel plumpness is a good indicator for the prediction of kernel plumpness and germination of the barley grains after harvest. This information is useful to estimate losses and cost/benefit of investment in the crop; the conclusion may therefore be drawn that irrespective of the year and independent of the lodging intensity, the effects on these variables are similar for the different dates of occurrence (booting until physiological maturity). The significant F value for the factor Date (Table 1) shows that there are significant differences between the levels, that is, some are more lodging-sensitive than others. Based on the results, ripening is the least sensitive phase to lodging effects, in absolute values of grain yield, followed by heading grain filling,

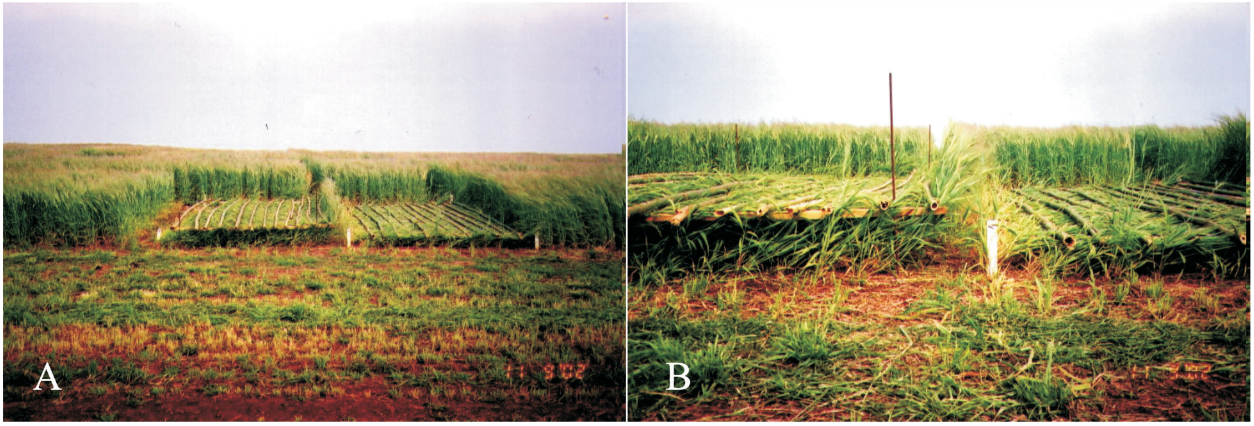

Figure 1. View of the lodging induction method applied: A – General and B – Detailed (Intensity 1 – 50% lodging or plants inclined 45°; Intensity 2 – 100% lodging or plants inclined 90°)

Table 1. Analysis of variance for score of lodging at harvest (SLH), grain yield (GY), kernel plumpness (KP), and germination (G)

Sources of variation	Prob > F			
	SLH	GY	KP	G
Year	**0.0396 ***	**0.0059 ****	**<0.0001****	**<0.0001****
Date	**0.0466 ***	**0.0380 ***	**0.0450 ***	**0.0225***
Intensity	0.2139	0.5101	0.7599	**0.0003****
Year*Date	0.8594	0.2610	0.0774	0.3553
Year*Intensity	**0.0490 ***	0.7038	0.3611	**0.0003****
Date*Intensity	0.1651	0.2701	0.9289	0.3606
Year*Date*Intensity	**0.0036 ****	0.4227	0.7826	0.5852

* and ** = significant at 5 and 1% of probability, respectively, by the F test

Table 2. Means comparisons tests for grain yield (GY), kernel plumpness (KP), and germination (G), applied independently to year, date of lodging induction and intensity of lodging induction

Factors	**Levels**	**GY** (kg ha^{-1})	**KP** (%)	**G** (%)
Year	2002	2,635.2 b	96.31 a	65.62 b
	2003	2,955.0 a	93.68 b	96.78 a
Date of lodging induction	Control	3,352.0 a	96.50 a	93.10 a
	Ripening	2,994.2 ab	96.12 a	83.50 b
	Heading	2,828.4 b	95.37 ab	81.00 b
	Grain filling	2,827.9 b	94.75 ab	82.10 b
	Booting	2,530.1 c	93.75 b	78.00 c
Intensity of lodging induction	50%	2,758.3 a	95.00 a	83.65 a
	100%	2,831.9 a	94.90 a	78.75 b

* Means followed by the same letter in a column did not differ by Duncan's test (P<0.05)
* Means comparison of performed independently for each factor

and then booting (Table 2). Statistically however, the grain yield performance under lodging at ripening differed from lodging at booting only. Considering the control plot (not subjected to induced lodging at all) as standard, the reduction in the grain yield was 10.67, 15.62, 15.64, and 24.52%, respectively, in comparison with lodging at ripening, heading, grain filling, and booting. Manitoba (2004) obtained results that agree with those reported here; he considered the period of 15 days after heading as the most sensitive to lodging, bearing in mind that in this study, there was no treatment of induction at the booting stage. Of the three yield components, the number of fertile spikes per area and the number of grains per spike are defined between the tillering and heading stages in cereals (Floss 2004), which explains the more significant yield reduction for these treatments. Lodging interferes with the even distribution of the sunlight over the tillers and interrupts the synchronic development in relation to the main tiller, reducing the number of fertile spikes per area unit (Manitoba 2004). Only the third yield component, grain weight, is not affected when lodging occurs in this period (between booting and heading). Pinthus (1973) reported grain yields reduced by 34% through induced lodging in barley at heading and by 24% twenty days after heading. These values are in line with the values obtained in this trial, although in greater magnitude. In a similar study, Sisler and Olson (1951) related a reduction of 65% in grain yield when lodging was induced at heading. This result is similar to observations of Manitoba (2004) who reported, respectively, 40% and 20% of yield reduction when lodging occurred close to heading and near physiological ripening. The level of lodging intensity did not affect the variable GY significantly (Table 2). These results did not corroborate those obtained by Day (1957) and Sisler and Olson (1951), where treatments of greater lodging intensity reduced the yield by a 50% higher proportion than those of low intensity. For the factor year, the climate conditions were determinant for significant differences by Duncan's test (5%). The mean GY in 2003 was statistically higher than in 2002, mainly owing to more sunlight and well-distributed rainfall over the course of the crop cycle 2003, in contrast to 2002 (Embrapa 2005).

Effect of induced lodging on Kernel Plumpness

The performance of variable KP was similar to GY with regard to the date of induction. Lodging induction at ripening presented the least impact on the kernel size, and differed statistically from the impact when lodging occurred at booting (Table 2). The absolute percentage differences compared to the control were much lower than the ones obtained for yield (0.39, 1.17, 1.81 and 2.85%, respectively, for ripening, heading, grain filling and booting). The lodging intensity did practically not affect the mean kernel size in both trials (Table 2), in contrast to the results obtained by Manitoba (2004) who observed a reduction of 8%. Unlike the findings for GY, level 1 (2002) of the factor year attained a higher grain mean percentage with sizes of over 2.5 mm, significantly different from 2003 by Duncan's test (5%). The interaction of the yield components number of spikes x kernel size explains these results partly, since the tillering period was impaired in 2002, which physiologically favored the development of the main stem and consequently of its respective spikes.

Effect of induced lodging on germination

Despite significant (Table 1), the year x intensity interaction for the variable Germination is practically not relevant and only indicates that the effect of lodging intensity on germination oscillates according to the year. Since every year differs a little climatically, no conclusions can be drawn in this respect. In independent analyses of the factors, significantly lower quality losses (reflected in germination) were verified by Duncan's test (5%) when lodging occurred at ripening at heading or at grain filling, as compared to lodging at the booting stage, which is in line with the responses verified for the variables GY and KP (Table 2). When the control is considered a quality parameter (at least 95% germination $\pm$2%), the quality of all other treatments (levels of the factor induction date) sank to an inappropriate level in view of the requirements of the malting industry, since the means were lower than 95% (MAPA 1996). In conclusion, lodging in barley is seriously detrimental for brewing purposes, corroborating observations of Berry et al. (2003). The germination mean in the treatments subjected to maximal lodging intensity (100%) was statistically inferior (Table 2) to the means of the treatments subjected to low intensity (50%). The direct contact with the soil and the difficulty of aeration of the spikes accelerated the process of quality degradation, resulting in the onset of the biochemical process of germination. Consequently, there was a reduction of 5% in the final product quality in terms of germination (from 83.65 to 78.75%). In spite of a higher quality loss for level 2 (100%), partial lodging (50%)

also reduced the germination percentage to intolerable levels for the malting industry (MAPA 1996). Manitoba (2004) also mentioned increments of 3 to 20% in the grain protein content under lodging conditions, which diminishes the grain malting quality even further. The occurrence of low spring temperatures and the high rainfall rates in the months October and November (the time of barley harvest), in 2002, affected germination significantly (Table 2), in comparison with the conditions of 2003, which were considered excellent for barley (Embrapa 2005). The reduction in the germination mean from 96.8 (2003) to 65.62% (2002) was highly significant and, in commercial terms, would change the kernel plumpness from barley class A (over 95% germination) to barley class C (under 90% germination). This difference of classification alone would depreciate the cereal price paid per ton by 90%, according to the price policies adopted by the Cia. Brasileira de Bebidas in 2004.

The last group of variables, which consists of the characteristic SLH, was the most sensitive of the tested factors, confirmed by the significant triple interaction. The decomposition of this variable is expressed in Table 3.

The results obtained in the analysis of linear correlation between lodging at the end of the cycle and the grain yield (Table 4) indicated that lodging on the crop at harvest time does not invariably result in quantitative losses. A positive effect was observed in 2002, for example, and in 2003, a negative effect among the variables, though both of low magnitude and non-significant. It is imperative to evaluate the moment when the incident occurred. The responses in the variables

Table 3. Means for the effects year, intensity of lodging induction and date of lodging induction on score of lodging at harvest

Date	2002			2003		
	Intensity			Intensity		
	50% - 45°	**100% - 90°**	**Mean**	**50% - 45°**	**100% - 90°**	**Mean**
Booting	B 13 b	A 45 a	**29**	A 34 a	B 15 c	**24**
Heading	A 70 a	B 8 b	**49**	A 34 a	A 30 b	**32**
Grain filling	A 63 a	B 35 a	**49**	B 9 b	A 50 a	**29**
Ripening	A 49 ab	B 0 c	**24**	A 9 b	A 10 c	**9**
Mean	**48**	**27**	**38**	**21**	**26**	**24**

* Means followed by the same lower case letter in a column did not differ by Duncan's test (P<0.05)
* Means followed by the same upper case letter in a row did not differ by Duncan's test (P<0.05)

Table 4. Pearson correlation index (r) between the variables GY and SLH for the levels of factor 1 (Year) and between the variables GY and G for the levels of factor 3 (Lodging intensity)

Factor	Level	GY x SLH	GY x G
Year	2002	0.20	-
	2003	-0.36	-
Intensity of lodging induction	50%	-	0.83**
	100%	-	0.90**

* and ** = significant at 5 and 1% probability, respectively, by the T test

grain yield and germination were clearly strongly linked. Independent of the lodging intensity, the association was positive and highly significant (Table 4).

CONCLUSION

The occurrence of lodging, regardless of the intensity, interferes with the final germination in barley. The progressive increase of the intensity affects germination strongly, while the quantitative traits seem to be independent.

Quantitative losses in barley caused by lodging are strongly associated to qualitative losses.

Lodging can be used as prediction tool for yield and grain quality loss in barley.

Efeito do acamamento induzido sobre o rendimento de grãos e a qualidade da cevada cervejeira

RESUMO - *O acamamento é um dos principais fatores limitantes à produtividade, qualidade e estabilidade de produção em cevada. O estudo teve como objetivo avaliar seus efeitos sobre caracteres agronômicos e qualitativos, quando induzido em diferentes estágios do desenvolvimento da cultura. Foi conduzido em Victor Graeff, RS, em delineamento de blocos casualizados com 4 repetições e composto por 3 fatores: ano, época e intensidade de indução. Foram avaliadas as variáveis rendimento de grãos (RG), classificação comercial (CC), germinação (G) e acamamento final (AC). Nenhuma interação significativa entre fatores foi observada para as variáveis RG e G. Os efeitos do acamamento induzido no emborrachamento e na maturação fisiológica foram distintos para RG, CC e G. O RG e a CC não foram afetadas significativamente pela intensidade de acamamento, diferentemente da variável G, que foi influenciada. O acamamento pode ser utilizado como preditor de perdas quantitativas e qualitativas em cevada.*

Palavras-chave*: Hordeum vulgare*, manejo, cereal.

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