RESEARCH PAPER

Lodging resistance and its associated traits in barley landraces (*Hordeum vulgare* L.) from arid areas in Algeria

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Abstract

Lodging is a serious problem in cereals damaging both yields, grain and forage quality but also increasing the difficulty of the harvest. This study was conducted in order to analyze the genetic variability and to evaluate the traits that are associated with lodging resistance. The analysis of variance revealed very highly significant differences for all the studied traits which showed a great variability between genotypes. Morphological investigations generally showed that the most resistant genotypes to lodging were those with the shorter total lengths of the first four basis internodes. Those which were susceptible to lodging possess against the longer four basis internodes. The correlations studies on the stem traits as well as the agro-pheno-morphological characters indicated that the lengths of the first four basis internodes were all positively correlated with each other. Diameters and weights of the four internodes were almost all positively correlated with each other. It was also showed that lodging was negatively correlated with the awn length and the 1000 grain weight but positively correlated with the tiller spike number per plant. Correlations between lodging and the lengths of the four basic internodes were all positive and very highly significant. The existing diversity for these traits and the relationships between them could help for directing breeding works for the lodging resistance.

Keywords: Barley; Lodging; genetic variability; basis internodes

ظاهرة الرقاد والصفات المرتبطة بها لدى أنماط محلية للشعير من المناطق القاحلة في الجزائر

ملخص

إن ظاهرة الرقاد لدى الحبوب تمثل مشكلا عويصا يلحق أضرارا بالإنتاج، بنوعية الحب، كما يزيد من صعوبة عملية الحصاد. أجريت هذه الدراسة من أجل دراسة التباين و كذلك من أجل تقييم الصفات المرتبطة بظاهرة الرقاد لدى اثنين و ثلاثين نمط من الشعير. أثبتت الدراسة الإحصائية وجود تباين كبير بين أنواع الشعير من خلال اختلافات ذات دلالة جد عالية لدى كل الصفات المدروسة. دلت التحقيقات المرفولوجية بشكل عام أن معظم الأنواع المقاومة للرقاد ، تميزت بأقصر المسافات فيم بين العقد القاعدية الأربعة على عكس الأنواع القابلة للرقاد و التي تميزت بأطول المسافات فيم بين هذه العقد. من جهة أخرى، دلت دراسة الارتباط بين الصفات الخاصة بالسيقان وكذلك المعطيات الفينولوجية والزراعية والمرفولوجية، أن كل المسافات فيم بين العقد القاعدية الأربعة كانت مترابطة ترابطا موجبا وجد قوي فيم بينها. لقد كانت أقطار و أوزان مسافات ما بين العقد القاعدية الأربعة، في معظمها، مترابطة موجبا مع بعضها البعض. كما دلت النتائج أيضا أن ظاهرة الرقاد كانت مترابطة سلبا مع طول السفا ووزن الألف حبة بينما ترابطت موجبا مع عدد التفرعات السنبلية . لقد ترابطت ظاهرة الرقاد ترابطا موجبا وجد قوي مع طول مسافات ما بين العقد القاعدية الأربعة. إن هذا التنوع بين أنواع الشعير فيم يخص هذه المعطيات وكذلك مدى الترابط فيما بينها قد يساعد على توجيه أبحاث التحسين الوراثي من أجل مقاومة الرقاد لدى الشعير.

الكلمات المفتاحية: الشعير، ظاهرة الرقاد، التنوع الوراثي، ما بين العقد القاعدية الأربعة.

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Introduction

The process by which the shoots of small grained cereals are displayed from their vertical stance is known as lodging. This can reduce yield by up to 80 % and causes several knock-on effects including reduced grain quality, greater drying costs and slower harvest. It is a problem that limits cereal productivity in both developed and developing countries (Berry et al., 2004).

Barley is particularly prone to lodging because it has tall, hollow stems (Bergal and Clemencet 1962). Thus, lodging resistance has become one of the major goals in crop breeding, particularly in barley (Chen et al., 2014). Lodging can be used as prediction tool for yield and grain quality loss in barley (Caierão, 2006).

Keller et al. (1999) reported that higher seed density will enhance lodging by increasing culm length and decreasing culm diameter as well as total root mass.

However a reduction in culm length does not seem to be the correct answer to increase lodging resistance (Berbigier 1968, Konoshi 1976).

Anatomical characteristics of the culm, mostly when associated with short basal internodes, can be more important than culm length per se (Pinthus, 1973).

The objective of the study was to evaluate the genetic diversity and to investigate the relationships between the phenol-agro-morphological traits and the lodging resistance.

Materials and methods

Genotypes & planting

The germplasm consists of 29 barley genotypes coming from rural regions of Algeria (Adrar, Tamanrasset, Touggourt, Ghardaïa, Béchar, Ouargla and El bayadh) in presence of three witnesses: Pane from Spain and two improved Algerian varieties Saïda and Tichedrett.

Genotypes were evaluated in Mitidja (plain in Algiers with an average rainfall exceeding 500 mm and a subhumid climate) at the National Agronomic Research Institute of Algeria (INRAA) during 2014-2015. This study was taken without fertilization, pesticides, and fungicides and without irrigation. The texture of the soil was a sandy clay loam texture. Planting occurred on 13 November 2014. The test was done using a completely randomized design on two plots. Rows were 4 m each with spacing of 50 cm between themselves. The distance between plants was 10 cm.

Measurements

Plant height (HPL) (cm), spike length (HEP) (cm), awn length (LBA) (cm), number of fertile tillers per plant (NTE), grain number per spike (NGE), spikelet number per spike (NEE), 1000 grain weight (PMG) (g) and spike weight (PEP) (g) were the quantitative traits evaluated at maturity and also days to heading (DEP) and days to maturity (DC). The lodging grade (LOD) was scored at maturity, with the use of 9°-scale, where 1 means no lodging and 9, the highest lodging. After harvesting, measures in the first four basis internodes of stems were made for all maturing genotypes, namely: the lengths of the first four basis internodes (LEN1, LEN2, LEN3, and LEN4) measured by centimeter; their diameters (DEN1, DEN2, DEN3 and DEN4) measured by millimeter and their weights (PEN1, PEN2, PEN3 and PEN4) measured in grams.

A random selection of 10 plants was done on tow plots (five plants per plot chosen from the central parts of each row) of the test to study the following characters: HPL, HEP, LBA, NTE, NGE, NEE, PEP and also: LEN1, LEN2, LEN3, LEN4, DEN1, DEN2, DEN3, DEN4, PEN1, PEN2, PEN3 and PEN4.

Statistical analysis

One-way analysis of variance (ANOVA) was performed by Fisher's least significant difference (LSD) method to test the significance difference between means. The data was statistically analyses by the Gen Stat Discovery (Edition 3, Stat Soft Inc.) and concerned the characters: HPL, NTE, HEP, LBA, NEE, NGE and PEP (table 1) and also the following traits: LEN1, LEN2, LEN3, LEN4, DEN1, DEN2, DEN3, DEN4, PEN1, PEN2, PEN3 and PEN4 (table 2).

Correlations were obtained by STATISTICA (Data analysis Software System, version 6, Stat Soft Inc.) and were performed based on the means values of characters: LEN1, LEN2, LEN3, LEN4, DEN1, DEN2, DEN3, DEN4, PEN1, PEN2, PEN3, PEN4, PEP and lodging grade (LOD) (table 3). Correlations were also done on the characters: LEN1, LEN2, LEN3, LEN4, HPL, NTE, HEP, LBA, NEE, NGE, PMG, PEP, DEP, DC and LOD (table 4).

Results

Variance analysis showed the existence of a great genetic variability ($P < 0.001$) in the germplasm for all the agro-morphological traits (table 1) and for all the characters concerning the stems (lengths, diameters and weights of the four basis internodes) (table 2).

Genotypes (13, 16, 17, 11, 28, 8, 18, 19, 9 and 15) with very long stems and those with long stems (33, 12, 25, 27, 14, 31 and 26) were resistant to lodging. Genotypes with short stems but slightly susceptible to lodging were 21 and 22 except the genotype 20 with short stem and resisting to lodging. All the genotypes with medium stems were susceptible to lodging (1, 2, 4 and 24). Genotypes with very long stems and susceptible to lodging were: 7, 10, 23, 5 and 29. Those with long stems and also susceptible to lodging were: 30 and 32.

Morphological investigations have generally shown that most genotypes resistant to lodging whether with long, very long or short stems, were those with the shorter total lengths of the first four basis internodes. Those which were susceptible to lodging possess against the longer four basis internodes.

On the other hand, the correlations studied on these characteristics as well as the agro-pheno-morphological characters showed that the lengths of the first four internodes were all positively correlated with each other. The length of the third inter-node was positively correlated to the diameter of the second inter-node. The diameters and weights of the four internodes were almost all positively correlated with each other. The spike weight was very strongly and positively correlated with the weight of the second, third and fourth inter-node. It was positively correlated with the first basis inter-node (table 3).

It was also showed that lodging is negatively correlated with the awn length and the 1000 grain weight but positively correlated with the tiller spike number per plant (table 4). Correlations between lodging and the lengths of the four basic internodes were all positive and very highly significant (table 3). There were no significant correlations between lodging and the following characters: Diameters, weights of the four basis internodes and spike weights (table 3).

Discussion

It was showed that genotypes with long or very long stems resisted to lodging and others with short or medium stems against were however susceptible to lodging. Indeed, no significant correlation was found

Table 1. ANOVASs of agro-morphological traits in 32 barley genotypes

Source of variation	DF	HPL	NTE	HEP	LBA	NEE	NGE	PEP
Genotype	31	39.74***	3.41***	46.02***	57.19***	16.49***	7.46***	25.73***
Error	288	57.68	17.83	0.64	0.76	1.58	80.18	0.54
CV %		6.9	42.4	10.8	7.7	11.8	16.9	21.9
SE		2.4	1.34	0.25	0.27	0.4	8.95	0.23
SED		3.4	1.89	0.36	0.38	0.56	4.11	0.33
LSD		6.69	3.72	0.7	0.76	1.11	8.1	0.64

***: Significant at P<0.001; SE: Standard Error; SED: Standard Errors of means; LSD: Least significant differences of means at 5 % level

Table 2. ANOVAs of lengths, diameters and weights of the four basis internodes of stems

Source of variation	DF	LEN1	LEN2	LEN3	LEN4	GEN1	GEN2	GEN3	GEN4	PEN1	PEN2	PEN3	PEN4
Genotype	31	8.43***	8.68***	10.0***	14.2***	3.7***	4.19***	4.37***	5***	3.67***	7.98***	11.03***	7.75***
Error	288	1.73	3.77	3.9	3.66	0.41	0.44	0.44	0.39	0.004	0.004	0.005	0.006
CV %		50	31.4	21.5	18	20.8	18.6	17.3	15.8	59.7	33.8	31	33.9
SE		1.31	1.94	1.98	1.91	0.64	0.66	0.66	0.62	0.07	0.06	0.07	0.08
SED		0.59	0.87	0.88	0.86	0.29	0.29	0.29	0.28	0.03	0.03	0.03	0.03
LSD		1.16	1.71	1.74	1.69	0.58	0.58	0.58	0.55	0.08	0.06	0.06	0.07

***: Significant at P<0.001; SE: Standard Error; SED: Standard Errors of means; LSD: Least significant differences of means at 5 % level

Table 3. Correlation matrix on lodging, spike weights, lengths, diameters and weights of the four basis internodes and 32 barley genotypes

	PEP	LEN1	LEN2	LEN3	LEN4	DEN1	DEN2	DEN3	DEN4	PEN1	PEN2	PEN3	PEN4
LEN1	-0.16NS												
LEN2	-0.08NS	0.93***											
LEN3	-0.13NS	0.73***	0.83***										
LEN4	-0.41*	0.61***	0.68***	0.91***									
DEN1	0.47*	0.2NS	0.25NS	0.41*	0.26NS								
DEN2	0.47*	0.2NS	0.25NS	0.41*	0.26NS	0.84***							
DEN3	0.46*	-0.19NS	-0.14NS	0.03NS	-0.06NS	0.45*	0.51**						
DEN4	0.47*	-0.09NS	-0.00NS	0.18NS	0.06NS	0.73***	0.84***	0.69***					
PEN1	0.77*	-0.13NS	0.02NS	0.03NS	-0.26NS	0.45*	0.45*	0.33NS	0.47*				
PEN2	0.74***	-0.16NS	-0.06NS	-0.01NS	-0.21NS	0.45*	0.47*	0.33NS	0.44*	0.69***			
PEN3	0.74***	-0.24NS	-0.09NS	-0.01NS	-0.19NS	0.46*	0.52**	0.42*	0.53**	0.69***	0.93***		
PEN4	0.7***	-0.12NS	-0.00NS	0.13NS	-0.03NS	0.56**	0.6***	0.46*	0.6***	0.66***	0.88***	0.95***	
LOD	-0.24NS	0.6***	0.6***	0.6***	0.63***	-0.01NS	-0.04NS	-0.32NS	-0.26NS	-0.31NS	-0.2NS	-0.27NS	-0.2NS

NS, No-significant; *P ‹ 0, 05; **P ‹ 0, 01; ***P ‹ 0,001

Tableau 4. Correlation matrix on the lengths of internodes, lodging, the pheno-agro-morphological traits and 32 barley genotypes

	LEN1	LEN2	LEN3	LEN4	HPL	NTE	HEP	LBA	NEE	NGE	PMG	DEP	DC	VER
LEN2	0.93***													
LEN3	0.73***	0.83***												
LEN4	0.61***	0.68***	0.91***											
HPL	-0.01NS	0.12NS	0.3 NS	0.15 NS										
NTE	0.04NS	0.14NS	0.27 NS	0.31 NS	0.32 NS									
HEP	-0.05NS	0.1NS	0.15 NS	-0.02 NS	0.71***	0.38*								
LBA	-0.30NS	-0.26 NS	-0.25 NS	-0.48*	0.55**	-0.14 NS	0.43*							
NEE	-0.11 NS	-0.01NS	0.06NS	-0.02NS	0.53**	0.46*	0.63***	0.22 NS						
NGE	0.08 NS	0.14 NS	0.16NS	0.01 NS	0.47**	0.07 NS	0.35 NS	0.45*	0.41*					
PMG	-0.28NS	-0.19 NS	-0.16 NS	-0.42 *	0.53**	-0.01 NS	0.55***	0.77***	0.37*	0.13 NS				
DEP	-0.41*	-0.28 NS	-0.12 NS	-0.27 NS	0.71***	-0.11 NS	0.51**	0.8***	0.44*	0.5**	0.68***			
DC	-0.25NS	-0.15NS	-0.14 NS	-0.37 NS	0.5**	-0.06 NS	0.45*	0.85***	0.27 NS	0.28 NS	0.75***	0.73***		
VER	0.6***	0.6***	0.6***	0.63***	0.16 NS	0.38*	0.01 NS	-0.39*	0.14 NS	0.3 NS	-0.39*	-0.33 NS	-0.36 NS	
PEP	-0.16NS	-0.08 NS	-0.13 NS	-0.41*	0.61***	-0.11 NS	0.60***	0.85***	0.44*	0.55**	0.83***	0.77***	0.77***	-0.24 NS

NS, Non-significatif ; *P ‹ 0,05 ; **P ‹ 0,01 ; ***P ‹ 0,001

between lodging and plant height. The length of the stem does not necessarily appear as a criterion for the resistance to lodging. In fact, according to Berbigier (1968) and Konishi (1976), a reduction in culm length does not seem to be the correct answer for increasing lodging resistance. However, Matušinsky et al. (2015) found a positive and very high significant correlation between lodging and the plant height.

Morphological investigations made to study the lodging resistance demonstrated through the analysis of variance that the differences between genotypes are very highly significant regarding the lengths, diameters and weights of the first four basis internodes. The existing diversity between genotypes for these characters and the relationships between them could help to guide selection works for the lodging resistance. On the diameter of the first three basis internodes, Hasnath Karim and Jahan (2013) found very highly significant differences among wheat genotypes, only for the third inter-node. For the first two basis internodes, the differences were not significant in the same study.

On the other hand, it was found that the lengths of the first four internodes were very highly and positively correlated with lodging. These results are similar to those of Chen et al. (2014) where the lengths of the six basic internodes correlated positively with lodging. According to Jezowski (1981), lines investigations have shown that the resistance to lodging in cereals is strongly related to the physical and morphological structure of the stem. Regarding flax, Menoux et al. (1982) indicate that many works on lodging lead to the conclusion that stem stocky, with short internodes and with relatively abundant supporting tissues, will be less susceptible to lodging. The weight of the spikes is positively correlated with all diameters of the four basis internodes. This result is consistent with conclusions of Chen et al. (2014) who found significant correlations between the weight of the ears and the diameters of the six basis internodes in barley. Correlations between lodging and the diameters of the four basis internodes were all no significant. It was the same for the weight of internodes. Pinthus (1967) found no correlation between culm diameter and lodging resistance in wheat. However a greater diameter of the lower internodes and the greater weight per unit length of the stem basis of wheat was suggested as a possible reason for better lodging resistance by Zuber et al. (1999). There is no significant correlation between lodging and spike weight. According to Hasnath Karim and Jahan (2013), genotypes with heavier ears appear to reach the same level of lodging resistance compared to genotypes with lighter ears. In a study taken by Matušinsky et al. (2015), there were no significant correlation between lodging and dry weight of productive tillers but positive and significant correlation was found between lodging and fresh weight of productive tillers in the same study. The 1000 grain weight and the awn length are significantly and negatively correlated with lodging indicating that these characters may be used in selection for increased lodging resistance. No significant correlation was found between lodging and the 1000 grain weight in a study taken by Matušinsky et al. (2015).

Conclusion

Lodging is a serious problem in cereals in general and very much in barley, damaging both yields, grain quality but also increasing the difficulty of the harvest.

From the morphological investigations, it was found that the short basal internodes can be more important than the stem length for lodging resistance. The 1000 grain weight, the awn length and the tiller spike number per plant were also associated with lodging resistance.

The existing diversity found between genotypes for all the traits studied and the relationships between them could help for directing selection works for the lodging resistance in barley.

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