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Genetic parameters and agronomic characterization of elite barley accessions under irrigation in the Cerrado

Ricardo Meneses Sayd[1*], Renato Fernando Amabile[2], Fábio Gelape Faleiro[2], Mateus Coelho Costa[1] and Ana Paula Leite Montalvão[3]

[1]Faculdade de Agronomia e Medicina Veterinária, Campus Universitário Darcy Ribeiro, Universidade de Brasília, , 70910-900, Brasília, Distrito Federal, Brazil. [2]Embrapa Cerrados, Empresa Brasileira de Pesquisa Agropecuária, Planaltina, Distrito Federal, Brazil. [3]Instituto Agro florestal Mediterrâneo, Universitat Politécnica de Valencia, Camino de Vera, Valencia, Spain. *Author for correspondence. E-mail: ricardo_sayd@hotmail.com

ABSTRACT. There is a demand for barley cultivars that are suitable for the malt industry as well as genotypes that are stable and better adapted for irrigation in the Cerrado. This study aimed to estimate the genetic parameters by assessing 69 barley genotypes from different countries, from 2012 to 2014, under irrigation in the Cerrado. Six agronomic characteristics were assessed: grain yield, plumpness kernel, thousand seeds weight, plant height, degree of plant lodging and days to heading. Analysis of variance, cluster test and phenotypic, genotypic and environmental correlations were performed. Significant effects were observed for genotypes, years and the G x E interaction. High values of broad-sense heritability (> 86%) were found for all the characteristics, which enabled direct selection. The Colombian accession MCU363PI402112 stood out for its agronomic characteristics. Genotype selection based on the phenotypic evaluations was possible due to their good experimental accuracy and precision. Precocious genotypes with high grain yields and homogeneous grain sizes were selected. Due to the environmental influence on the grain yield, additional studies concerning the components of yield in this environment are necessary to facilitate the selection of more productive genotypes.

Keywords: *Hordeum vulgare* L.; yield; G x E interaction; genetic resources.

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Introduction

The search for a germplasm that can be introduced into plant breeding programs is indispensable for developing new cultivars that meet the demands of the productive sector in terms of the agronomic traits of interest. The constant search for selection and recombination strategies to increase the plants' efficiencies and genetic gains is equally important. In general, breeders seek to incorporate those genetic resources that have favorable alleles for the agronomic traits of interest to increase their frequencies in breeding populations.

To aid the barley breeding program based on the selection of superior genotypes that are more adapted to the Cerrado irrigated conditions, the agronomic characterization of accessions from the germplasm bank is of fundamental importance, providing knowledge about the full productive potential and agronomic traits of commercial interest (Amabile, Faleiro, Capettini, & Sayd, 2017).

The different responses of the genotypes according to changes in environmental conditions represent a problem to producers and a great challenge to breeders. It is in the interest of both that plants present stability in both quality and yield both in different locations and over years, in addition to high yields. An alteration of the relative performance of genotypes due to different environments is called the genotype by environment interaction (G x E) (Borém & Miranda, 2005).

The planning and performance of experiments in breeding programs are based on interpretations and estimates of the genetic parameters that indicate the experimental precision and accuracy, the proportion of total variance due to the genetic differences, and the prediction of gains with plant selection (Cruz, Regazzi, & Carneiro, 2004). Experiments on the selection of genotypes for at least two years are necessary to segregate the environmental effects in the response of the genotypes. These effects can be minimized by adding sites and evaluating genotypes in different years.

The study of the genotype by environment interaction is fundamental and has been systematically conducted in the barley breeding programs performed at Embrapa and partners and in other programs in other countries. Solonechnyi et al. (2015) found the occurrence of the G x E interaction regarding the grain yields of 17 genotypes of barley during 2013 and 2014 in two experimental fields located in Ukraine. In Ethiopia, 64 genotypes introduced from barley germplasm banks in three experimental fields were tested, observing G x E interactions for characteristics linked to yield (Hailu, Alamerew, Nigussie, & Assefa, 2015).

In the Cerrado, Amabile et al. (2008) reported the G x E interaction in barley and observed the influence of the environmental effect (year) over the performance of the BRS Deméter under irrigated conditions. Amabile et al. (2015) estimated the genetic parameters of 39 elite cultivars from the Embrapa work collection. However, studies on this type of interaction were not performed in the Cerrado region, mainly considering a large number of elite accessions that require assessment. This study aimed to estimate the genetic, phenotypic, and environmental parameters and the agronomic behaviors of 69 high-yield barley accessions over three years under the irrigated cropping system in the Cerrado.

Material and methods

The study evaluated 69 accessions of elite barley, two-row and six-row, which were previously selected for their high yields from hundreds of accessions available at the Germplasm Bank of the Embrapa Recursos Genéticos e Biotecnologia, and BRS 180 served as a control. The experiments were performed between the months of May and September 2012, 2013, and 2014, under a central pivot irrigation system, in the Experimental Field of Embrapa Cerrados (CPAC), Planaltina, Distrito Federal, Brazil, located at 15°35’30” latitude South and 47°42’30” longitude West, at an elevation of 1,007 m, on a “Latossolo Vermelho distrófico típico argiloso” (Rhodic Hapludox).

The experimental design was a randomized complete block design with three replicates. The plots consisted of six 5-m-long rows, spaced 20 cm apart, with a useful area of 4.8 m^2 for each plot, and a density of 300 plants per square meter.

The experimental area, according to Köppen, is located in the Cerrado morphoclimatic domain, with tropical wet and dry climate (Aw) (Nimer, 1989). In the sowing furrow, according to the results of the soil analysis, 16 kg ha^{-1} of N, 120 kg ha^{-1} of P_2O_5, 64 kg ha^{-1} K_2O, and 40 kg ha^{-1} of N were applied as fertilizer treatments upon the appearance of the fully expanded fifth leaf (Amabile, Minella, Oliveira, & Fronza, 2007).

Six agronomic characteristics were assessed: 1. Yield - estimated grain yield (kg ha^{-1}); 2. PK - plumpness kernel (> 2.5 mm) (%), according to Brasil (1996); 3. TSW - thousand seeds weight (g) (Brasil, 2009); 4. Height - plant height (cm) - mean of three random plants per plot; 5. LOD - degree of plant lodging; and 6. DH - days to heading (period, in days, from emergence to the visible appearance of 50% of the spikes inside the useful area of the plot). The evaluations of plant height, lodging degree, and days to heading were performed in the experimental field, and the evaluations of yield, plumpness kernel, and TSW were performed in the Seed Laboratory of Embrapa Cerrados.

The data were submitted to analysis of variance and the means were grouped together by the Scott-Knott test at 1% significance. The genotypes were ranked regarding the Yield characteristic for each environment.

The estimates of heritability at the level of mean (H^2), and coefficients of experimental (CEV), genetic (CGV), and relative (CRV) variations for each of the analyzed characteristics were calculated using the Genes program (Cruz, 2013).

The phenotypic, genotypic, and environmental correlations were measured by estimating the phenotypic, genotypic, and environmental variances and covariances between the characteristics two by two, determined according to Kempthorne (1966), using the Genes program (Cruz, 2013).

To classify the correlations, the intervals proposed by Carvalho, Lorencetti, and Benin (2004) were adopted, in which the intensities are considered perfect ($|r| = 1$); very strong ($0.90 \le |r| < 1$); strong ($0.60 \le |r| < 0.90$); medium ($0.30 \le |r| < 0.60$); weak ($0.00 < |r| < 0.30$) or null ($r = 0$).

Results and discussion

The values of F were highly significant ($p \leq 0.01$) for genotype, environment -years, and the G x E interaction for all the characteristics, thus indicating the effects of the different elite accessions, years, and interactions on the agronomic characteristics assessed. The effect of the G x E interaction is particularly important to show the variations in the agronomic performance of the elite accessions when they are evaluated in different years.

For all the characteristics evaluated, the values of F were above 5.26, which is the value suggested by Steel and Torrie (1980) that will allow one to make a safe statistic inference and to indicate a high selective accuracy. The values of F for the effect of genotypes ranged from 7.6 (Yield) to 50.4 (TSW), thus showing the existence of differences among the means of the accessions. The values of F for the effect of environment ranged from 17.4 for DH to 162.7 for TSW, and the values for the G x E interaction ranged from 5.2 (Yield) to 24.5 (Height) (Table 1).

Table 1. Analysis of variance, mean, and genetic parameters (heritability – H^2; coefficients of variation genetic - CGV; environmental - CEV; and relative - CRV) of the characteristics grain yield (Yield), plumpness kernel (PK), thousand seeds weight (TSW), plant height (Height), degree of plant lodging (LOD), and days to heading (DH), evaluated in 69 elite barley accessions during the years 2012, 2013, and 2014 at Embrapa Cerrados.

	Degrees of freedom	F Values					
		Yield	PK	TSW	Height	LOD	DH
Genotype	68	7.6**	32.7**	50.4**	43.0**	42.8**	68.3**
Environment	2	91.5**	83.1**	162.7**	76.0**	99.1**	17.4**
G x E	136	5.2**	7.0**	19.3**	24.5**	11.1**	24.4**
Residue	408						
Mean		4,636.5	66.5	43.2	77.6	41.6	58.6
Estimators		Estimates of genetic parameters					
		Yield	PK	TSW	Height	LOD	DH
H^2(%)		86.96	96.94	98.01	97.67	97.60	98.53
CVG		12.06	18.51	9.31	9.15	72.47	6.41
CEV		14.02	9.86	3.97	4.23	33.59	2.34
CVR		0.86	1.87	2.34	2.16	2.15	2.73

Significant at 5% probability; ** Significant at 1% probability.

The F values for environment and the G x E interaction were lower than those obtained by Sayd, Amabile, Faleiro, Montalvão, and Coelho (2017) for the same characteristics with 113 genotypes in two locations. Therefore, we inferred that for the characteristics evaluated in the irrigated conditions of Cerrado, the local factor had a greater influence on the phenotypic variation of the genotypes than the year factor. These results are consistent with those of Borém and Miranda (2005), who concluded that the G x E interaction generally has less relevance for monogenic characteristics and more homogeneous sites and perennial species compared to polygenic characteristics, heterogeneous sites and annual species.

According to Robertson (1959), there are two types of G x E interactions: simple and complex. The simple interaction indicates the presence of genotypes adapted to a wide range of environments. The complex interaction indicates the presence of materials adapted to environments. To identify the nature of the interaction, it is necessary to analyze the adaptability and stability in several sites.

High values of heritability indicate that the direct selection can successfully be used under these experimental conditions. Heritability is one of the most important genetic parameters that a breeder uses to assess a metric characteristic and to select subjects that can obtain genetic gains in barley and other crops (Amabile & Faleiro, 2014). Therefore, due to the high computations of H^2 obtained in the experiments, a high selective accuracy is expected, which will maximize the genetic gains for the next selection and recombination cycles. The estimate of heritability (H^2) also indicates the reliability with which the phenotypic value represents the genotypic value and determines the proportion of gain obtained by selection (Falconer, 1989). Sayd et al. (2017) obtained wide heritability values of the same magnitude in 113 elite genotypes of barley in two sites under irrigated conditions in the Cerrado. Addisu and Shumet (2015), evaluating 36 genotypes from Ethiopia, reported high values of H^2 for the same quantitative traits in barley. Amabile and Faleiro (2014) conducted an extensive review on heritability in barley and concluded that for most agronomic traits, the H^2 values are generally high (above 80%). The trait grain yield, due to its quantitative profile, is reported as the experimental condition with the lowest H^2 values (Delogu et al., 1988; Nadziak, Kudła, & Małysa, 1994; Pesaraklu, Soltanloo, Ramezanpour, Kalate, & Nasrollah, 2016), although depending on the population or experimental conditions, the trait grain yield can present high values (Jalata, Ayana, & Zeleke, 2011; Addisu & Shumet, 2015).

In addition to the heritability, another important parameter that indicates experimental accuracy is the coefficient of genotypic variation (CGV), which quantifies the magnitude of the genetic variability present in the genotypes evaluated in different treatments (Resende, 2002). It is important to consider the CGV/CEV ratio, as represented by the CRV (coefficient of relative variation). When the value of the CGV is superior to the value of the CEV, the genotypic contribution is higher than the environmental effect in the phenotypic expression. Thus, the conditions of selection for such characteristics are favored for breeding. Table 1 shows that the values of CRV were higher than those for all characteristics, except Yield. This value was expected due to the higher environmental variance in the composition of the phenotypic variance of Yield. An alternative for an efficient selection of genotypes for Yield would be the indirect selection through characteristics correlated to productivity. Previous experiments conducted in the Cerrado under irrigation have demonstrated favorable selection conditions (Sayd et al., 2017; Amabile et al., 2015). In trials conducted under rainfed conditions, the CVR values were less than one unit for agronomic traits in barley (Adissu & Shumet, 2015; Yadav, Singh, Pandey, & Singh, 2015; Ahmadi, Vaezi, & Pour-Aboughadareh, 2016).

Another characteristic that indicates the appropriate environmental control in these experiments is the coefficient of environmental variation (CEV). The estimates of this parameter ranged from 2.34% (DH) to 33.59% (LOD). According to the evaluation criteria of Pimentel-Gomes (1985), there were four characteristics with a low CEV (PK, TSW, Height and DH), one characteristic with a medium CEV (Yield), and another characteristic with a high CEV (LOD). However, the magnitudes of these CEVs are similar to those found by other authors (Amabile et al., 2015; Sayd et al. 2017) and are within the acceptable values in agricultural experimentation.

The main characteristic for barley, as well as for most crops, is Yield. The values for Yield presented the greatest variations in the years 2014 and 2012, with CEVs of 18.51% and 14.7%, respectively, while in 2013, the CEV was 4.84%. The whole CEV presented in Table 1 shows a value of 14.02%. Sayd et al. (2017) obtained a low CEV value (3.97%) from a comparison of 113 elite genotypes of barley in two sites under irrigation in the Cerrado. In this case, there was a better environmental control to make the selection when the genotypes were compared in the same year and at different sites.

The genotypic, phenotypic and environmental correlations between the evaluated characteristics were mostly non-significant and of low magnitude. Generally, pleiotropy and close linkage are the two major reasons for genetic trait correlations and are often confounded at the level of genes (Gardner & Latta, 2007). The highest correlation was observed between TSW and PK, which indicates that the larger the grains were, the higher the weight of the grain mass was. An important absence of correlation was observed for DH x Yield, which shows the potential for obtaining genotypes that are both early and of high yield (Table 2). Weak correlations but with the same signal of this experiment between traits were obtained by Raham (2015). Other studies under irrigated conditions of Cerrado showed correlations similar to those obtained in this study (Amabile et al., 2015; Sayd et al., 2017).

Table 2. Genotypic, phenotypic, and environmental correlation coefficients among the characteristics estimated grain yield (Yield), plumpness kernel (PK), thousand seeds weight (TSW), plant height (Height), degree of plant lodging (LOD), and days to heading (DH) in 69 accessions of barley during the years 2012, 2013, and 2014 in the CPAC experimental field.

		Yield	PK	TSW	Height	LOD	DH
Yield							
PK	r_f	0.0614*					
	r_g	0.0566					
	r_a	0.01498					
TSW	r_f	-0.0402	0.5529**				
	r_g	-0.0437	0.5656				
	r_a	0.0034	0.0636				
Height	r_f	0.0229	0.0082	-0.1282			
	r_g	0.0205	0.0083	-0.1316			
	r_a	0.0734	0.0058	0.0270			
LOD	r_f	0.2091	-0.3861	0.0807	0.012		
	r_g	0.2124	-0.3942	-0.0834	0.011		
	r_a	0.2416	-0.0967	0.0410	0.071		
DH	r_f	-0.3352	-0.2879*	-0.0766	0.133	0.0901	
	r_g	-0.3573	-0.2912	-0.0775	0.136	0.0937	
	r_a	-0.1028	-0.1547	-0.0274	0.017	-0.1024	

*Significant at 5% probability; ** Significant at 1% probability.

Similar to Yield and as a characteristic influenced by the environment, the characteristics PK and LOD showed high values of CEV (Table 1) compared to those observed by Sayd et al. (2017). These contrasting values indicated the necessity of data-gathering studies concerning genotypes at different sites and, primarily, in different years of growth. These studies are important for obtaining a wider knowledge of elite and promising barley in irrigated cultivation in the Cerrado. For the characteristics TSE, Height and DH, the CEV values were close to those obtained by Sayd et al. (2017) and Sayd, Amabile, Faleiro, and Bellon (2015), who only collected the parameters at different sites.

The agronomic characteristics assessed based on the main demands from the producers and the industry served to verify the stability and potentiality of the genotypes along three years under irrigated conditions in the Cerrado. Among the most productive (means above 5,200 kg ha^{-1}) and stable genotypes along the three years of evaluation are three Canadian genotypes (CI 15560 QB 136-4-1, CI 15591 QB 139-1, and CI 15580 QB 136-41), four Colombian genotypes (MCU 3634 PI 402112, MCU 3449 PI 401927, MCU 3870 PI 402348, and CI 10022), one Ethiopian genotype (CI 12918), one American genotype (CI 13683 NUMAR), and the Brazilian control BRS 180, which were all six-row and cream-colored genotypes. The control BRS 180, a cultivar adapted to the conditions of the Cerrado, had the highest value for Yield (7,318 kg ha^{-1}) (Table 5), in the year 2014. However, this cultivar obtained high computations of Yield in other years, ranking first in 2014 and second in the sum of rankings in 2013. However, the genotypes MCU 3634 PI 402112, CI 15580 QB 136-41, and CI 13683 NUMAR exceeded or were not significantly different from the control BRS 180 in all years (Tables 3, 4, and 5) and could be selected as potential cultivars for the Cerrado. Values of this magnitude indicate the potential of these genotypes as an option for the current cultivars that average 6,000 kg ha^{-1} in irrigated conditions in the Cerrado (Amabile et al., 2017).

Table 3. Means of the genotypes, characteristics, heritability, and variation coefficients of the estimated characteristics, including grain yield (Yield – kg ha^{-1}), plumpness kernel (PK - %), thousand seeds weight (TSW - g), plant height (Height - cm), degree of plant lodging (LOD - %), and days to heading (DH - days), in 69 barley genotypes submitted to the Scott-Knott test at 1%, the estimates of heritability at the level of the mean (h^2) and the coefficient of environmental variation (CV) in 2012.

[1]Rank	Genotype	Yield		PK		TSW		Height		LOD		DH		[2]TE	[2]CO
56	CI 13824 ATLAS 68	3339	d	67	b	51.0	a	74.6	c	63.3	b	64.3	c	6	USA
1	CI 10022	6807	a	69	b	45.5	b	71.6	c	100.0	a	55.3	d	6	Colombia
32	CI 13711	4401	c	81	a	51.6	a	76.0	c	0.0	d	56.6	d	6	Colombia
40	CI 10071 WOLFE	4205	c	85	a	42.0	c	61.3	e	0.0	d	53.0	d	6	Canada
20	MCU 3870 PI 402348	5092	b	91	a	47.1	b	85.0	b	30.0	c	53.3	d	6	Colombia
29	MCU 3502 PI 401980	4478	c	93	a	42.8	c	85.3	b	0.0	d	53.0	d	6	Colombia
47	CI 12068 MAZOWIECKI	3874	d	58	c	38.3	d	83.3	b	0.0	d	55.0	d	6	Poland
8	MCU 3654 PI 402132	5340	b	91	a	53.6	a	72.0	c	91.6	a	50.3	e	6	Colombia
37	MCU 3449 PI 401927	4255	c	64	c	45.0	b	73.0	c	93.3	a	62.3	c	6	Colombia
30	CI 06244	4465	c	73	b	47.5	b	65.3	d	96.6	a	54.6	d	6	EUA
24	CI 09952	4714	c	75	b	53.0	a	85.3	b	90.0	a	57.0	d	6	Russia
34	MCU 3884 PI 402362	4324	c	83	a	43.6	c	60.3	e	0.0	d	54.6	d	6	Colombia
65	MCU 3852 PI 402330	2220	e	78	b	38.5	d	62.0	e	0.0	d	55.0	d	6	Colombia
62	CI 12367 BRANISOVKY	3096	d	69	b	45.5	b	76.3	c	0.0	d	67.3	b	2	Czech Republic
35	MCU 3865 PI 402343	4321	c	86	a	47.3	b	72.0	c	83.3	a	53.6	d	6	Colombia
59	CARINA PI 371632	3231	d	65	c	44.5	b	85.6	b	0.0	d	66.6	b	2	Germany
15	MCU 3634 PI 402112	5178	b	87	a	50.5	a	74.3	c	0.0	d	51.3	e	6	Colombia
6	CI 12918	5448	b	82	a	52.1	a	81.3	b	91.6	a	53.3	d	6	Ethiopia
61	MCU 3750 PI 402228	3151	d	84	a	42.8	c	72.0	c	0.0	d	50.0	e	6	Colombia
43	CI 15323 2222-79	4118	c	55	c	46.6	b	71.0	c	93.3	a	66.6	b	6	Tunisia
13	MCU 3878 PI 402356	5240	b	75	b	50.3	a	76.0	c	0.0	d	50.3	e	6	Colombia
48	CI 09962	3831	d	84	a	53.3	a	63.6	d	0.0	d	65.3	b	6	Iran
4	MCU 3478 PI 401956	5890	a	58	c	42.8	c	85.0	b	28.3	c	51.3	e	6	Colombia
57	CI 06109 VELVON	3339	d	75	b	38.3	d	85.3	b	90.0	a	75.6	a	6	EUA
54	CI 14041	3373	d	71	b	47.6	b	93.6	a	63.3	b	66.0	b	6	Ethiopia
45	CI 07772	4078	c	70	b	44.3	c	76.3	c	100.0	a	51.0	e	6	India
17	CI 15580 QB 136-41	5167	b	85	a	43.0	c	72.3	c	100.0	a	58.0	c	6	Canada
21	MCU 3454 PI 401932	5046	b	68	b	41.5	c	82.3	b	65.0	b	52.6	d	6	Colombia
58	CI 15279 2528-23	3251	d	45	d	38.1	d	66.0	d	41.6	c	67.3	b	6	Tunisia
44	CI 10017 RASPA COMUN 1085	4114	c	38	d	41.1	c	85.0	b	100.0	a	64.0	c	6	Colombia
50	CI 14031	3684	d	55	c	46.8	b	74.3	c	0.0	d	67.3	b	6	Ethiopia
68	MCU 3484 PI 401962	1198	e	65	c	40.6	c	73.3	c	0.0	d	48.6	f	6	Colombia
26	MCU 3461 PI 401939	4645	c	83	a	45.0	b	86.3	b	0.0	d	51.0	e	6	Colombia
46	CI 09961	4044	c	79	a	54.1	a	76.3	c	60.0	b	56.3	d	6	Iran

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27	CI 14925 ELS 6402-512	4641	c	61	c	41.6	c	74.6	c	0.0	d	63.6	c	6	Ethiopia
51	CI 15565 QB 136-20	3673	d	76	b	43.3	c	91.0	a	0.0	d	62.3	c	6	Canada
60	CI 11493 FRUGHERSTE STANKAS	3226	d	75	b	48.5	b	75.0	c	0.0	d	65.3	b	2	Germany
49	CI 10078 ATLAS 57	3830	d	76	b	46.5	b	82.6	b	0.0	d	66.0	b	6	USA
33	MCU 3556 PI 402034	4362	c	72	b	45.3	b	83.6	b	0.0	d	63.3	c	6	Colombia
14	CI 15591 QB 139-1	5183	b	79	a	28.5	f	85.0	b	33.3	c	57.3	d	6	Canada
63	CI 06946	3087	d	22	d	33.5	e	83.0	b	100.0	a	53.3	d	6	Iran
12	CI 13715	5252	b	72	b	42.6	c	72.6	c	30.0	c	62.6	c	6	Colombia
53	MCU 3816 PI 402294	3544	d	93	a	50.3	a	71.6	c	0.0	d	52.0	e	6	Colombia
28	MCU 3851 PI 402329	4538	c	83	a	44.8	b	73.3	c	0.0	d	63.0	c	6	Colombia
2	MCU 3469 PI 401947	6393	a	94	a	43.3	c	75.0	c	0.0	d	48.0	f	6	Colombia
16	CI 09958	5176	b	91	a	51.1	a	63.6	d	0.0	d	60.6	c	6	Morocco
41	MCU 3827 PI 402305	4167	c	96	a	52.5	a	75.3	c	0.0	d	51.6	e	6	Colombia
67	CI 13894	1314	e	64	c	47.3	b	92.6	a	0.0	d	53.6	d	6	USA
39	CI 10501 ATHENAIS S-50-34	4236	c	84	a	47.6	b	58.0	e	75.0	b	55.0	d	6	Cyprus
52	CI 09959	3555	d	84	a	53.8	a	68.0	c	0.0	d	54.0	d	6	Morocco
36	CI 15560 QB 136-4-1	4270	c	72	b	43.0	c	82.3	b	91.6	a	62.3	c	6	Canada
18	MCU 3489 PI 401967	5164	b	86	a	45.0	b	85.6	b	0.0	d	50.3	e	6	Colombia
38	CI 06188	4239	c	43	d	38.3	d	74.3	c	100.0	a	63.0	c	6	Mexico
64	MCU 3653 PI 402131	2257	e	86	a	42.1	c	61.3	e	0.0	d	50.3	e	6	Colombia
10	CI 12920	5272	b	73	b	51.1	a	85.6	b	100.0	a	53.3	d	6	Ethiopia
9	CI 13683 NUMAR	5285	b	40	d	36.8	d	70.6	c	0.0	d	66.0	b	6	USA
69	MCU 3719 PI 402197	1154	e	73	b	45.6	b	72.6	c	0.0	d	64.6	b	6	Colombia
66	MCU 3858 PI 402336	2201	e	74	b	42.6	c	80.6	b	0.0	d	65.6	b	6	Colombia
11	MCU 3883 PI 402361	5259	b	69	b	45.0	b	73.6	c	0.0	d	54.0	d	6	Colombia
22	GALOVER (C A N 1126) PI 361636	5039	b	76	b	45.1	b	84.6	b	0.0	d	55.0	d	2 and 6	Denmark
3	CI 10018 RASPA PRECOZ 604	6171	a	81	a	41.0	c	83.3	b	100.0	a	53.6	d	6	Colombia
31	MCU 3571 PI 402049	4460	c	90	a	52.1	a	75.0	c	0.0	d	48.0	f	6	Colombia
42	MCU 3721 PI 402199	4130	c	74	b	44.1	c	72.0	c	0.0	d	63.3	c	6	Colombia
23	E 3/416 PI 356495	5017	b	35	d	42.3	c	72.0	c	100.0	a	55.3	d	6	Ethiopia
5	HHOR 2325/58 PI 329126	5597	b	41	d	35.5	d	55.6	e	0.0	d	63.3	c	6	Afghanistan
55	MCU 3452 PI 401930	3346	d	72	b	52.0	a	67.3	d	0.0	d	54.6	d	6	Colombia
25	MCU 3832 PI 402310	4702	c	83	a	44.0	c	83.0	b	0.0	d	62.6	c	6	Colombia
7	MCU 3592 PI 402070	5364	b	84	a	43.0	c	73.3	c	0.0	d	46.0	f	6	Colombia
19	BRS 180	5104	b	86	a	45.1	b	61.3	e	0.0	d	53.3	d	6	Brazil
	Mean	4249		73.1		45.1		75.7		32.0		57.6			
	H^2	90.0		90.9		93.8		96.8		97.3		97.2			
	CV	14.7		11.0		4.8		3.5		37.4		3.1			

[1]Rank - Ranking of genotypes in relation to the Yield characteristic. [2]TE - Type of ear; [2]CO - Country of origin.

Table 4. Means of the genotypes, characteristics, heritability, and variation coefficients of the estimated characteristics, including grain yield (Yield – kg ha^{-1}), plumpness kernel (PK - %), thousand seeds weight (TSW - g), plant height (Height - cm), degree of plant lodging (LOD - %), and days to heading (DH - days), in 69 barley genotypes submitted to the Scott-Knott test at 1%, the estimates of heritability at the level of the mean (H^2), and the coefficient of environmental variation (CV) in 2013.

[1]Rank	Genotype	Yield		PK		TSW		Height		LOD		DH		[2]TE	[2]CO
47	CI 13824 ATLAS 68	4314	e	75	d	44.3	c	79.0	f	90.0	a	63.3	d	6	EUA
17	CI 10022	5444	b	70	e	42.3	d	69.6	i	95.0	a	58.6	g	6	Colombia
14	CI 13711	5533	b	73	d	41.0	d	84.0	d	98.3	a	59.6	f	6	Colombia
19	CI 10071 WOLFE	5337	b	75	d	39.0	d	91.6	b	95.0	a	60.0	f	6	Canada
20	MCU 3870 PI 402348	5237	c	75	d	38.3	d	94.3	a	98.3	a	60.3	f	6	Colombia
22	MCU 3502 PI 401980	5147	c	82	c	43.3	c	87.0	c	83.3	b	58.6	g	6	Colombia
24	CI 12068 MAZOWIECKI	5128	c	70	e	33.3	f	81.3	e	91.6	a	60.6	f	6	Poland
27	MCU 3654 PI 402132	5065	c	80	c	38.3	d	79.0	f	76.6	b	54.3	i	6	Colombia
9	MCU 3449 PI 401927	5767	b	73	d	50.0	b	82.3	e	0	g	61.6	e	6	Colombia
23	CI 06244	5136	c	71	e	40.6	d	76.0	g	96.6	a	60.3	f	6	USA

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45	CI 09952	4322	e	83	c	44.6	c	84.0	d	76.6	b	57.6	g	6	Russia
25	MCU 3884 PI 402362	5111	c	62	f	44.6	c	64.3	k	96.6	a	52.3	j	6	Colombia
41	MCU 3852 PI 402330	4541	d	75	d	39.6	d	69.6	i	15.0	f	60.3	f	6	Colombia
58	CI 12367 BRANISOVKY	3988	e	53	h	44.0	c	78.6	f	70.0	b	64.3	d	2	Czech Republic
32	MCU 3865 PI 402343	4939	c	74	d	45.3	c	74.0	h	16.6	f	61.3	e	6	Colombia
56	CARINA PI 371632	4050	e	85	b	40.6	d	80.0	f	0	g	67.6	b	2	Germany
3	MCU 3634 PI 402112	6031	a	71	e	35.6	e	83.3	d	95.0	a	54.6	i	6	Colombia
43	CI 12918	4471	d	83	c	48.6	b	76.0	g	95.0	a	62.6	e	6	Ethiopia
39	MCU 3750 PI 402228	4634	d	85	b	47.6	b	72.0	h	18.3	f	63.6	d	6	Colombia
63	CI 15323 2222-79	3636	f	71	e	48.6	b	79.6	f	96.6	a	65.6	c	6	Tunisia
50	MCU 3878 PI 402356	4234	e	60	f	39.6	d	73.0	h	36.6	d	53.3	i	6	Colombia
38	CI 09962	4671	d	91	a	57.0	a	69.3	i	40.0	d	60.3	f	6	Iran
15	MCU 3478 PI 401956	5524	b	72	d	36.0	e	83.0	e	71.6	b	60.0	f	6	Colombia
29	CI 06109 VELVON	4987	c	71	e	40.6	d	79.3	f	60.0	c	68.6	a	6	USA
64	CI 14041	3629	f	69	e	46.0	c	80.0	f	26.6	e	68.6	a	6	Ethiopia
28	CI 07772	5005	c	62	f	41.3	d	69.0	i	76.6	b	52.0	j	6	India
4	CI 15580 QB 136-41	5983	a	74	d	45.3	c	95.0	a	56.6	c	62.6	e	6	Canada
40	MCU 3454 PI 401932	4600	d	72	d	44.3	c	85.0	c	86.6	a	60.6	f	6	Colombia
18	CI 15279 2528-23	5430	b	73	d	45.6	c	83.0	e	95.0	a	65.6	c	6	Tunisia
51	CI 10017 RASPA COMUN 1085	4193	e	71	e	43.6	c	78.0	f	96.6	a	65.6	c	6	Colombia
61	CI 14031	3719	f	57	g	40.0	d	83.6	d	36.6	d	67.0	b	6	Ethiopia
1	MCU 3484 PI 401962	6508	a	72	d	34.3	e	86.0	c	61.6	c	50.3	k	6	Colombia
62	MCU 3461 PI 401939	3644	f	68	e	43.3	c	91.0	b	76.6	b	62.0	e	6	Colombia
13	CI 09961	5553	b	86	b	48.6	b	80.0	f	76.6	b	60.3	f	6	Iran
52	CI 14925 ELS 6402-512	4171	e	57	g	44.6	c	79.0	f	98.3	a	66.0	c	6	Ethiopia
33	CI 15565 QB 136-20	4861	c	72	d	42.3	d	84.0	d	88.3	a	67.0	b	6	Canada
37	CI 11493 FRUGHERSTE STANKAS	4728	d	83	c	49.0	b	67.0	j	0	g	66.0	c	2	Germany
16	CI 10078 ATLAS 57	5516	b	86	b	43.0	c	85.6	c	30.0	e	68.6	a	6	EUA
67	MCU 3556 PI 402034	3455	f	72	d	42.0	d	87.6	c	0	g	64.0	d	6	Colombia
35	CI 15591 QB 139-1	4736	d	63	f	35.3	e	86.0	c	95.0	a	57.6	g	6	Canada
21	CI 06946	5234	c	33	j	34.0	f	84.0	d	95.0	a	60.6	f	6	Iran
48	CI 13715	4284	e	62	f	44.3	c	61.6	l	96.6	a	55.3	i	6	Colombia
26	MCU 3816 PI 402294	5067	c	72	d	44.0	c	74.3	h	76.6	b	54.3	i	6	Colombia
7	MCU 3851 PI 402329	5828	b	71	e	38.3	d	74.0	h	98.3	a	63.6	d	6	Colombia
10	MCU 3469 PI 401947	5749	b	75	d	44.0	c	76.0	g	16.6	f	52.6	j	6	Colombia
68	CI 09958	3199	g	88	a	58.0	a	76.0	g	38.3	d	57.0	h	6	Morocco
44	MCU 3827 PI 402305	4444	d	64	f	41.0	d	68.0	j	76.6	b	51.0	k	6	Colombia
8	CI 13894	5823	b	51	h	36.0	e	76.0	g	0	g	60.3	f	6	USA
53	CI 10501 ATHENAIS S-50-34	4157	e	63	f	35.6	e	79.6	f	95.0	a	58.0	g	6	Cyprus
31	CI 09959	4952	c	85	b	45.0	c	73.0	n	30.0	e	57.3	g	6	Morocco
11	CI 15560 QB 136-4-1	5733	b	50	h	33.0	f	87.0	n	96.6	a	65.0	c	6	Canada
54	MCU 3489 PI 401967	4134	e	69	e	40.3	d	84.0	d	46.6	d	57.0	h	6	Colombia
60	CI 06188	3790	f	42	i	35.6	e	84.3	d	98.3	a	67.3	b	6	México
30	MCU 3653 PI 402131	4953	c	62	f	38.6	d	90.0	b	96.6	a	54.3	i	6	Colombia
42	CI 12920	4488	d	54	h	40.6	d	85.3	c	95.0	a	58.3	g	6	Ethiopia
5	CI 13683 NUMAR	5959	a	32	j	44.6	c	84.0	d	96.6	a	69.0	a	6	EUA
49	MCU 3719 PI 402197	4235	e	65	e	40.3	d	79.0	f	46.6	d	65.6	c	6	Colombia
57	MCU 3858 PI 402336	4030	e	72	e	40.3	d	82.3	e	20.0	f	58.6	g	6	Colombia
46	MCU 3883 PI 402361	4318	e	32	j	36.0	e	83.3	d	40.0	d	54.6	i	6	Colombia
12	GALOVER (C A N 1126) PI 361636	5609	b	45	i	31.3	f	82.3	e	96.6	a	62.3	e	2 and 6	Denmark
66	CI 10018 RASPA PRECOZ 604	3484	f	43	i	43.0	c	74.0	h	95.0	a	56.3	h	6	Colombia
36	MCU 3571 PI 402049	4735	d	62	f	32.0	f	75.6	g	96.6	a	52.0	j	6	Colombia
69	MCU 3721 PI 402199	2845	g	52	h	34.0	f	76.6	g	30.0	e	63.6	d	6	Colombia
34	E 3/416 PI 356495	4814	d	17	k	32.0	f	57.6	m	100.0	a	61.6	e	6	Ethiopia
65	HHOR 2325/58 PI 329126	3586	f	36	j	35.6	e	60.3	l	0	g	65.0	c	6	Afghanistan
59	MCU 3452 PI 401930	3821	f	62	f	35.0	e	64.0	k	0	g	56.3	h	6	Colombia
6	MCU 3832 PI 402310	5847	b	43	i	33.3	f	80.0	f	0	g	60.0	f	6	Colombia

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55	MCU 3592 PI 402070	4087	e	52	h	40.0	d	86.0	c	0	g	52.6	j	6	Colombia
2	BRS 180	6244	a	60	f	38.6	d	78.6	f	23.3	e	58.0	g	6	Brazil
	Mean	4760		65.7		41.1		78.9		62.5		60.3			
	H^2	97.3		99.4		96.3		99.8		99.1		99.2			
	CV	4.8		2.9		4.3		1.2		9.4		1.1			

[1]Rank – Ranking of genotypes in relation to the Yield characteristic. [2]TE - Type of ear; [2]CO - Country of origin.

Table 5. Means of the genotypes, characteristics, heritability, and variation coefficients of the estimated characteristics, including grain yield (Yield – kg ha^{-1}), plumpness kernel (PK - %), thousand seeds weight (TSW - g), plant height (Height - cm), degree of plant lodging (LOD - %), and days to heading (DH - days), in 69 barley genotypes submitted to the Scott-Knott test at 1%, the estimates of heritability at the level of mean (H^2), and the coefficient of environmental variation (CV) in 2014.

[1]Rank	Genotype	Yield		PK		TSW		Height		LOD		DH		[2]TE	[2]CO
12	CI 13824 ATLAS 68	5469	a	61	b	46.6	e	82.3	b	85.0	a	57.3	d	6	USA
25	CI 10022	5047	b	47	c	39.0	i	81.0	b	93.3	a	58.6	d	6	Colombia
44	CI 13711	4644	b	62	b	55.4	b	76.3	c	6.6	c	55.3	e	6	Colombia
58	CI 10071 WOLFE	4336	b	72	a	36.2	j	93.0	a	10.0	c	61.3	c	6	Canada
10	MCU 3870 PI 402348	5534	a	76	a	37.3	j	96.0	a	6.6	c	58.0	d	6	Colombia
42	MCU 3502 PI 401980	4663	b	81	a	40.3	i	84.6	b	0.0	c	60.0	c	6	Colombia
47	CI 12068 MAZOWIECKI	4596	b	57	b	37.1	j	81.3	b	43.3	b	58.0	d	6	Poland
31	MCU 3654 PI 402132	4972	b	56	b	44.3	f	75.6	c	3.3	c	55.3	e	6	Colombia
7	MCU 3449 PI 401927	6073	a	72	a	51.4	d	73.6	c	1.6	c	58.3	d	6	Colombia
20	CI 06244	5213	a	64	b	40.5	i	77.0	c	81.6	a	55.3	e	6	USA
29	CI 09952	5012	b	80	a	50.5	d	84.0	b	5.0	c	59.3	c	6	Russia
55	MCU 3884 PI 402362	4428	b	75	a	40.8	i	64.6	d	3.3	c	61.0	c	6	Colombia
9	MCU 3852 PI 402330	5716	a	71	a	41.9	h	77.3	c	0.0	c	62.0	b	6	Colombia
51	CI 12367 BRANISOVKY	4530	b	61	b	36.4	j	84.3	b	6.6	c	62.3	b	2	Czech Republic
17	MCU 3865 PI 402343	5348	a	73	a	49.6	d	74.6	c	0.0	c	52.6	f	6	Colombia
68	CARINA PI 371632	3335	b	72	a	42.1	g	72.6	c	0.0	c	53.6	f	2	Germany
5	MCU 3634 PI 402112	6138	a	82	a	44.4	f	91.0	a	0.0	c	55.0	e	6	Colombia
8	CI 12918	5932	a	62	b	50.5	d	85.0	b	83.3	a	58.0	d	6	Ethiopia
13	MCU 3750 PI 402228	5454	a	70	a	43.3	g	93.0	a	0.0	c	57.3	d	6	Colombia
41	CI 15323 2222-79	4689	b	46	c	35.4	k	73.0	c	96.6	a	57.3	d	6	Tunisia
4	MCU 3878 PI 402356	6382	a	65	b	44.8	f	92.6	a	0.0	c	57.3	d	6	Colombia
67	CI 09962	3478	b	64	b	50.2	d	78.3	c	40.0	b	57.0	d	6	Iran
45	MCU 3478 PI 401956	4616	b	59	b	40.3	i	84.3	b	6.6	c	57.3	d	6	Colombia
66	CI 06109 VELVON	3492	b	43	c	41.6	h	86.0	b	50.0	b	57.3	d	6	USA
48	CI 14041	4587	b	53	b	40.9	h	82.3	b	13.0	c	57.3	d	6	Ethiopia
19	CI 07772	5250	a	42	c	40.5	i	57.6	e	66.6	b	58.6	d	6	India
6	CI 15580 QB 136-41	6105	a	55	b	38.3	j	95.0	a	60.0	b	57.3	d	6	Canada
57	MCU 3454 PI 401932	4342	b	59	b	40.3	i	63.0	d	23.0	c	58.0	d	6	Colombia
62	CI 15279 2528-23	3943	b	38	c	50.4	d	64.0	d	88.3	a	58.0	d	6	Tunisia
34	CI 10017 RASPA COMUN 1085	4877	b	35	c	38.1	j	79.6	b	71.6	a	59.3	c	6	Colombia
64	CI 14031	3869	b	41	c	43.1	g	84.3	b	43.3	b	61.3	c	6	Ethiopia
56	MCU 3484 PI 401962	4426	b	81	a	42.7	g	78.0	c	0.0	c	59.3	c	6	Colombia
33	MCU 3461 PI 401939	4898	b	76	a	44.3	f	80.6	b	0.0	c	59.3	c	6	Colombia
18	CI 09961	5252	a	57	b	52.5	c	91.6	a	10.0	c	58.0	d	6	Iran
37	CI 14925 ELS 6402-512	4787	b	41	c	40.3	i	94.0	a	78.3	a	59.3	c	6	Ethiopia
11	CI 15565 QB 136-20	5487	a	66	b	38.2	j	92.3	a	16.0	c	59.6	c	6	Canada
54	CI 11493 FRUGHERSTE STANKAS	4452	b	68	b	53.2	c	81.0	b	6.6	c	57.3	d	2	Germany
65	CI 10078 ATLAS 57	3515	b	74	a	41.2	h	80.6	b	46.6	b	64.6	a	6	USA
49	MCU 3556 PI 402034	4572	b	54	b	43.3	g	88.6	a	16.0	c	62.6	b	6	Colombia
3	CI 15591 QB 139-1	6525	a	71	a	42.9	g	90.3	a	26.0	c	63.0	b	6	Canada
61	CI 06946	4087	b	31	c	34.6	k	93.3	a	63.3	b	59.3	c	6	Iran
52	CI 13715	4505	b	74	a	40.6	i	82.0	b	0.0	c	59.3	c	6	Colombia
27	MCU 3816 PI 402294	5039	b	64	b	38.2	j	73.0	c	30.0	b	54.3	e	6	Colombia
22	MCU 3851 PI 402329	5185	a	74	a	53.5	c	85.6	b	0.0	c	62.6	b	6	Colombia
46	MCU 3469 PI 401947	4598	b	73	a	39.9	i	80.0	b	0.0	c	64.6	a	6	Colombia
30	CI 09958	4984	b	71	a	45.8	e	75.6	c	40.0	b	58.6	d	6	Morocco
69	MCU 3827 PI 402305	3291	b	79	a	58.7	a	74.6	c	0.0	c	58.0	d	6	Colombia
23	CI 13894	5052	b	33	c	37.5	j	85.3	b	40.0	b	54.6	e	6	USA
39	CI 10501 ATHENAIS S-50-34	4710	b	60	b	44.2	f	55.6	e	93.3	a	56.6	d	6	Cyprus

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36	CI 09959	4862	b	72	a	43.4	g	76.3	c	0.0	c	57.3	d	6	Morocco
2	CI 15560 QB 136-4-1	6627	a	59	b	43.3	g	85.0	b	85.0	a	57.3	d	6	Canada
63	MCU 3489 PI 401967	3913	b	69	a	55.5	b	87.3	b	6.6	c	55.3	e	6	Colombia
35	CI 06188	4871	b	36	c	41.5	h	86.0	b	93.3	a	63.0	b	6	Mexico
28	MCU 3653 PI 402131	5025	b	68	b	43.7	g	76.0	c	50.0	b	59.3	c	6	Colombia
50	CI 12920	4555	b	53	b	45.9	e	72.0	c	83.3	a	60.6	c	6	Ethiopia
21	CI 13683 NUMAR	5213	a	40	c	46.7	e	64.6	d	60.0	b	55.3	e	6	USA
53	MCU 3719 PI 402197	4470	b	75	a	44.2	f	79.3	c	10.0	c	55.3	e	6	Colombia
40	MCU 3858 PI 402336	4705	b	73	a	41.5	h	78.0	c	16.0	c	57.6	d	6	Colombia
14	MCU 3883 PI 402361	5433	a	51	b	42.6	g	75.0	c	6.6	c	57.3	d	6	Colombia
59	GALOVER (C A N 1126) PI 361636	4280	b	29	c	37.4	j	79.3	c	0.0	c	52.6	f	2 e 6	Denmark
15	CI 10018 RASPA PRECOZ 604	5391	a	65	b	50.5	d	80.0	b	93.3	a	53.0	f	6	Colombia
24	MCU 3571 PI 402049	5049	b	82	a	50.4	d	77.6	c	0.0	c	52.6	f	6	Colombia
32	MCU 3721 PI 402199	4929	b	78	a	43.7	g	75.3	c	13.0	c	53.0	f	6	Colombia
38	E 3/416 PI 356495	4723	b	55	b	37.4	j	94.3	a	90.0	a	53.0	f	6	Ethiopia
43	HHOR 2325/58 PI 329126	4663	b	36	c	32.6	l	67.0	d	10.0	c	57.3	d	6	Afghanistan
26	MCU 3452 PI 401930	5045	b	74	a	40.5	i	76.6	c	6.6	c	56.0	d	6	Colombia
60	MCU 3832 PI 402310	4249	b	57	b	37.5	j	77.0	c	0.0	c	57.3	d	6	Colombia
16	MCU 3592 PI 402070	5353	a	64	b	49.9	d	71.0	c	10.0	c	58.0	d	6	Colombia
1	BRS 180	7318	a	76	a	40.5	i	83.0	b	0.0	c	61.0	c	6	Brazil
	Mean	4900		61		43.4		80.1		30.3		57.9			
	H^2	54.2		90.0		99.2		89.6		88.2		92.7			
	CV	18.5		12.5		1.9		6.1		66.5		2.2			

[1]Rank - Ranking of genotypes in relation to the Yield characteristic. [2]TE - Type of ear; [2]CO - Country of origin.

For the characteristic PK, the value used by the breeding program of Embrapa Cerrados and recommended by the Brazilian Ministry of Agriculture, Livestock, and Supply (MAPA) is >80% (Brasil 1996). The larger the grain is, the higher the proportion of starch and, consequently, the higher the efficiency of sugar usage in beer production. Among the 69 genotypes assessed, 27 were classified above 80% in 2012, and only 12 and five genotypes were classified above 80% in 2013 and 2014, respectively (Tables 3, 4, and 5). The mean PK along the three years had the same performance, with the highest mean observed in 2012 (73.1%), followed by those in 2013 (65.7%) and 2014 (61.9%). Amabile et al. (2017) reported a mean of 83% for 39 elite genotypes evaluated in 2009, and these values served as a goal for selection. The most promising genotypes for their high classification and stability were the Colombian six-row MCU 3634 PI 402112, MCU 3469 PI 401947, and MCU 3502 PI 401980, reaching values above 91% in 2012 (Tables 3, 4, and 5).

For the characteristic thousand seeds weight (TSW), the Iranian genotypes I 0996 and CI 09961 and the Moroccan CI 09958 had the highest weights, with values typically above 50 g. The genotype with the lowest value was also of Iranian origin (CI 06946), with a weight ranging from 33 to 34 g within the three years. The yearly means were similar, with the highest value reported in 2012 (45.1 g). In 2013, the lowest mean was recorded (41.1 g), and in 2014, the mean was 43.3 g (Tables 3, 4, and 5). A great variation in relation to this trait, with values between 33 and 64 g among the 18 Ethiopian genotypes, was obtained by Adissu and Shumet (2015). Values with great variation were also described by Amabile et al. (2017) and Sayd et al. (2017) in brewery barley in the Cerrado.

The plant height ranged from 55.6 cm (H HOR 2325/58 PI 329126) to 96.0 cm (MCU 3870 PI 402348) (Tables 2 and 4). The highest genotypes were of Canadian and Colombian origin, with values above 80 cm. In the year 2012, the lowest mean (75.7 cm) was recorded, followed by those recorded in 2013 (77.0 cm), and 2014 (80.1 cm). Values between 70 and 80 cm are considered ideal for the conditions of the Cerrado, thus contributing to the lower lodging of plants (Amabile et al., 2015). In breeding programs worldwide, genotypes with low size and greater resistance to lodging are sought (Ordon, Ahlemeyer, Werner, Köhler, & Friedt, 2005). Thus, the values of plant height obtained in this study showed that most of the elite accessions evaluated are adequate for the cropping system in the Cerrado.

The German two-row cultivars CARINA PI 371632 and CI 11493 FRUGHERSTE STANKAS and the six-row Colombian genotypes MCU 3832 PI 402310 and MCU 3452 PI 401930 were highly resistant to lodging in all trials (Tables 3, 4, and 5). Among the 69 genotypes evaluated, 28 had LOD values below 30%. The selection of shorter and more lodging-resistant genotypes reduces the production costs. This reduction can be attributed to not using growth reducers for crop management. The characteristic LOD had great variation among the trials due to the climate differences among the years evaluated. In 2013, when there was the highest rainfall, the lowest CEV was observed, and in general, the genotypes presented the highest percentage of lodging. In 2012 and 2014, the LOD values were lower, allowing a higher variation of the genotype performances. It is important to emphasize that the correlation between lodging and Yield was low and not significant (Table 2), as observed by Amabile et al. (2015). This result indicates the feasibility of selecting genotypes with high yield and low lodging levels.

The feasibility of barley in the Cerrado is primarily correlated with the irrigated cropping system. In this environment, it is essential to search for earlier genotypes with heading cycles and, consequently, to select those genotypes with the most efficient use of water. In the irrigated system, the relevance of early genotypes is also due to the economic bias because the irrigated area is cleared as quickly as possible for the next crop. The Colombian genotype MCU 3634 PI 402112 was an area that presented a lower DH, ranging from 51 to 55 days over the three years (Tables 3, 4, and 5). This genotype, in addition to being early, was one of the outstanding genotypes in terms of grain yield, and held potential to be selected for future evaluations and to compose the breeding basis of the breeding program. In addition to this genotype, other Colombian genotypes were highlighted for their precocity.

The means of DH among the years were close, at 57.6 days in 2012, 60.3 days in 2013, and 57.9 days in 2014 (Tables 3, 4, and 5). The evaluated genotypes obtained heading dates of same magnitude as those found by Amabile et al. (2015), who reported a mean of 59 days for 39 elite barley genotypes under irrigation in the Cerrado.

The values obtained are considered precocious when compared to Palestinian varieties that showed a DH ranging from 88 to 112 days (Shtaya et al., 2015), 20 Ethiopian genotypes (74 to 100 days) evaluated by Ebrahim, Shiferaw, and Hailu (2015), 36 Ethiopian varieties that showed a DH ranging from 65 to 92 days (Addisu & Shumet, 2015), and even more compared to winter genotypes with a cycle of 180 days (Sameri, Takeda, & Komatsuda, 2006).

Based on the genetic parameters obtained for the 69 elite barley accessions evaluated under an irrigated system in the Cerrado during three consecutive years of cropping, the experimental precision and accuracy for most agronomic characteristics were considered adequate. In addition, the effect of the G x E interaction was observed for all agronomic characteristics evaluated, which indicated the importance of the evaluation of elite accessions in different years and environments to subsidize the selection of more adapted and stable genotypes in the conditions of the Cerrado.

Conclusion

The Colombian accession MCU 3634 PI 402112 was the main agronomic characteristic evaluated. Moreover, we selected early genotypes with high grain yields and homogeneous grain sizes, which are important characteristics for irrigated systems in the Cerrado and for use in the brewing industry. Therefore, due to the great environmental influence on the grain yield, it is necessary to evaluate the genotypes in different environments and years to promote the selection of the best materials with experimental precision and accuracy.

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