REFERÊNCIA
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Agronomic characterization of high-yielding irrigated barley accessions in the Cerrado

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Abstract – The objective of this work was to estimate the genetic, phenotypic, and environmental parameters of 113 barley accessions (*Hordeum vulgare*), previously selected based on high yield, in an irrigated production system in the Cerrado (Brazilian savanna), for use in breeding programs in Brazil. The experiment was conducted in 2013 at two sites in the Federal District, using a randomized complete block design with three replicates. The evaluated traits were: grain yield, kernel plumpness, thousand grain weight, plant height, lodging, and days to heading. Significant differences were observed between environment and accessions for all studied traits, as well as genotype x environment interaction. The MCU 3832 PI 402310, MCU 3484 PI 401962, CI 08053 Custer, MCU 3634 PI 402112, and MCU 3816 PI 402294 accessions stood out regarding grain yield and kernel plumpness. It is possible to obtain high selection gains with high heritability values. However, indirect selection is not recommended in the experimental conditions due to the low genotypic and phenotypic correlations obtained. It is also possible to select barley accessions with high yield and early heading date simultaneously, an important factor in the genotype selection process for future experiments. The accessions from Colombia are the most adapted to the Cerrado conditions.

Index terms: *Hordeum vulgare*, elite genotypes, genetic resources, malting quality, plant breeding.

Caracterização agronômica de acessos de cevada de alta produtividade sob irrigação no Cerrado

Resumo – O objetivo deste trabalho foi estimar parâmetros genéticos, fenotípicos e ambientais de 113 acessos de cevada (*Hordeum vulgare*), previamente selecionados com base em alta produtividade, em sistema de produção irrigado no Cerrado, para uso em programas de melhoramento no Brasil. O experimento foi realizado em 2013, em dois locais no Distrito Federal, tendo-se utilizado o delineamento experimental de blocos ao acaso, com três repetições. Avaliaram-se as características: rendimento de grãos, classificação comercial de primeira, peso de mil grãos, altura de plantas, acamamento e dias para espigamento. Foram observadas diferenças significativas entre ambientes e acessos para todas as características avaliadas, além de interação genótipo x ambiente. Os acessos MCU 3832 PI 402310, MCU 3484 PI 401962, CI 08053 Custer, MCU 3634 PI 402112 e MCU 3816 PI 402294 destacaram-se em relação ao rendimento de grãos e à classificação comercial de primeira. É possível obter altos ganhos de seleção com altos valores de herdabilidade. No entanto, a seleção indireta não é recomendada nas condições experimentais, em razão das baixas correlações genotípicas e fenotípicas obtidas. Também é possível a seleção simultânea de acessos de cevada com alto rendimento e ciclo de espigamento precoce, fator decisivo no processo de escolha de genótipos para futuros experimentos. Os acessos colombianos são os mais adaptados às condições de Cerrado.

Termos para indexação: *Hordeum vulgare*, genótipos de elite, recursos genéticos, qualidade de malteação, melhoramento de plantas.

Introduction

Barley is the fourth most grown cereal crop in the world, after corn, wheat, and rice. It is a plant with great adaptability, sown in several regions of the globe and at different latitudes. In Brazil, it is mainly sown in the South as a winter crop (Agostinetto et al., 2015). The country produces 317 thousand tons in 85 thousand hectares (Faostat, 2016), which only meets 43% of the demands of the Brazilian malt-production industry. For this reason, to supply the national beer industry, 350 thousand tons of barley are still imported

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yearly to reach the production of 1.3 million tons of malt (Ferreira et al., 2016).

Irrigated barley is cultivated in the states of Goiás, São Paulo, Minas Gerais, and in Distrito Federal, while dryland barley is grown in the states of the Southern region of Brazil, where the BRS Brau, BRS Elis, and BRS Cauê cultivars are used (Minella et al., 2013). Recently, other cultivars have been recommended for the Cerrado (Brazilian savanna) region, such as BRS 195, BRS Sampa, BRS - Deméter, BRS Manduri, and BRS Savanna (Amabile et al., 2014).

However, despite the availability of cultivars, Brazil still remains as one of the world's largest malt importers due to the small production in the country. In order to reduce this dependency, there is a continuous and growing demand for genotypes with malting quality adapted to the Cerrado region, which makes the selection of genotypes in this specific environment necessary (Amabile et al., 2013).

This shows that more knowledge about the genetic resources of barley is fundamental, especially when considering elite genotypes with good agronomic traits, originating from different plant breeding programs from several parts of the world. In this context, the characterization of genetic resources for breeding programs has been contributing significantly to the main qualitative and quantitative gains of Brazilian agriculture. More specifically, barley evaluation, selection, and breeding are important for the development of genetic materials that fill the requirements of the irrigated production system of the Cerrado, establishing the species as an economic and agronomic alternative for the region.

The objective of this work was to estimate the genetic, phenotypic, and environmental parameters of 113 barley accessions (*Hordeum vulgare*), previously selected based on high yield, in an irrigated production system in the Cerrado (Brazilian savanna), for use in breeding programs in Brazil.

Materials and Methods

A total of 113 hulled beer barley (*Hordeum vulgare* L.) acessions of two-row an six-row were evaluated, and the six-row cultivar BRS 180 was used as the control (Tables 1 and 2). Theses accessions were previously selected for grain yield in a study performed by Monteiro (2012) at Embrapa Cerrados, agronomically characterizing 435 accessions of barley from the germplasm bank of Embrapa Recursos Genéticos e Biotecnologia. The experiments were conducted from May to September 2013 in two sites in Distrito Federal, Brazil, under center pivot irrigation system. Site 1 is located in the experimental field of Embrapa Cerrados (CPAC) (15º35'57"S, 47º42'38"W, at an altitude of 1,007 m), whereas site 2 is located at the experimental field of Embrapa Produtos e Mercado (SPM) (15°54'53"S, 48°02'14"W, at an altitude of 1,254 m). The soil of both sites is classified as a Latossolo Vermelho distrófico típico argiloso (Rhodic Hapludox). A randomized complete block design with three replicates was used. 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, with a density of 300 plants per square meter. According to the soil analysis, 16 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5, and 64 kg ha^{-1} K_2O were applied to the sowing groove, and 40 kg ha^{-1} N were applied by the time the fifth fully expanded leaf arose (Amabile et al., 2007).

Six traits were evaluated: estimated grain yield (kg ha^{-1}); kernel plumpness (>2.5 mm) in percentage, according to Brasil (1996); thousand grain weight (TSW) in grams (Regras…, 2009); plant height in centimeters, as the average of three plants per plot; degree of plant lodging (LOD), with data transformed into arc sine $X^{0.5}\times100^{-1}$, in which X is the value in percentage of lodging; and days to heading (DH), which is the period, in days, from emergence to when 50% of the spikes inside the useful area of the plot were visible. The assessments of plant height, degrees of lodging, and heading were performed in the experimental fields of CPAC and SPM. The evaluations of grain yield, kernel plumpness, and TSW were carried out at the seed laboratory of Embrapa Cerrados.

The collected data were subjected to analysis of variance (Anova), and the averages were grouped by the Scott-Knott test, at 1% probability. Phenotypic variance (σ^2_f), genotypic quadratic component (σ^2_g), heritability (h^2), and the coefficients of environmental (EVC), genetic (GVC), and relative (CVr) variance were estimated for each trait, using the Genes software (Universidade Federal de Viçosa, Viçosa, MG, Brazil). For the Anova, individual and group analyses were also performed for each trait.

The phenotypic, genotypic, and environmental correlations were measured based on the estimates of

Table 1. Averages of 113 barley (*Hordeum vulgare*) accessions for different traits at the Embrapa Cerrados site.

Genotype	Origin	Yield (kg ha^{-1})	PK (%)	TSW (g)	Height (cm)	LOD (arc sine)	DH (days)	Type	Cultivar	Color
2075C PI 371450	Switzerland	5,318.0c	26.0o	33.6g	79.0h	0.0j	64.7e	6	Yes	Cream
MCU 3592 PI 402070	Colombia	4,087.0g	51.3i	40.0e	86.0e	0.0j	52.7m	6	No	Cream
MCU 3458 PI 401936	Colombia	4,443.3f	25.3o	36.6f	64.3n	0.0977a	54.0l	6	No	Cream
MCU 3576 PI 402054	Colombia	4,520.3e	12.0q	31.6g	90.0c	0.0j	55.0l	6	Yes	Cream
MCU 3832 PI 402310	Colombia	5,847.3b	42.6l	33.3g	80.0g	0.0j	60.0h	6	No	Cream
MCU 3452 PI 401930	Colombia	3,821.0g	61.6g	35.0g	64.0n	0.0j	56.3k	6	No	Cream
H HOR 2325/58 PI 329126	Afghanistan	3,586.6h	35.6m	35.6	60.3	0.0j	65.0e	6	Yes	Cream
CI 15324 2260-85	Tunisia	3,391.6h	58.6h	36.3f	69.3l	0.044h	65.0e	6	Yes	Cream
MCU 3568 PI 402046	Colombia	5,330.6c	44.3k	33.0g	70.0l	0.0733d	52.0m	6	No	Cream
E 3/416 PI 356495	Ethiopia	4,814.6e	16.6p	32.0g	57.6p	0.1a	61.7g	6	Yes	Cream
CI 15325 2244-87	Tunisia	4,215.0f	40.6l	37.0	78.3h	0.0363h	64.7e	6	Yes	Cream
CI 06450 Oziery	Poland	3,526.0h	33.0n	28.3h	83.6f	0.0j	60.3h	6	Yes	Cream
CI 14857 ELS 6402-441	Ethiopia	1,905.3j	51.0f	36.6f	78.0h	0.0j	68.0b	6	Yes	Cream
MCU 3721 PI 402199	Colombia	2,845.6i	51.6g	34.0g	76.6i	0.0543g	63.7f	6	Yes	Cream
MCU 3571 PI 402049	Colombia	4,735.0e	61.0g	32.0g	75.6i	0.0983a	52.0m	6	No	Cream
CI 10018 Raspas Precoz 604	Colombia	3,484.0h	42.3c	43.0c	74.0j	0.0977a	56.3k	6	Yes	Cream
CI 13069 Irba Moda	Ethiopia	3,421.3h	11.6q	36.0f	88.0d	0.0977a	57.3j	6	Yes	Cream
CI 11684	Afghanistan	3,381.0h	29.3o	38.6e	77.3i	0.0983a	68.0b	6	No	Cream
CI 15296 Djebali 2316-57	Tunisia	2,759.6i	46.3k	41.6d	85.0e	0.0977a	66.0d	6	Yes	Cream
CI 07416 Dang – Bari 42	South Korea	1,536.3j	53.3i	33.0g	80.0g	0.044h	70.7a	6	Yes	Cream
Galover (C A N 1126) PI 361636	Denmark	5,609.3c	44.6k	31.3g	82.3f	0.0983a	62.3g	2/6	Yes	Cream
CI 10016 Raspa	Colombia	3,942.3g	35.3m	32.3g	94.6b	0.0543g	65.3e	6	Yes	Cream
MCU 3883 PI 402361	Colombia	4,318.0f	31.6n	36.0f	83.3f	0.063f	54.7l	6	Yes	Cream
MCU 3858 PI 402336	Colombia	4,030.0g	71.0e	40.3d	82.3f	0.044h	58.7i	6	Yes	Cream
MCU 3656 PI 402134	Colombia	4,374.0f	32.3n	37.6e	81.0g	0.0993a	58.0i	6	No	Cream
CI 14712 Orange Lemma	United States	4,304.6f	26.0o	27.6h	94.0b	0.0683e	59.0i	2/6	No	Cream
MCU 3719 PI 402197	Colombia	4,235.0f	64.6f	40.3d	79.0h	0.0683e	65.7d	6	Yes	Cream
CI 13683 Numar	United States	5,959.3b	31.6n	44.6c	84.0f	0.0983a	69.0b	6	Yes	Cream
CI 12920	Ethiopia	4,488.0f	53.0i	40.6d	85.3e	0.0977a	58.3i	6	Yes	Cream
MCU 3653 PI 402131	Colombia	4,953.0d	61.0g	38.6e	90.0c	0.0983a	54.3l	6	Yes	Cream
CI 06147	Egypt	3,866.6g	46.3k	35.0g	97.3a	0.0983a	67.0c	6	Yes	Cream
CI 12916	Ethiopia	3,465.6h	52.6i	39.3e	94.0b	0.0993a	65.7d	6	Yes	Cream
MCU 3780 PI 402258	Colombia	4,307.0f	59.6g	36.6f	81.3g	0.0543g	64.7e	6	Yes	Cream
CI 06188	Mexico	3,790.3g	41.0l	35.6f	84.3f	0.0993a	67.3c	6	Yes	Cream
MCU 3489 PI 401967	Colombia	4,134.0f	68.0f	40.3d	84.0f	0.0683e	57.0j	6	Yes	Cream
CI 15560 QB 136-4-1	Canada	5,733.0b	49.0j	33.0g	87.0q	0.0983a	65.0e	6	No	Cream
CI 09959	Morocco	4,952.6d	84.6b	45.0c	73.0q	0.0543g	57.3j	6	Yes	Cream
CI 15280 2728-25	Tunisia	3,071.3i	46.0k	38.0r	81.0g	0.0993a	67.3c	2/6	Yes	Cream
CI 10501 Athenais S-50-34	Cyprus	4,157.3f	62.3g	35.6f	79.6g	0.0977a	58.0i	6	Yes	Cream
CI 13894	United States	5,823.0b	51.0i	36.0i	76.0i	0.0j	60.3h	6	No	Cream
CI 12271	Iran	4,064.0g	45.3k	29.3j	73.6j	0.0483g	66.7c	6	Yes	Cream
MCU 3876 PI 402354	Colombia	3,457.0h	32.6n	43.6i	76.6i	0.0683e	52.7m	6	Yes	Cream
MCU 3827 PI 402305	Colombia	4,444.0f	63.3g	41.0m	68.0m	0.088b	51.0n	6	No	Cream
CI 09958	Morocco	3,199.0h	87.6b	58.0i	76.0i	0.0617f	57.0j	6	Yes	Cream
MCU 3469 PI 401947	Colombia	5,749.6b	75.0d	44.0i	76.0i	0.0407h	52.7m	6	No	Cream
MCU 3851 PI 402329	Colombia	5,828.6b	70.6j	38.3j	74.0j	0.0993a	63.7f	6	No	Cream
MCU 3816 PI 402294	Colombia	5,067.6d	72.0e	44.0j	74.3j	0.088b	54.3l	6	No	Cream
CI 13715	Colombia	4,284.6f	61.6g	44.3c	61.6o	0.0983a	55.3k	6	No	Cream
CI 10256	Japan	3,432.6h	67.0f	46.0c	63.3n	0.0983a	52.3m	6	Yes	Cream
CI 06946	Iran	5,234.6d	32.6n	34.0g	84.0f	0.0977a	60.7h	6	Yes	Cream
CI 07255	United States	5,245.6d	32.3n	34.0g	99.0a	0.0983a	60.0h	6	No	Cream
BRS 180	Brazil	6,142.0a	73.6d	39.3e	84.0f	0.0j	59.0i	6	Yes	Cream
CI 15591 QB 139-1	Canada	4,736.0e	62.3g	35.3	86.0e	0.0977a	57.7j	6	No	Cream
CI 07607	India	4,148.3f	38.0m	39.0e	69.0l	0.0977a	55.3k	6	No	Cream
MCU 3556 PI 402034	Colombia	3,455.3h	71.6e	42.0d	87.6d	0.0j	64.0f	6	No	Cream
CI 07156	United States	3,830.3g	36.3m	38.6e	76.0i	0.0993a	69.3b	6	No	Cream
CI 10078 Atlas 57	United States	5,516.6c	85.0b	43.0c	85.6e	0.0543g	68.7b	6	Yes	Cream

Continuation...

Continuation...

Genotype	Origin	Yield (kg ha-1)	PK (%)	TSW (g)	Height (cm)	LOD (arc sine)	DH (days)	Type	Cultivar	Color
CI 11493 Frugherste Stankas	Germany	4,728.0e	82.0c	49.0b	67.0m	0.0j	66.0d	2	Yes	Cream
CI 09882 Gondar	Ethiopia	4,787.0e	35.0m	44.3c	82.0f	0.0407h	70.7a	6	Yes	Cream
CI 12598	Ethiopia	3,230.6h	49.3j	48.0b	70.3l	0.056g	55.7k	6	Yes	Cream
CI 10082 Weibull S 4468	Sweden	3,496.6h	56.3h	41.3d	79.0h	0.0977a	67.3c	2	Yes	Cream
CI 15565 QB 136-20	Canada	4,861.3e	71.6e	42.3d	84.0f	0.0943a	67.0c	6	No	Cream
CI 14925 ELS 6402-512	Ethiopia	4,171.6f	56.3h	44.6c	79.0h	0.0993a	66.0d	6	Yes	Cream
2043C PI 371415	Switzerland	2,823.3i	53.3i	41.0d	67.0m	0.0967a	66.0d	6	Yes	Cream
CI 09961	Iran	5,553.3c	85.3b	48.6b	80.0g	0.088b	60.3h	6	Yes	Cream
CI 08053 Custer	United States	5,719.3b	56.0h	43.3c	88.6d	0.0993a	67.3c	6	Yes	Cream
MCU 3461 PI 401939	Colombia	3,644.3h	68.0f	43.3c	91.0c	0.088b	62.0g	6	No	Cream
MCU 3484 PI 401962	Colombia	6,508.3a	71.6e	34.3g	86.0e	0.0787d	50.3n	6	No	Cream
CI 14031	Ethiopia	3,719.0g	56.6h	40.0e	83.6f	0.0603f	67.0c	6	Yes	Cream
CI 10017 Raspa Comun 1085	Colombia	4,193.6f	70.0e	43.6c	78.0h	0.0983a	65.7d	6	Yes	Cream
CI 15279 2528-23	Tunisia	5,430.0c	72.6d	45.6c	83.0f	0.0977a	65.7d	6	Yes	Cream
CI 15302 1356-33	Tunisia	3,550.0h	40.3l	38.3e	85.0e	0.0993a	63.7f	6	Yes	Cream
MCU 3454 PI 401932	Colombia	4,600.0e	71.3e	44.3c	85.0e	0.0933a	60.7h	6	No	Cream
CI 15580 QB 136-41	Canada	5,983.0b	73.3d	45.3c	95.0b	0.0757d	62.7g	6	No	Cream
CI 07772	India	5,005.0d	61.0g	41.3d	69.0l	0.088b	52.0m	6	Yes	Cream
CI 14041	Ethiopia	3,629.3h	68.6f	46.0c	80.0g	0.0517g	68.7b	6	Yes	Cream
MCU 3467 PI 401945	Colombia	4,593.3e	71.6e	40.3d	87.6d	0.0603f	62.7g	6	No	Cream
CI 06109 Velvon	United States	4,987.3d	70.0e	40.6d	79.3h	0.0763d	68.7b	6	Yes	Cream
MCU 3478 PI 401956	Colombia	5,524.6c	71.6e	36.0f	83.0f	0.085b	60.0h	6	No	Cream
CI 09962	Iran	4,671.0e	91.6a	57.0a	69.3l	0.063f	60.3h	6	Yes	Cream
MCU 3878 PI 402356	Colombia	4,234.6f	60.0g	39.6e	73.0j	0.0603f	53.3m	6	No	Cream
CI 10697	Iran	4,642.6e	42.6l	48.3b	79.6g	0.0977a	57.0j	6	Yes	Cream
CI 15323 2222-79	Tunisia	3,636.0h	70.0e	48.6b	79.6g	0.0983a	65.7d	6	Yes	Cream
MCU 3750 PI 402228	Colombia	4,634.0e	84.3b	47.6b	72.0k	0.0423h	63.7f	6	No	Cream
CI 12918	Ethiopia	4,471.3f	82.3c	48.6b	76.0i	0.0977a	62.7g	6	Yes	Cream
MCU 3634 PI 402112	Colombia	6,031.6b	70.3e	35.6f	83.3f	0.0977a	54.7l	6	No	Cream
E 273/4 PI 356414	Ethiopia	3,845.3g	61.6g	45.0c	59.6o	0.063f	60.7h	6	Yes	Cream
Carina PI 371632	Germany	4,050.0g	84.0b	40.6d	80.0g	0.0j	67.7c	2	Yes	Cream
CI 15281 3102-16	Tunisia	4,116.6f	52.6i	41.0d	84.6e	0.0993a	67.7c	2/6	Yes	Cream
CI 02109 White Smyrna	United States	4,230.3f	68.3f	46.6b	85.6e	0.0983a	60.7h	2	Yes	Cream
MCU 3865 PI 402343	Colombia	4,939.6d	73.0d	45.3c	74.0j	0.0407h	61.3h	6	No	Cream
CI 13704	England	3,309.0h	70.0e	48.6b	83.0f	0.0577g	58.0i	2	Yes	Black
CI 12367 Branisovicky	Czech Republic	5,275.3d	81.0c	40.0e	76.0i	0.02i	67.3c	2	Yes	Cream
CI 12262	Iran	3,988.0g	52.3i	44.0c	78.6h	0.084c	64.3e	6	Yes	Cream
CI 10114 Carlsberg II	Denmark	2,943.0i	58.3h	42.3d	73.0j	0.0603f	66.3d	2	Yes	Cream
MCU 3852 PI 402330	Colombia	4,541.0e	74.0d	39.6e	69.6l	0.0387h	60.3h	6	No	Cream
A HOR 55/61 PI 327910	Bulgaria	4,262.3f	48.3j	39.6e	72.6j	0.088b	60.7h	6	Yes	Cream
CI 10140	Afghanistan	4,642.6e	72.3e	40.6d	77.6h	0.0533g	54.3l	6	Yes	Cream
MCU 3884 PI 402362	Colombia	5,111.0d	61.0g	44.6c	64.3n	0.0983a	52.3m	6	No	Cream
MCU 3778 PI 402256	Colombia	4,656.6e	71.6e	39.0e	94.0b	0.096a	63.0g	6	Yes	Cream
CI 09952	Russia	4,322.0f	82.0c	44.6c	84.0f	0.088b	57.7j	6	Yes	Cream
MCU 3448 PI 401926	Colombia	5,635.3c	59.3g	38.6e	88.6d	0.0363h	55.7k	6	No	Cream
CI 06244	United States	5,136.3d	71.0e	40.6d	76.0i	0.0983a	60.3h	6	Yes	Cream
MCU 3449 PI 401927	Colombia	5,767.6b	72.3e	50.0b	82.3f	0.0j	61.7g	6	No	Cream
MCU 3654 PI 402132	Colombia	5,065.6d	79.6c	38.3e	79.0h	0.088b	54.3l	6	No	Cream
CI 12068 Mazowiecki	Poland	5,128.3d	68.6f	33.3g	81.3g	0.096a	60.7h	6	Yes	Cream
MCU 3502 PI 401980	Colombia	5,147.3d	81.0c	43.3c	87.0d	0.0917b	58.7i	6	No	Cream
MCU 3870 PI 402348	Colombia	5,237.6d	74.3d	38.3e	94.3b	0.0993a	60.3h	6	No	Cream
CI 10071 Wolfe	Canada	5,337.6c	74.3d	39.0e	91.6c	0.0977a	60.0h	6	Yes	Cream
CI 13711	Colombia	5,533.6c	72.0e	41.0d	84.0f	0.0993a	59.7h	6	No	Cream
CI 10022	Colombia	5,444.0c	69.3e	42.3d	69.6l	0.0977a	58.7i	6	Yes	Cream
CI 13824 Atlas 68	United States	4,314.3f	75.0d	44.3c	79.0h	0.095a	63.3g	6	Yes	Cream
MCU 3850 PI 402328	Colombia	5,446.6c	85.6b	44.6c	78.6h	0.089b	61.0h	6	Yes	Cream

[(1)]Yield, grain yield, PK; kernel plumpness; TSW, thousand seed weight; Height, plant height; LOD, lodging; and DH, days to heading. Different letters next to treatments indicate significant differences by the Scott-Knott test, at 1% probability.

Table 2. Averages of 113 barley (*Hordeum vulgare*) accessions for different traits at the Embrapa Produtos e Mercado site.

Genotype	Origin	Yield (kg ha^{-1})	PK (%)	TSW (g)	Height (cm)	LOD (arc sine)	DH (days)	Type	Cultivar	Color
2075C PI 371450	Switzerland	6,009i	70.6c	46.0e	85.0c	0.0107e	51.0i	6	Yes	Cream
MCU 3592 PI 402070	Colombia	6,468g	77.3b	33.3h	94.3a	0.0000f	50.3j	6	No	Cream
MCU 3458 PI 401936	Colombia	5,530k	53.0e	48.0d	74.0e	0.1000a	50.0j	6	No	Cream
MCU 3576 PI 402054	Colombia	5,061l	52.3e	46.0e	96.3a	0.0107e	49.6j	6	Yes	Cream
MCU 3832 PI 402310	Colombia	7,695b	78.6b	41.0f	87.6b	0.0000f	50.6j	6	No	Cream
MCU 3452 PI 401930	Colombia	7,154d	88.3a	51.0c	77.6d	0.0000f	51.0i	6	No	Cream
H HOR 2325/58 PI 329126	Afghanistan	9,187a	78.3b	43.6f	74.3e	0.0000f	53.0h	6	Yes	Cream
CI 15324 2260-85	Tunisia	5,731j	71.0c	46.3e	77.3d	0.0720b	52.0i	6	Yes	Cream
MCU 3568 PI 402046	Colombia	7,241d	60.3d	42.3f	83.0c	0.1000a	49.6j	6	No	Cream
E 3/416 PI 356495	Ethiopia	7,082e	79.0b	39.3g	69.0e	0.1000a	52.6h	6	Yes	Cream
CI 15325 2244-87	Tunisia	4,784m	70.3c	47.3e	85.0c	0.0500d	50.0j	6	Yes	Cream
CI 06450 Oziery	Poland	6,272h	67.0c	39.3g	87.6b	0.0107e	50.6j	6	Yes	Cream
CI 14857 ELS 6402-441	Ethiopia	5,348l	63.6c	43.3f	88.0b	0.0107e	56.6f	6	Yes	Cream
MCU 3721 PI 402199	Colombia	5,583k	90.3a	53.0c	86.0c	0.0670c	56.0g	6	Yes	Cream
MCU 3571 PI 402049	Colombia	6,533g	86.6a	44.3f	85.0c	0.1000a	49.3j	6	No	Cream
CI 10018 Raspa Precoz 604	Colombia	6,669f	72.0c	44.6e	84.3c	0.1000a	52.0i	6	Yes	Cream
CI 13069 Irba Moda	Ethiopia	5,304l	40.6e	48.0d	91.0b	0.1000a	51.6i	6	Yes	Cream
CI 11684	Afghanistan	5,219l	67.6c	43.0f	87.0b	0.1000a	58.0e	6	No	Cream
CI 15296 Djebali 2316-57	Tunisia	5,381l	83.6a	54.0c	90.0b	0.1000a	58.0e	6	Yes	Cream
CI 07416 Dang – Bari 42	South Korea	3,923o	77.3b	32.3h	87.3b	0.0630c	58.3e	6	Yes	Cream
GALOVER (C A N 1126) PI 361636	Denmark	5,815j	81.0b	36.6g	90.0b	0.1000a	51.0i	2/6	Yes	Cream
CI 10016 Raspa	Colombia	4,761m	84.6a	52.6c	98.3a	0.0707b	53.3h	6	Yes	Cream
MCU 3883 PI 402361	Colombia	6,138h	69.3c	46.3e	92.3b	0.0870a	54.3h	6	Yes	Cream
MCU 3858 PI 402336	Colombia	6,078i	82.6b	45.3e	87.6b	0.0543c	54.0h	6	Yes	Cream
MCU 3656 PI 402134	Colombia	5,025l	47.0e	42.0f	92.3b	0.1000a	54.3h	6	No	Cream
CI 14712 Orange Lemma	United States	4,801m	48.3e	42.6f	97.6a	0.0830b	53.3h	2/6	No	purple
MCU 3719 PI 402197	Colombia	6,433g	88.6a	52.6c	87.6b	0.0880a	55.0g	6	Yes	Cream
CI 13683 Numar	United States	7,049e	76.0b	45.6e	89.3b	0.1000a	58.0e	6	Yes	Cream
CI 12920	Ethiopia	6,268h	76.6b	53.6c	90.0b	0.1000a	61.6c	6	Yes	Cream
MCU 3653 PI 402131	Colombia	6,533g	74.0b	45.6e	96.3a	0.1000a	62.3c	6	Yes	Cream
CI 06147	Egypt	4,110o	58.6d	47.0e	98.0a	0.1000a	63.6b	6	Yes	Cream
CI 12916	Ethiopia	6,256h	68.0c	46.6e	96.0a	0.1000a	62.0c	6	Yes	Cream
MCU 3780 PI 402258	Colombia	6,258h	68.0c	46.3e	87.6b	0.0777b	60.6d	6	Yes	Cream
CI 06188	Mexico	6,234h	80.6b	45.3e	91.3b	0.1000a	61.0d	6	Yes	Cream
MCU 3489 PI 401967	Colombia	6,140h	87.6a	46.3e	87.3b	0.1000a	55.6g	6	Yes	Cream
CI 15560 QB 136-4-1	Canada	6,124h	80.0b	51.3c	84.0c	0.1000a	51.0i	6	No	Cream
CI 09959	Morocco	6,133h	85.3a	51.0c	85.3c	0.0630c	61.0d	6	Yes	Cream
CI 15280 2728-25	Tunisia	5,133l	76.3b	46.0e	85.3c	0.1000a	63.6b	2/6	Yes	Cream
CI 10501 Athenais S-50-34	Cyprus	5,695j	89.3a	54.3c	88.3b	0.1000a	56.6f	6	Yes	Cream
CI 13894	United States	6,191h	76.6b	37.3g	82.0c	0.0000f	57.6e	6	No	Cream
CI 12271	Iran	4,146o	68.0c	41.6f	83.0c	0.0707b	61.0d	6	Yes	Cream
MCU 3876 PI 402354	Colombia	5,250l	76.0b	52.6c	85.0c	0.0817b	52.6h	6	Yes	Cream
MCU 3827 PI 402305	Colombia	5,562k	89.3a	53.0c	80.0c	0.1000a	50.3j	6	No	Cream
CI 09958	Morocco	6,559g	93.0a	47.0e	82.3c	0.0777b	56.0g	6	Yes	Cream
MCU 3469 PI 401947	Colombia	6,722f	85.6a	41.3f	84.6c	0.0630c	49.6j	6	No	Cream
MCU 3851 PI 402329	Colombia	6,962e	87.6a	43.3f	82.3c	0.1000a	58.0e	6	No	Cream
MCU 3816 PI 402294	Colombia	7,724b	83.3a	47.3e	84.6c	0.1000a	56.6f	6	No	Cream
CI 13715	Colombia	6,303h	86.0a	52.0c	74.3e	0.1000a	55.0g	6	No	Cream
CI 10256	Japan	4,613n	81.6b	55.3b	74.0e	0.1000a	53.0h	6	Yes	Cream
CI 06946	Iran	5,822j	79.0b	44.3f	90.3b	0.1000a	55.6g	6	Yes	Cream
CI 07255	United States	5,756j	59.0d	46.3e	103.6a	0.1000a	49.6j	6	No	Cream
BRS 180	Brazil	7,358c	88.6a	42.6f	85.0c	0.0107e	50.0j	6	Yes	Cream
CI 15591 QB 139-1	Canada	7,286d	81.3b	50.3d	92.3b	0.1000a	51.6i	6	No	Cream
CI 07607	India	5,729j	65.0c	37.6g	82.3c	0.1000a	53.3h	6	No	Cream
MCU 3556 PI 402034	Colombia	6,336h	78.0b	42.3f	89.0b	0.0000f	53.3h	6	No	Cream
CI 07156	United States	7,037e	71.0c	46.0e	84.3c	0.1000a	61.0d	6	No	Cream
CI 10078 Atlas 57	United States	5,670j	89.0a	51.0c	92.0b	0.0827b	61.3d	6	Yes	Cream

Continuation...

Continuation...

Genotype	Origin	Yield (kg ha-1)	PK (%)	TSW (g)	Height (cm)	LOD (arc sine)	DH (days)	Type	Cultivar	Color
CI 11493 Frugherste Stankas	Germany	5,474	81.0	48.3	72.3	0.0440	57.0	2	Yes	Cream
CI 09882 Gondar	Ethiopia	5,738j	49.6e	57.0b	85.6c	0.0630c	60.6d	6	Yes	Cream
CI 12598	Ethiopia	4,538n	64.3c	51.0c	84.3c	0.0743b	49.6j	6	Yes	Cream
CI 10082 Weibull S 4468	Sweden	5,539k	66.0c	45.0e	87.6b	0.1000a	63.6b	2	Yes	Cream
CI 15565 QB 136-20	Canada	6,414g	88.3a	33.0h	90.0b	0.1000a	50.0j	6	No	Cream
CI 14925 ELS 6402-512	Ethiopia	6,358g	75.3b	44.0f	87.6b	0.1000a	50.6j	6	Yes	Cream
2043C PI 371415	Switzerland	6,460g	57.0d	33.6h	79.0d	0.1000a	53.0h	6	Yes	Cream
CI 09961	Iran	6,146h	88.0a	43.0f	90.0b	0.1000a	54.0h	6	Yes	Cream
CI 08053 Custer	United States	7,559b	65.0c	47.6e	93.6a	0.1000a	57.6e	6	Yes	Cream
MCU 3461 PI 401939	Colombia	6,751f	85.3a	47.0e	95.0a	0.1000a	51.0i	6	No	Cream
MCU 3484 PI 401962	Colombia	6,930e	82.3b	36.6g	88.0b	0.0917a	50.3j	6	No	Cream
CI 14031	Ethiopia	6,601f	79.3b	51.6c	92.6b	0.0777b	60.0d	6	Yes	Cream
CI 10017 Raspa Comun 1085	Colombia	5,534k	86.3a	51.6c	83.0c	0.1000a	57.3f	6	Yes	Cream
CI 15279 2528-23	Tunisia	6,233h	65.6c	48.6d	87.6b	0.1000a	55.6g	6	Yes	Cream
CI 15302 1356-33	Tunisia	5,098l	67.0c	33.3h	91.6b	0.1000a	56.0g	6	Yes	Cream
MCU 3454 PI 401932	Colombia	5,117l	85.3a	44.6e	89.3b	0.1000a	50.0j	6	No	Cream
CI 15580 QB 136-41	Canada	6,152h	70.3c	47.0e	94.0a	0.0917a	50.3j	6	No	Cream
CI 07772	India	5,949i	87.6a	45.3e	74.3e	0.0857a	55.0g	6	Yes	Cream
CI 14041	Ethiopia	5,918i	78.6b	58.6a	87.6b	0.0543c	56.6f	6	Yes	Cream
MCU 3467 PI 401945	Colombia	4,745m	80.3b	52.0c	90.6b	0.0707b	50.3j	6	No	Cream
CI 06109 Velvon	United States	5,181l	81.0b	53.0c	82.3c	0.0763b	60.3d	6	Yes	Cream
MCU 3478 PI 401956	Colombia	6,054i	86.0a	44.6e	86.0c	0.1000a	53.0h	6	No	Cream
CI 09962	Iran	5,758j	87.6a	62.6a	76.3d	0.0817b	56.0g	6	Yes	Cream
MCU 3878 PI 402356	Colombia	6,233h	77.0b	51.3c	84.6c	0.0683b	50.0j	6	No	Cream
CI 10697	Iran	4,740m	71.3c	53.6c	84.6c	0.1000a	50.3j	6	Yes	Cream
CI 15323 2222-79	Tunisia	5,735j	84.6a	55.3b	85.6c	0.1000a	57.6e	6	Yes	Cream
MCU 3750 PI 402228	Colombia	5,205l	84.3a	54.3c	85.6c	0.0577c	58.3e	6	No	Cream
CI 12918	Ethiopia	7,207d	77.0b	60.3a	87.6b	0.1000a	57.0f	6	Yes	Cream
MCU 3634 PI 402112	Colombia	7,132d	87.3a	46.6e	82.0c	0.1000a	51.0i	6	No	Cream
E 273/4 PI 356414	Ethiopia	6,128h	46.0e	52.0c	76.6d	0.0707b	52.0i	6	Yes	Cream
CARINA PI 371632	Germany	6,225h	75.0b	49.3d	79.0d	0.0107e	62.0c	2	Yes	Cream
CI 15281 3102-16	Tunisia	4,493	58.0	45.6	92.0	0.1000	68.0	2/6	Yes	Cream
CI 02109 White Smyrna	United States	5,054l	66.6c	54.6c	87.6b	0.1000a	60.0d	2	Yes	Cream
MCU 3865 PI 402343	Colombia	7,215d	85.6a	53.6c	83.0c	0.0707b	58.0e	6	No	Cream
CI 13704	England	4,152o	80.6b	56.0b	90.0b	0.0733b	63.0b	2	Yes	Black
CI 12367 Branisovicky	Czech Republic	5,447k	89.6a	35.3g	84.0c	0.0000f	67.3a	2	Yes	Cream
CI 12262	Iran	4,249o	79.6b	35.6g	85.0c	0.1000a	68.3a	6	Yes	Cream
CI 10114 Carlsberg II	Denmark	4,737m	88.3a	45.0e	83.3c	0.0757b	68.0a	2	Yes	Cream
MCU 3852 PI 402330	Colombia	7,360c	88.0a	47.0e	80.6c	0.0440d	57.3f	6	No	Cream
A HOR 55/61 PI 327910	Bulgaria	6,124h	60.3d	44.0f	79.0d	0.1000a	56.3f	6	Yes	Cream
CI 10140	Afghanistan	4,307o	80.6b	46.6e	87.6b	0.0777b	53.0h	6	Yes	Cream
MCU 3884 PI 402362	Colombia	6,226h	84.6a	46.6e	73.3e	0.1000a	50.3j	6	No	Cream
MCU 3778 PI 402256	Colombia	4,424n	73.6b	44.6e	95.6a	0.1000a	55.0g	6	Yes	Cream
CI 09952	Russia	6,441g	85.0a	48.3d	87.6b	0.0950a	55.3g	6	Yes	Cream
MCU 3448 PI 401926	Colombia	5,757j	71.6c	37.3g	92.3b	0.0543c	53.0h	6	No	Cream
CI 06244	United States	5,883i	84.6a	45.0e	84.3c	0.1000a	52.6h	6	Yes	Cream
MCU 3449 PI 401927	Colombia	6,818e	90.3a	51.3c	84.6c	0.0000f	50.3j	6	No	Cream
MCU 3654 PI 402132	Colombia	7,182d	90.6a	46.3e	86.6b	0.1000a	50.6j	6	No	Cream
CI 12068 Mazowiecki	Poland	6,740f	72.3c	41.6f	86.6b	0.1000a	50.6j	6	Yes	Cream
MCU 3502 PI 401980	Colombia	6,170h	92.0a	45.6e	90.6b	0.1000a	50.6j	6	No	Cream
MCU 3870 PI 402348	Colombia	7,347c	81.0b	42.0f	97.6a	0.1000a	50.3j	6	No	Cream
CI 10071 Wolfe	Canada	6,068i	81.0b	36.6g	95.0a	0.1000a	50.3j	6	Yes	Cream
CI 13711	Colombia	5,690j	79.3b	44.0f	87.6b	0.1000a	49.3j	6	No	Cream
CI 10022	Colombia	6,434g	75.6b	36.6g	82.3c	0.1000a	52.0i	6	Yes	Cream
CI 13824 Atlas 68	United States	6,738f	74.6b	52.6c	83.6c	0.1000a	53.3h	6	Yes	Cream
MCU 3850 PI 402328	Colombia	5,979i	72.6c	51.6c	87.6b	0.0897a	58.6e	6	Yes	Cream

(1)Yield, grain yield; PK, kernel plumpness; TSW, thousand seed weight; Height, plant height; LOD, lodging; and DH, days to heading. Different letters next to treatments indicate significant differences by the Scott-Knott test, at 1% probability.

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the respective variances and covariances between the traits, two by two, according to Kempthorne (1966), also using the Genes software (Universidade Federal de Viçosa, Viçosa, MG, Brazil).

For the classification of the correlations, the intervals proposed by Carvalho et al. (2004) were adopted, in which the intensities are ranked as: perfect (|r| = 1); very strong (0.90≤ |r| <1.00); strong (0.60≤ |r| <0.90); medium (0.30≤ |r| <0.60); weak (0.00< |r| <0.30); and null (r = 0).

Results and Discussion

The joint Anova showed the existence of significant differences among the accessions for all evaluated traits (Table 3), highlighting the variability among barley accessions, which is desired in pre-breeding works.

Significant effects of environment and genotype x environment interaction were also observed for the studied traits. This can be largely attributed to the difference in altitude between the experimental fields, of approximately 200 m, which directly affects temperature and favors environments of milder climates. This difference contributes to the increase in the genotype x environment interaction and, consequently, to the greater phenotypic variability of the quantitative traits, as reported by Kaczmarek et al. (1999).

According to Resende & Duarte (2007), regarding selective accuracy, in order to achieve values of 90% or more, considered ideal by Steel & Torrie (1980), F-values for the cultivar must be equal to or higher than 5.26 for a safe statistical interference. In the present study, regarding genotype x environment interaction, the F-value was only lower than the ones proposed by Resende & Duarte (2007) for lodging (4.7), showing high selection accuracy (Table 3).

Another genetic parameter that indicates experimental precision is the EVC; the lower this value is, the more precise is the experiment. However, the analysis of the EVC value must be considered according to the particularities of each trait and crop evaluated (Costa et al., 2002). In the present study, the values of the EVC varied from 1.39% for DH to 6.93% for LOD, which are considered low, indicating a good environment control (Table 3).

Genotypic variance is associated with the genetic differences among the specimens. Higher values for this component are an indication of higher genetic variability, which enables the identification of superior genotypes (Vencovsky, 1987). It was observed that the estimate of genotypic variance was the main component of phenotypic variance among the following traits: yield, kernel plumpness, TSW, height, LOD, and DH (Table 3).

The CVr is represented by the ratio between the GVC and the EVC. According to Vencovsky (1987), values above the unit for the CVr indicate good chances of gains with the application of selection among populations, suggesting that the trait can be handled with higher probability of genetic gains in breeding in experiments with two or three replicates.

The values of the GVC were higher than those of the EVC for all traits. The traits with higher CVr were: DH, yield, and LOD, with 6.23, 4.55, and 3.88%, respectively (Table 3). The value of the CVr for LOD contrasts with that obtained by Amabile et al. (2015) in irrigated conditions in the Cerrado, which can be explained by the fact that these authors studied a lower number of cultivars, which are considered elite and, therefore, probably presented a lower CVr value for LOD (0.54%); however, as in the present study (Table 3), Amabile et al. (2015) also found high values for DH (5.33%) and yield (2.72%).

The percentage of genetic variability that is transmitted from the parents to the descendants is obtained through h^2 (Lush, 1949). The high yields aspired by the breeder can be reached by the selection of traits that contribute to grain yield and that have both high h^2 and genetic gain. Consequently, the components of variance and h^2 with the genetic parameters are important for the definition of strategies aiming at the higher efficiency of the breeding program. The broad-sense h^2 ranged from 99.57% for LOD to 97.91% for TSW (Table 3). The following values of high magnitude were also found for the same traits: above 84%, in 18 accessions gathered in Ethiopia (Addisu & Shumet, 2015); and from 62 to 84%, in F1 and F2 populations from ten Indian cultivars in a study performed during winter in India (Yadav et al., 2015).

The genotypic, phenotypic, and residual correlation coefficients between the evaluated traits in the present study were, in general, considered of low magnitude when compared with those found by Sayd (2014) and

Amabile et al. (2015), of 0.6 and 0.8, respectively. However, higher relationships, of 0.4, were observed between PK and TSW (Table 4), which is in alignment with Amabile et al. (2015), who reported a strong correlation of 0.6 between PK and TSW, which facilitates the evaluation process of the traits and also indirect selection. The genotypic and phenotypic correlation coefficients between height and LOD, in turn, were inexpressive, allowing the selection of tall plants with an adequate architecture that minimizes lodging, according to Ceccarelli et al. (1992).

In the comparison between averages for estimated grain yield at the CPAC site, the Colombian genotype MCU 3484 PI 401962 stood out positively with 6,508 kg ha^{-1}, similarly to the Brazilian control cultivar BRS 180, with 6,142 kg ha^{-1} (Table 1). At the SPM site (Table 2), the control cultivar BRS 180, with 7,358 kg ha^{-1}, was overcome statistically by the four following genotypes, presenting values considered of high magnitude: the Afghan cultivar H HOR 2325/58 PI 329126, with 9,187 kg ha^{-1}; the Colombian genotypes MCU 3816 PI 402294 and MCU 3832 PI 402310, with 7,724 and 7,695 kg ha^{-1}, respectively; and the North American cultivar CI 08053 Custer, with 7,559 kg ha^{-1} (Table 2). At both sites, phenotypes from the American continent presented higher yield potential when compared with the genotypes from the other continents. Moreover, as expected, the six-row genotypes showed higher values for yield.

Values of 9,000 kg ha^{-1} were also achieved in experiments at Embrapa Cerrados with lineages from International Maize and Wheat Improvement Center (CIMMYT) introduced into the Cerrado, but with no malt quality (Amabile & Faleiro, 2014). Sanchez et al. (2015) obtained lower values – 5,848, 5,449, and 4,767 kg ha^{-1}, respectively, in the Cerrado – for the BRS Sampa, Manduri, and BRS 195 cultivars, recommended for irrigated areas. Values lower than the ones observed in the present study were also reported by Amabile et al. (2013), who found average of 5,908 kg ha^{-1} for the BRS Savanna cultivar, with values ranging from 4,726 to 8,659 kg ha^{-1} in trials performed in different locations and years in the Cerrado. However, there is still the possibility of grain yield gains using genotypes from the germplasm bank that are being introduced as cultivars and used in breeding blocks.

For kernel plumpness, the SPM site presented 51 genotypes with values above 80%, the lower limit adopted by the breeding program, whereas the CPAC site presented only 13 genotypes. At the CPAC site, the following genotypes stood out positively: six-row cultivars from Morocco – CI 09958 (87.6%) and CI 09959 (84.6%) – and from Iran – CI 09962 (91.6%) and CI 09961 (85.3%); besides two-row cultivars from Germany – CI 11493 Frugherste Stankas (82%) and Carina PI 371632 (84%) – and from the Czech Republic – CI 11367 Branisovicky (81%) (Table 4). At the SPM site, 37 genotypes were similar to the control BRS 180

Table 3. Analysis of variance and genetic parameters for grain yield, kernel plumpness (PK), thousand seed weight (TSW), plant height, degree of plant lodging (LOD), and days to heading (DH), evaluated in 113 barley (*Hordeum vulgare*) accessions at two sites.

Sources of variation(1)	DF (2)	F-values					
		Yield	PK	TSW	Height	LOD	DH
Blocks/Environment	4						
Blocks	2						
Block x environment	2						
Genotype	112	125.7**	69.0**	48.0**	91.5**	234.4**	171.2**
Environment	1	15,887.0**	1,238.9**	627.5**	198.3**	64.4**	3,797.5**
Genotype x Environment	112	55.7**	19.7**	18.7**	27.0**	4.7**	53.5**
Residue	448						
h^2 (%)		99.20	98.55	97.91	98.90	99.57	99.41
GVC		14.70	19.47	11.20	10.14	43.18	7.42
EVC		3.23	5.79	4.00	2.61	6.93	1.39
CVr		4.55	3.36	1.74	2.80	3.88	6.23

(1)h^2, heritability; GVC, coefficient of genetic variance; EVC, coefficient of environmental variance; and CVr, coefficient of relative variance. (2)DF, degrees of freedom. **Significant by the F-test, at 1% probability.

(88.6%), among them: six-row genotypes from Iran, Morocco, the United States, Colombia, Cyprus, Canada, India, Russia, and Tunisia; and two-row genotypes from the Czech Republic and Denmark (Table 2).

These results highlight the varying responses of the genotypes to the different evaluated environments. However, the Moroccan cultivar CI 09958 stood out at both sites, with values of 87.6% for CPAC and of 93% for SPM, showing high potential and higher stability for this trait in comparison with the other accessions. High values for kernel plumpness, above 80%, were also reported by: Amabile et al. (2013), who studied 39 elite two-row and six-row genotypes in irrigated conditions in the Cerrado; and Smith et al. (2013), who assessed 7 cultivars of high quality adapted the central north region of the United States, during six years, at four different sites.

The average for TSW of the accessions at the CPAC site (40.2 g) was lower than the one at SPM (46.4 g), showing the difference between the two environments (Tables 1 and 2, respectively). However, the Iranian cultivar CI 09962 had high values at both sites: 57 g at CPAC, which was statistically similar to the weight of the Moroccan cultivar CI 09958, of 58 g; and 62.6 g at SPM, which does not differ statistically from the weights of the Ethiopian cultivars CI 12918 and CI 14041, of 60.3 and 58.6 g, respectively. These values show the positive correlation between the traits PK and TSW (Table 2), which is benefic to the breeding program. Among the accessions, only CI 12918 presented yield above 6,000 kg ha^{-1} in at least one site, emphasizing the low correlation between TSW and yield. Two other two-row cultivars stood out positively at both sites: CI 02109 White Smyrna from the United States and CI 09882 Gondar from England.

Table 4. Genotypic (r_g), phenotypic (r_p), and environmental (r_e) correlation coefficients between grain yield, kernel plumpness (PK), thousand seed weight (TSW), plant height, degree of plant lodging (LOD), and days to heading (DH) in 113 barley (*Hordeum vulgare*) accessions.

		Yield	PK	TSW	Height	LOD
PK	r_p	0.2858				
	r_g	0.2889				
	r_e	0.0166				
TSW	r_p	-0.0739	0.3974			
	r_g	-0.0753	0.4028			
	r_e	0.0200	0.1000			
Height	r_p	-0.0776	-0.1263	-0.1719		
	r_g	-0.0790	-0.1290	-0.1747		
	r_e	0.0637	0.0823	0.0029		
LOD	r_p	-0.0249	-0.0241	0.1115	0.0910	
	r_g	-0.0245	-0.0241	0.1127	0.0916	
	r_e	-0.0970	-0.0284	0.0214	0.0038	
DH	r_p	-0.3365	-0.0139	0.1053	0.1013	-0.0153
	r_g	-0.3393	-0.0141	0.1064	0.1018	-0.0152
	r_e	0.0618	0.0057	0.0289	0.0402	-0.0288

In the literature, Smith et al. (2013) observed TSW ranging from 56 to 59 g in seven beer cultivars recently released, values close to the ones of the accessions analyzed in the present study. Mirosavljević et al. (2015) reported an average of 40.8 g for 19 genotypes of two-row winter beer barley during three years of assessment in Serbia.

For plant height, the tallest accessions, all above 94 cm, were: CI 07255 from the United States and CI 06147 from Egypt (Table 1) in the CPAC site; and CI 10016 Raspa from Colombia and CI 07255 from the United States in the SPM site (Table 2). The Ethiopian cultivar E 3/416 PI 356495 showed the lowest height at both environments, 57.6 cm at CPAC and 69 cm at SPM. The small size of this genotype makes it interesting to explore, since breeding programs have predicted, among their goals, the selection of short plants to avoid lodging (Amabile et al., 2015). The height of the accessions ranged from 57.6 cm for E 3/416 PI 356495 to 99 cm for CI 07255 at the CPAC site, and from 69 cm for E 3/416 PI 356495 to 103.6 cm for CI 07255 at the SPM site, with averages of 79.5 and 86.4 cm, respectively.

The Canadian genotypes presented heights above 84 cm at both sites and were characterized as tall. In contrast, the genotypes from South America showed great variation in height, varying from short, to medium, to tall. The Asian, European, and African genotypes showed smaller variations for this trait and were characterized as medium, except the CI 06147 cultivar from Egypt.

The behavior of the genotypes regarding lodging was considerably more intense at the SPM site than at CPAC. This behavior is due to the higher altitude of the first environment, which creates a more humid microclimate, favoring higher growth and, consequently, plant lodging. Of the 113 accessions evaluated, 14 did not lodge at the CPAC site and 8 did not lodge at the SPM site. Still, at the SPM site, 87 genotypes presented high lodging, above 0.0630, while at CPAC, 70 genotypes showed high lodging.

The values for lodging obtained in the present study were higher than the averages of 28% reported by Mirosavljević et al. (2015), in trials performed with winter barley during three years, and of 25%, by Smith et al. (2013), for seven cultivars released in the United States. The Colombian genotypes MCU 3592 PI 402070, MCU 3576 PI 402054, and MCU 3452 PI 401930, as well as the control cultivar BRS 180, stood out positively and did not present lodging at both environments. No grouping tendency was observed when considering countries of origin and level of lodging.

Lodging, therefore, is a non-limiting trait, which can be solved with the use of growth reducers. However, the search for high-yielding genotypes with a more resistant stem allows the producer to reduce production costs and diminishes the risk of losses at harvest due to lodging.

Regarding DH, the most precocious genotypes were all six-row, originating from Colombia: MCU 3571 PI 402049, CI 13711 (both 49.3 days), and MCU 3469 PI 401947 (49.6 days) at the SPM site; and MCU 3484 PI 401962 (50.3 days) and MCU 3827 PI 402305 (51 days) at the CPAC site. The genotypes with higher yields presented heading cycles of around 50 to 60 days, similar to the ones obtained by the cultivar recommended for the Cerrado by Amabile et al. (2013). Values of around 55 days were also found for seven cultivars released in the United States in trials performed during six years by Smith et al. (2013).

The average of the genotypes was of 55 days at the SPM site and of 61 days at the CPAC site, with a difference of 6 days from one environment to the other (Tables 1 and 2). These averages are considered low when compared with the one obtained by Yadav et al. (2015) of 75 days for precocious Indian genotypes, in trials performed in India. It should be noted that more precocious genotypes are interesting for use in irrigated systems in Brazil, considering the advantage of the early release of areas for sowing of summer crops in the country.

Conclusions

1. The MCU 3832 PI 402310, MCU 3484 PI 401962, CI 08053 Custer, MCU 3634 PI 402112, and MCU 3816 PI 402294 accessions stand out regarding grain yield and kernel plumpness.

2. High selection gains may be obtained with high hereditability values, but indirect selection is not recommended in the experimental conditions because of the low genotypic and phenotypic correlations observed.

3. It is possible to select barley accessions with high yield and precocious heading cycle simultaneously, a decisive factor in the process of genotype selection for future trials.

4. The accessions from Colombia are the most adapted to the Cerrado conditions.

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