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Comparison and quality evaluation of hull-less and covered Brazilian barley for food industry application

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ABSTRACT: Barley has a wide range of end uses. However, the technological characteristics expected from barley present different standards according to the destination of the cereal. Grain β-glucan content is the most important attribute for varieties destined for the food market due to blood glucose and cholesterol-reducing properties. High protein content, test weight, and huller rate may also add value to different end uses. In Brazil, the main destination for barley is malt production; however, not every lot achieves malting standards. To determine the quality of Brazilian barley for food industries, 9 covered barley cultivars and 8 hull-less barley breeding lines were studied. Thousand kernel weight (TKW), hectoliter weight (HW), huller rate (HR), protein, and β-glucan contents were analyzed. The hull-less breeding lines presented higher averages when compared to the covered group, except in protein content. Correlations between "β-glucan and HW", "β-glucan and TKW", and "TKW and HW" were positive. On the other hand, "HW and protein content" and "β-glucan and protein content" presented a negative correlation. There are bromatological quality differences between Brazilian hull-less breeding lines and covered varieties. Brazilian barley germplasm presents great industrial potential, not only for malt production and animal feed but also for human food applications.

Key words: β-glucan; hectoliter weight, *Hordeum vulgare*; naked barley; protein

Comparação e avaliação da qualidade de cevadas brasileiras nuas e cervejeiras para aplicações em indústria de alimentos

RESUMO: A cevada tem diversas aplicações como produto final. Suas características bromatológicas e tecnológicas determinam sua melhor finalidade. O conteúdo de β-glucana dos grãos é o atributo mais importante para a destinação ao mercado de alimentos, devido a propriedades funcionais de redução da glicemia e colesterolemia. A quantidade de proteína, testes de peso e taxa de descascamento também podem influenciar na destinação do cereal. No Brasil, a principal aplicação da cevada é o malte, porém, nem todos os lotes são aprovados pelos padrões exigidos pelas maltarias. Para determinar o potencial da cevada brasileira na indústria de alimentos, foram estudados 9 cultivares de cevada com casca e 8 linhagens sem casca. Foram analisados o peso de mil sementes (TKW), peso de hectolitro (HW), percentual de casca (HR), proteína e β-glucana. As linhagens sem casca apresentaram médias maiores nos atributos avaliados, exceto no teor de proteína. Correlações entre "β-glucana e HW", "β-glucana e TKW" e "TKW e HW" foram positivas. Por outro lado, "HW e teor de proteína" e "β-glucana e teor de proteína" tiveram correlação negativa. Ficou claro que há diferenças na qualidade bromatológica entre a cevada brasileira com e sem casca. Não obstate, o germoplasma brasileiro tem grande potencial industrial, não só para malte e ração animal, mas também para aplicações em alimentos para humanos.

Palavras-chave: β-glucana; peso do hectolitro; *Hordeum vulgare*; proteína; cevada nua

Introduction

Barley is among the most ancient cereal crops grown in the world. Archeological evidence suggests the existence of barley in Egypt along the River Nile around 17,000 years ago (Idehen et al., 2017). A broad range of end uses, such as human consumption, malt for the brewing and distilling industry and animal feeding, makes barley one of the most important cereal crops in the world ranking as the fourth most produced cereal after maize, wheat, and rice (Ferreira et al., 2016). Generally, barley is classified according to its use. The most common classification is covered and hull-less barley, also known as naked, mainly used for human consumption. While in some countries, such as Japan, hull-less barley has several advantages over covered cultivars, including higher crop prices for the farmers and more stable demand from barley food manufacturers (Nagamine et al., 2012), in Brazil, hull-less varieties are only cropped in experimental scales and malt is the main destination for barley grain. An assessment of genetic diversity in Brazilian barley using SSR markers pointed out that the number of alleles detected in genotypes released in the 1980s was higher, whereas most of the cultivars released thereafter showed lower polymorphism information content, clustered in separate subgroups from the older cultivars (Ferreira et al., 2016). The same study recommended the use of a more diverse panel of genotypes in order to exploit new alleles in Brazilian barley breeding programs. Sayd et al. (2018) reported good performance of hull-less barley cropped under irrigation in the Brazilian savanna. However, since 1990, the acrage has been decreasing because when barley is not appropriated for malt production, the cereal is used for animal feed, which is not profitable for farmers (De Mori & Minella, 2015). High protein content is an undesirable quality issue for malt industries, which expect protein content between 10 to 12%. Grain size uniformity is also expected for malt, which could be a problem in six-row barley varieties (Baik et al., 2011).

For food uses, barley grain is first abraded to produce pot or pearled barley, after which it can be further processed to grits, flakes, and flour. In Western countries, pearled barley, whole, flaked, or ground, is used in breakfast cereals, stew, soups, porridge, bakery flour blends, and baby foods. In Middle Eastern and African countries, barley is pearled and ground, and used in soup, flatbread, and porridge (Tamm et al., 2015). Interest in barley as a food crop has been renewed, caused mainly by the beneficial effects of β-glucan. Mixed linkage (1→3)(1→4)-β-D-glucans are the major non-starch polysaccharides present in various tissues of barley. Barley β-glucan has been associated with lowering plasma cholesterol, reducing the glycemic index, and reducing the risk of colon cancer (Idehen et al., 2017). The β-glucan content in barley is around 2% to 10%, depending on the genotype and conditions of the growing environment (Baik & Ullrich, 2008). Hull-less barley generally contains higher concentrations of this soluble fiber (Šterna et al., 2017), when compared to covered barley, considering that hull-less varieties were developed for human consumption in foods (Takeda et al., 2004).

In the recent years, Brazil imported approximately 350 thousand tons of barley annually to supply domestic needs, and 75% of this was destined to produce malt for beer brewing (Ferreira et al., 2016). Over the years, Brazilian cultivars have been selected for the malt and brewery industry, which has contributed to low β-glucan concentrations in national barley, since fiber interferes negatively in the malting process (Lizarazo, 2003). However, despite being genetically designed, climate conditions can affect barley quality. After being rejected for malt production, due to high protein levels, high β-glucan concentration, or grain size variations, it is not clear if covered barley can or not be destined for the food industry to maintain the profits for farmers.

To the best of our knowledge, nothing has been reported in the open literature about the differences between Brazilian covered barley cultivars and hull-less Brazilian barley lines, their β-glucan content and industrial performance when considering applying grain for human consumption in food. The aim of this study was to evaluate the variation in food quality characteristics of hull-less and covered Brazilian barley, comparing quality standards for the food industry and malting processes, and to determine if covered Brazilian barley is suitable for human consumption in food rather than malt.

Material and Methods

Nine different covered barley cultivars (BRS Brau, BRS Cauê, BRS Elis, BRS Itanema, BRS Korbel, BRS Mandurí, BRS Sampa, MN 6021 and BRS Aliensa) (Embrapa, 2019) and eight breeding lines of hull-less barley were studied**.** Field experiments were conducted during the winter of 2015, in three experimental trials on value for cultivation and use of Brazilian Agricultural Research Corporation (Embrapa Trigo) located in three field sites, Taquarivaí (SP), Passo Fundo (RS) e Vitor Graeff (RS), Brazil. Five cultivars (BRS Brau, BRS Korbel, BRS Elis, MN6021 and BRS Cauê) were cultivated in two different areas, Passo Fundo, RS (PF), and Victor Graeff, RS (VG). The barley cultivars were assessed using a completely randomized design, and each cultivar, at the site, had three replicates. Table 1 shows the cultivars accordingly to ecological and agronomical adaptation and its respective site location. The soil in the three site locations is classified as red latosol (Santos et al., 2018). Due to the limited number of seeds, he breeding lines were cultivated with one replication, at one site, Passo Fundo, RS.

Barley samples were evaluated for bromatological characteristics at the Laboratory of Food Science of State University of Londrina, Londrina, PR.

β-glucan concentration

β-Glucans were determined with a mixed-linkage β-glucan detection assay kit Megazyme_International Ltd., Wicklow, Ireland), according to the AACC32-23.01 method (AACC, 1999). The moisture content of all samples was determined with a Precisa HA60 IR moisture analyzer (Precisa Instruments,

Table 1. Barley cultivars and lines, their site location and respectively environmental data.

Cultivar/Line	Site Location	Latitude	Longitude	Altitude (m)	Precipitation* (mm)
BRS Sampa	SP	23º 55' 28" S	48º 41' 35" W	555	720
BRS Aliensa	SP				
BRS Mandurí	SP				
BRS Itanema	SP				
BRS Brau	VG	28º 33' 37" S	52º 44' 54" W	411	1050
BRS Korbel	VG				
BRS Elis	VG				
MN 6021	VG				
BRS Cauê	VG				
BRS Brau	PF	28º 15' 46" S	52º 24' 24" W	687	1050
BRS Korbel	PF				
BRS Elis	PF				
MN 6021	PF				
BRS Cauê	PF				
149853	PF				
149852	PF				
149857	PF				
149858	PF				
149846	PF				
149841	PF				
149859	PF				

*INMET (2017).

Diekinton, Germany). Data were reported on a dry basis and are the mean values of six replications.

Protein

Nitrogen content in barley grains was determined by the Kjeldahl method (AOAC, 1995). Protein concentration was obtained using the 6.25 conversion index. Samples were analyzed in duplicate, and dry basis results were expressed in percentage.

Thousand kernel weight (TKW)

Thousand kernel weight was determined by weighing a hundred grains using an analytical balance (Kern-Sohn, Balingen, Germany) and multiplying the average by 10, according to the AACC method 55-10.1 (AACC, 1983). Six replicates were analyzed.

Hectoliter weight (HW)

Hectoliter weight was determined six times in a hectoliter weight apparatus (Mediza, Panambi, Brazil) and expressed in kg hL^{-1} (Brasil, 2009). HW was calculated by multiplying the weight in kilograms of a quarter-liter of barley grains by 100 and dividing into 1 L volume.

Grain size (G > 2mm)

Grains larger than two millimeters were determined by sieving 50 grams of barley grains for one minute using a 2 mm sieve, in Granutest equipment (T model, Produtest, Paulinea, Brazil). The weight of grains retained in the sieve was determined, and the results were expressed as a percentage of initial weight. Six replications were performed for the analysis.

Hulled rate (HR)

Fifty grams of barley grains were hulled in laboratory huller equipment (Codema Inc., Maple Grove, USA) for 75 seconds. After hulling, caryopsis weights were measured, and results were expressed as a percentage of initial weight. The analysis was performed six replications in each sample.

Fifty grams of barley were hulled in a laboratory huller equipment (Codema Inc., Maple Grove, USA) for 75 seconds. After hulling, caryopsis weights were measured, and results were expressed as a percentage of initial weight. However, in order to avoid false high efficiency in the dehulling process, caryopsis that were hulled at the end of the 75 seconds were separated and quantified as a percentage of total weight after the dehulling process. Results of hulled rate were expressed as two percentages: the percentage of weight that left the dehulling process and the percentage of dehulled caryopsis combining the two data. Six replications were performed in each sample for the analysis.

Statistical analysis

Results shown in Table 2 had the data processed by the statistical software program Statistica 7 for ANOVA (analysis of variance). Significant differences between means were tested with the Tukey test ($p \leq 0.05$). Pearson correlation coefficients were calculated by the 3.4.1 version of R Core Team (2017) Statistical Software. The results shown in Table 4 were calculated by a completely randomized factorial design (2 x 5), with ten treatments by two different location (Passo Fundo and Victor Graeff) and five barley cultivars. Data were submitted to analysis of variance (ANOVA) and means were compared by the Tukey test at 5% of significance.

Table 2. Results of Thousand Kernel Weight (TKW), Hectoliter Weight (HW), Hulled Rate (HR), β-glucan and protein concentration of covered and hull-less barle**y.**

	Site location	TKW (g)	HW (kg hL^{-1})	HR		β-glucan	Protein
				(%)			
BRS Sampa	SP	36.15 cdef (±0.20)	68.40 c (±0.57)	91.05 defg (±1.02)	5 a (±0)	3.87 bcd (±0.30)	10.96 b (±0.09)
BRS Aliensa	SP	39.12 efgh (±0.12)	66.40 bc (±0.57)	85.55 bcdefg (±3.51)	5 a (±1)	3.57 abcd (±0.04)	12.55 f (±0.04)
BRS Madurí	SP	32.97 bcd (±0.20)	68.40 c (±0.56)	89.09 cdefg (±0.29)	5 a (±1)	3.49 abcd (±0.19)	10.88 b (±0.06)
BRS Itanema	SP	45.48 i (±0.17)	68.80 c (±5.65)	91.88 defg (±0.46)	5 a (±0)	4.16 d (±0.29)	11.16 bcd (±0.06)
BRS Brau	PF	35.36 cde (±0.21)	63.40 bc (±0.85)	80.97 abcdef (±1.04)	15 (±2)	3.26 abcd (±0.16)	12.63 f (±0.03)
BRS Brau	VG	31.66 bc (±0.08)	60.40 abc (±0.57)	81.60 abcdefg (±1.33)	15 (±2)	2.87 abc (±0.19)	11.71 e (±0.08)
BRS Korbel	PF	40.22 fgh (±0.10)	59.20 abc (±4.52)	76.71 abcd (±3.62)	22 (±3)	2.82 ab (±0.14)	11.43 cde (±0.09)
BRS Korbel	VG	29.91 b (±0.12)	52.60 a (±1.41)	69.66 a (±4.04)	20 (±2)	3.41 abcd (±0.28)	10.49 a (±0.09)
BRS Elis	PF	35.42 cde (±0.12)	57.80 ab (±7.07)	86.25 bcdefg (±1.22)	17 (±2)	3.21 abcd (±0.04)	12.82 f (±0.06)
BRS Elis	VG	29.72 b (±0.13)	59.20 abc (±0.57)	73.34 ab (±0.31)	18 (±2)	3.07 abcd (±0.14)	13.59 g (±0.04)
MN 6021	PF	36,57 defg (±0.22)	61.60 abc (±2.26)	79.57 abcde (±5.98)	23 (±2)	3.68 abcd (±0.22)	12.76 f (±0.02)
MN 6021	VG	24.96 a (±0.19)	56.80 ab (±1.13)	78.87 abcde (±5.18)	20 (±3)	3.35 abcd (±0.10)	12.53 f (±0.05)
BRS Cauê	PF	35.42 cde (±0.12)	57.00 ab (±1.41)	74.72 abc (±0.57)	21 (±2)	2.98 abcd (±0.14)	ND (±0.08)
BRS Cauê	VG	35.42 cde (±0.12)	52.20 a (±0.85)	66.65 a (±3.19)	20 (±2)	2.56 a (±0.15)	ND (±0.03)
AVERAGE of covered barley		34.87 A	60.87 A	80.42 A		3.31 A	13.03 A
149855	PF	40.31 fgh (±0.01)	78.2 d (±0.28)	97.43 fg (±0.04)	100 a (±0)	3.75 abcd (±0.10)	11.12 bcd (±0.12)
149853	PF	40.55 fgh (±0.06)	75.4 d (±0.28)	98.12 g (±1.98)	100 a (±0)	3.39 abcd (±0.30)	11.18 bcd (±0.25)
149852	PF	40.65 fgh (±0.03)	76 d (±0.54)	97.16 fg (±0.36)	100 a (±0)	3.92 bcd (±0.21)	11.43 cde (±0.08)
149857	PF	41.08 ghi (±0.08)	75.6 d (±0.56)	95.65 efg (±0.07)	100 a (±0)	4.15 d (±0.27)	11.07 bc (±0.12)
149858	PF	41.18 hi (±0.08)	76.4 d (±0.57)	96.56 fg (±0.31)	100 a (±0)	4.12 d (±0.24)	11.39 cde (±0.04)
149846	PF	41.31 hi (±0.03)	75.2 d (±0.56)	94.43 efg (±0.52)	100 a (±0)	4.03 cd (±0.28)	11.65 e (±0.04)
149841	PF	42.03 hi (±0.03)	78 d (±0.57)	97.96 g (±0.42)	100 a (±0)	3.44 abcd (±0.13)	10.46 a (±0.06)
149859	PF	42.31 hi (±0.12)	75.2 d (±0.57)	96.70 fg (±0.76)	100 a (±0)	3.96 bcd (±0.14)	11.44 de (±0.07)
AVERAGE of hull-less barley		41.18 B	76.25 B	96.75 B		3.85 B	11.21 B

SP: São Paulo, VG: Victor Graeff, PF: Passo Fundo / ND: not determined due to insufficient material.
Means followed by the same lower letters in the column indicate that there was no significant difference ($p \geq 0.05$) between samples. Same capital letters in the column indicate there was no significant difference between averages of covered and hull-less barley grains.

Results and Discussion

Results of thousand kernel weight (TKW), hectoliter weight (HW), hulled rate (HR), β-glucan, and protein concentrations are presented in Table 2. Results of grain size (G > 2mm) were not included as there were no differences between analyzed samples.

The percentage of grains larger than 2 mm varied from 96.84 to 100% with an average of 98.79 ±1.13%. Barley grain size is traditionally used to evaluate the commercial quality of covered barley. High quality malt is expected from large barley grains (Brasil, 1996). The coefficients of variation for the kernel size parameter were low, indicating that barley grain samples presented uniformity in size.

For food industry engineering processes, such as air transport, drying, milling and malting, geometric features of cereal grain, including barley, are very important. Kernel size and shape influence the electrostatic separation of barley from extraneous material, as well as the development of sizing and grading machinery (Sykorova et al., 2009).

The thousand kernel weight (TKW) is a typical indicator of the mean kernel size (Sykorova et al., 2009). Thousand-kernel weight is a predictive physical analysis for cereal grains as it is directly proportional to starch content and grain filling, which might improve yield in industrial processes.

Results of the TKW showed that hull-less grains are denser than the majority of covered barley analyzed, and the hull-less lines were not statistically different from each other. From the covered barley group, BRS Itanema presented great grain filling, and together with BRS Aliensa, BRS Korbel (PF) and MN6021 (PF) was similar to some hull-less varieties.

Sykorova et al. (2009) found TKW results between 38 and 50 grams for barley cropped in the Czech Republic, which matches some results found in this paper. MN6021 (VG) was the worst cultivar in grain filling with only 24.96 grams in TKW. Negamine et al. (2012) affirm that TKW had a negative correlation to the pearling time, which means that high TKW is good for food processing. TKW also has a positive correlation with grain size and barley quality (Nagamine et al., 2012), so a high quality classification is expected in malting and food processes for BRS Itanema, followed by BRS Aliensa (PF) and BRS Korbel (PF). Although hull-less varieties presented high TKW, high quality classification is expected only in food processes, since husks are lost during harvest, which is a problem for malting processes (Baik et al., 2011). Rey et al. (2009) also found higher plump kernels in hull-less lines when compared them with covered varieties.

Volume weight is a key quality characteristic, especially for farmers, as one of the quality bonus characteristics. In Japan, the standard value for a quality bonus when purchasing barley for food industries is 840 g L^{-1} (Nagamine et al., 2012). Hectoliter weight is a measure of grain sample density, which can be an indicator of pre-harvest sprouting adversely affecting the grain. High hectoliter in barley samples indicates good performance in the malting process.

The Grain Industry Association of Western Australia determines barley as Class 1 for malt grain with HW up to 65.0 kg hL^{-1} and barley Class 2 grain with HW between 63.0 and 64.9 kg h L^{-1} (GIWA, 2010). According to this standard, BRS Sampa, BRS Aliensa, BRS Manduri, and BRS Itanema from the malting barley group were classified as Class 1, which means all samples cropped in Taquarivaí, (SP), indicating good climate conditions for barley production in São Paulo in 2015. Only BRS Brau (PF) was classified as Class 2, and other covered samples cultivated in the South of Brazil were Class 3, which is not desirable for farmers or the malt industry.

Hull-less samples had the highest HW in this research. Rey et al. (2009) also found higher HW in hull-less lines when compared to covered barley, which varied from 64 to 77 kg h L^{-1}. No hull-less samples achieved the malt standards. This is because hull-less varieties are not suitable for malt and loss of the husks affects HW results. However, in food industries, high HW helps raise yield processes (Baik et al., 2011). The general reason why hull-less lines may yield more than covered varieties is simply the weight of the husks, which are estimated to be 11 to 13% of the grain yield (Rey et al., 2009).

Husk not only protects barley grain but is also important in brewing. Grain damage can interfere negatively in the malting process. On the other hand, hulling is an important step for barley food products.

The hulled rate in hull-less barley was up to 95% (Table 2) since many caryopses from hull-less barley lose husk during harvest (Baik et al., 2011). The American standard for winter cereals is at least 74% of de-hulled grains. However, this standard may vary according to cereal use, year, climate conditions, and cultural habits (Tamm et al., 2015). According to this American standard, only hull-less barley would be well accepted in food industries. Although some covered barley presented more than 85% yield in dehulling process, this high efficiency is not true due to low percentages of dehulled grain (BRS Sampa (SP), BRS Aliensa (SP), BRS Manduri (SP), BRS Itanema (SP) and BRS Elis (PF)). These covered varieties tend to maintain husks tightly, which is suitable for the malting process but not for food processes. Food industries that accept covered barley for food use should consider more aggressive dehulling machines, such as polishing and lapping equipment, which generally demands high-energy supplies and sophisticated machine regulation in order to maintain the fibers and whole grain composition (Baik et al., 2011).

The β-glucan content is important information for barley grain utilization. In beer production processes, β-glucans determine wort viscosity and, beer filtration rates, and form a barrier for hydrolytic enzymes attacking starch and protein within the cell walls. Accordingly, low β-glucan content of grain and/or its breakdown during malting are critical issues in brewing. The importance of a minimal amount of β-glucans has been reported for foam stability of beer (Baik & Ullrick, 2008).

For food application, high β-glucan concentration is desirable due to its functional effects (Šterna et al., 2017). On the other hand, the technological properties of β-glucans in food processing and end-use quality, except for malting and brewing, are little known. A close positive relationship between total β-glucan content and grain hardness was determined and this may be related to thicker endosperm cell walls in high β-glucan lines (Baik & Ullrick, 2008). Although hull-less barley is described in the literature as having higher β-glucans content compared to covered cultivars (Soares et al., 2007), in our study, some hull-less and covered grains showed no differences in β-glucan quantification when comparing samples one by one. On the other hand, when analyzing averages from covered and hull-less groups, there were significant difference between them (Table 2), which matches reports in the literature. Rey et al. (2009) reported that hull-less cultivars and lines had an average β-glucan value of 5.5% compared with 3.5% for hulled cultivars/lines. Šterna et al. (2017) found that β-glucans in hull-less and covered barley grains in Poland ranged from 3.44 to 4.97%. Helm & Francisco (2004) reported the β-glucan content of some

Brazilian hull-less barley as 3.70 - 3.77%, which is quite similar to the average of 3.85% found in this study.

The U.S. malting and brewing industry currently specifies a range of protein from 11.5 to 13.5% (Rey et al., 2009). In Brazil, for malting process, levels from 10 to 12% are expected, in order to guarantee foam stability and sensorial properties in beer (Minella, 2001). Although higher grain protein should be a desirable attribute in animal feed and human food, there are currently no premiums paid for high protein in barley grains (Rey et al., 2009).

BRS Aliensa, BRS Brau (PF), BRS Elis (PF and VG) and MN6021 (PF and VG) were not suitable for malt due to high protein concentration (Table 2). This characteristic makes the malting process longer and results in beer with low stability (Minella, 2001). Šterna et al. (2017) found that crude protein content in barley grain samples cropped in Poland ranged from 10.5 to 13.9%, which matches the results found in this study. On the other hand, Brazilian authors reported protein from 12.55 to 15.92 in hull-less lines (Helm & Francisco, 2004), which is higher than the findings in the current study. Higher crude protein content in barley was usually accompanied by lower starch and dietary fiber content (Šterna et al., 2017). Starch and total dietary fiber were not quantified in this study; however, this could be one of the reasons why the average of the total crude protein in hull-less barley group is lower than average in the hulled barley group, with statistical difference. BRS Cauê was not analyzed due to insufficient quantities of material.

Correlations among grain parameters are shown in Table 3. The high HW in hull-less lines suits the TKW results (Table 2) since TKW and HW have a positive correlation (0.73*) as TKW and HW are both weight measurements. Similar results were reported by Rey et al. (2009).

β-glucan presented a positive correlation with TKW (0.48*) and HW (0.63*), which is in accordance with Elfverson (1999), who affirms that grain size and cell wall thickness seems to positively influence β-glucan concentration.

Table 3. Pearson's Correlations among the analyzed properties of barley samples.

	TKW	HW	Protein	β-glucan
TKW	1	0.73 *	-0.23 ns	0.48 *
HW	-	1	-0.51 *	0.63 *
Protein	-	-	1	-0.45 *
β-glucan	-	-	-	1

TKW: thousand kernel weight, HW: hectoliter weight, *Significant at 5% level; ns: not significant.

The correlation between β-glucan and protein concentrations was negative (-0.45*). Ehrenbergerová et al. (2008) did not find a significant correlation between β-glucan and protein, although Rey et al. (2009) and Šterna et al. (2017) observed a positive correlation between these factors, which seems to vary depending on climate conditions and varieties.

The correlation between protein and HW was negative (-0.51*) as grains that have high HW also have great grain filling, meanings that starch is available in high concentrations. This high starch concentration reduces the percentage of protein when expressing grain composition. Whereas, Nagamine et al. (2012) found a positive correlation between grain protein content and volume weight only in barley grains cropped in 2008 but not in grains from 2009. The amount of divergent data reported in the literature emphasizes that correlations among grain characteristics can be affected by many factors, such as the wide range of environmental conditions and genetic attributes.

In Table 2, divergent results can be observed within the same cultivar grown in different areas, making it clear that not only genetic determines grain characteristics. Despite the fact that cultivars were genetically designed for specific environmental conditions, which is the reason why the same cultivar is not cropped and suitable for both states, São Paulo and Rio Grande do Sul, even when cropped in different areas located in the same state of Rio Grande do Sul (Passo Fundo and Victor Graeff), different characteristics were observed.

Environmental conditions create interactions between genotype and the same variety can express different characteristics when cropped in different areas, which is known as phenotype (genotype combined with the environment). Whereas, when considering the environment and genotype, it is also possible to identify an additional effect: the interaction between them. The influence of the environment demonstrates that cultivars developed differently in different locations, and that genetic factors are not the only factors that determine grain characteristics (Tamm et al., 2015). To better demonstrate the influence of the environment in the same cultivar, results from barley varieties that were cropped in two different areas are compared in Table 4.

Whereas samples cultivated in Victor Graeff had statistically lower Thousand Kernel Weight (TKW) than those cropped in

Table 4. Comparison between the same cultivar in two different crop location and between averages of samples cropped in Passo Fundo and samples cropped in Victor Graeff

	TKW (g)		HW (kg hL^{-1})		β-glucan (%)		Protein (%)	
	Passo Fundo	Victor Graeff	Passo Fundo	Victor Graeff	Passo Fundo	Victor Graeff	Passo Fundo	Victor Graeff
BRS Brau	35.36 a	31.66 a	63.40 a	60.40 a	3.26 a	2.88 b	12.62 a	11.71 b
BRS Korbel	40.22 a	29.91 b	59.20 a	52.60 a	2.82 a	3.41 a	11.43 a	10.49 b
BRS Elis	35.43 a	29.72 b	57.80 a	59.20 a	3.21 a	3.07 a	12.82 a	13.59 b
MN 6021	36.57 a	24.96 b	61.60 a	56.80 a	3.68 a	3.35 b	12.76 a	12.53 b
BRS Cauê	35.42 a	35.42 a	57.00 a	52.20 a	2.98 a	2.56 a	ND	ND
Average	36.60 B	30.34 A	59.80 B	56.24 A	3.19 A	3.05 A	12.40 B	12.08 A

TKW: thousand kernel weight, HW: hectoliter weight, ND: not determined due to insufficient sample quantities. Same cultivars and characteristics followed by the same letters are not statically different (p ≥ 0.05). Capital letters were used to compare averages of the same characteristics in a different area (PF and VG).

Table 5. Summary of ANOVA for influence of the environment on barley characteristics.

Characteristics	Sum square				VC (%)
	Genotype	Local	Genotype x local	Error	
TKW	14.46*	196.23*	22.77*	1.07	3.09
HW	35.78*	133.13*	2.27	5.51	4.08
Protein	44.49*	5.85*	3.34*	0.005	0.5
β-glucan	0.59*	0.63*	0.11	0.06	7.78

TKW: thousand kernel weight, HW: hectoliter weight, * Statistically significant (5%) in F Test.

Passo Fundo, BRS Brau and BRS Cauê did not show differences in TKW at different locations (Table 4). Hectoliter weight (HW) was not different when comparing the same cultivar in both places. However, when analyzing averages, the group of cultivars cropped in Passo Fundo had higher HW than the group of the same cultivars cropped in Victor Graeff. No differences in the β-Glucan concentrations were observed between the averages of the groups from Passo Fundo and Victor Graeff. Only BRS Brau and MN6021 demonstrated higher β-glucan content when cropped in Passo Fundo. It is estimated that 66% of the variability in β-glucan content was attributable to genotype (Rey et al., 2009). Our results support the assertion that genetics is more important than environment in β-glucan content in grain. However, the environment may also influence β-glucan content; higher precipitation during the flowering time and grain filling period and lower temperatures during the flowering time had negative effects on the concentration of β-glucans (Ehrenbergerová et al. 2008). BRS Brau and BRS Cauê showed statistical differences in β-glucan content when cropped in Passo Fundo, (RS) and Victor Graeff (RS) (Table 4), which reinforces some influence of environment in β-glucan content in these two varieties.

Šterna et al. (2017) and Wamser & Mundstock (2007) showed that protein content was significantly influenced by variety, year, and nitrogen fertilizer rates. High protein concentration in grains can be enhanced by using fertilizers that contain nitrogen, which means that the environment and crop management influence protein content. In addition, it has been reported that protein content in barley of the same genotype varied from 8.1 to 14.7% at different locations with similar nitrogen fertilization levels (Šterna et al., 2017). Table 4 shows that all varieties cropped in both location (Passo Fundo and Victor Graeff) had different protein content and those cropped in Passo Fundo showed higher protein concentration than those cropped in Victor Graeff, except BRS Elis (Table 4). Our results match those found in the literature.

According to ANOVA, genotype and environment were significant for all study grain characteristics. On the other hand, the interaction between genotype and environment affected only Thousand Kernel Weight and Protein content (Table 5).

Passo Fundo produced barley with better quality characteristics, such as higher HW and TKW. For food industries, Passo Fundo is also the better place to crop barley due to the higher protein content of the grains. On the other hand, Victor Graeff is better for producing barley for malting since high protein content in grains is a technological problem. The reasons why Passo Fundo performed differently from Victor Graeff might involve altitude and crop management, since rain was not different between the areas.

Conclusions

Although hull-less barley lines had higher TKW, HW, HR and β-glucan content, they also had lower protein content when comparing the average of hull-less and covered groups (Table 2). The hull-less and covered barley differed in chemical composition and physical properties.

Our research indicates that there is a significant environmental interference that can discard barley for malt. However, the barley might still be suitable for food industries. Approval of the barley health claim may increase interest in, and markets for, food barley. To meet this demand, barley processors are likely to require the production of barley cultivars due to their high β-glucan contents, which could be a potential market for hull-less lines and for covered barleys that are not suitable for malt. Barley can be used for feed, malting, and food, and there is great potential to improve barley for all these uses.

Overall, the data of this study demonstrated the main differences between Brazilian hull-less lines and covered varieties. However, in order to discuss further the effects of genotype, environment, and their interactions, which could contribute to variation in grain composition, particularly protein content, more than one harvest is necessary, in different site locations.

This study contributes to understanding of the composition and physical properties of Brazilian barley varieties and points out characteristics that could indicate the most suitable end uses.

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