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RESEARCH ARTICLE

Comparison of different hulled wheat genotypes in terms of yield, morphological, and nutritional properties

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Abstract This study is conducted to characterize the yield and some of hulled wheat's morphological and nutritional attributes. For this purpose, a total of 88 local hulled wheat samples were collected, including 7 T. *dicoccum*, 28 T. *monococcum*, 7 T. *speldoides*, 23 T. *boeoticum*, 3 T. *araraticum*, 4 *Triticum sp*, 2 T. *urartu* and 14 T. *turgidum* genotype was used as plant material. The field experiment was conducted for two years, from 2017 to 2018 and 2018 to 2019. The findings showed that grain yield varied between 40.75–398.75 g/m^2, biological yield 86.90–1166.33 g/m^2, harvest index 18.15–53.96%, spike length 1.2–8.1 cm, plant height 29.8–82.8 cm and length of upper internode 18.4–53 cm. The auricle color of the genotypes was white, and no hairiness or waxiness was observed. Most of the genotypes have developed erect. Crude ash contents of the hulled wheat vary between 1.7 and 5.10%, crude protein 10.12-19.48%, dietary fiber 2.2-8.2%, total starch 49.50–67.98%, resistant starch 0.25–3.38%, non-resistant starch 48.08–64.95%, amylose 3.43–42.88%, amylopectin 57.13–96.58%. Hulled wheat species and genotypes showed significant differences in yield and nutritional properties. Many genotypes used in the study have the potential to be cultured in field agriculture and contribute to the production of nutritional products in the future with their superior characteristics. In addition to testing genotypes in different climate and soil conditions, conducting research on the production of different foods is recommended.

Keywords Hulled wheat · Species · Yield · Food quality

Introduction

Wheat, including *Triticum* and *Aegilops*, belongs to the *Gramineae* family. *Triticum* is divided into three groups: diploid ($2n = 2x = 14$), tetraploid

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($2n=4x=28$), and hexaploid ($2n=6x=42$) (Kaplan et al. 2014). In comparison to durum and bread wheat cultivars, these two ancient wheat grains include more vitamins A and B, phenolic compounds, protein, tocols, carotenoids, resistant starch, dietary fiber, amino acids, and micronutrients (Akar et al. 2019). Because it can be grown easily in unfavorable climate and soil conditions, has strong tillering, resistance to fungi and drought, and competition with weeds, hulled wheat is more widely grown in low-input farming systems and organic farming conditions than bread and durum wheat (Kaplan et al. 2014; Tekin et al. 2018). Additionally, it has been highly recommended to include spelt in the diet programs of patients undergoing treatment for conditions like high blood cholesterol, colitis, allergies, rheumatoid arthritis, depression, and cancer (Strehlow et al. 1994). As a result, products made from spelt wheat will be a healthier alternative to modern wheat products for health-conscious people (Kulathunga et al. 2020). It is reasonable to presume that the grains of ancient wheat species are acceptable for food production to fulfill the growing demand for more productive products (Akar et al. 2019). Due to the robust demand for ancient wheat on the international market, ancient wheat types are being reintroduced into agriculture (Kulathunga and Şimşek 2023). Therefore, more information must be required about the quality of wheat, processability, functional qualities, and nutrients (Shewry 2018).

Considering wheat's extensive nutritional value, grain quality is important worldwide. A study that compared bread made with modern wheat flour to those made with hulled flour found that bread made with hulled flour contained less total starch (low glycemic), more resistant starch, and less rapidly digested proteins (Bonafaccia et al. 2000). Nevertheless, the nutritional properties of grain are influenced not only by genetic factors but also by ecological factors (Kardes et al. 2021). Genetic diversity could improve grain quality (Zeibig et al. 2024). Compared to cultivars, selected genotypes for new cultivation have significant advantages over cultivars (Luo et al. 2022). Therefore, identifying favorable traits and selecting appropriate genotypes are significant processes. The nutritional characteristics of these extinct species, such as starch, dietary fiber, and phytic acid, have been handled as noted in a few research reports. The present study aims to determine the yield, morphological, and nutritional characteristics of different hulled wheat genotypes.

Material and method

Eighty-eight local hulled wheat were used as plant material: 7 T. *dicoccum*, 28 T. *monococcum*, 7 T. *speldoides*, 23 T. *boeoticum*, 3 T. *araticum*, 4 *Triticum sp*, 2 T. *Urartu and* 14 T. *turgidum* (Supplementary Table 1). Hulled wheat genotypes were provided from the National Plant Germplasm System (USDA) TRI, CGN, and VIR. The field experiment was conducted for two years, from 2017 to 2018 and 2018 to 2019, in the Agricultural Faculty of Erciyes University. Field experiments were conducted with an incomplete block design. Seeds were sown to have an 18 cm row spacing, and each plot had four rows. Plot sizes were arranged as 200 × 72 cm, 100 kg ha^{-1} N and 8 kg ha^{-1} P_2O_5 were applied to the soil according to the soil analysis results. Of each dose of nitrogen, 1/3 was given at sowing, 1/3 tillering, and the remaining 1/3 before panicle formation. Total P_2O_5 was applied at sowing. Three times, weeding was performed during the plant development.

Biochemical assays

Wheat grains were dried and ground (IKA MF 10.1, Staufen, Germany) and prepared for chemical analyses. Samples were preserved at + 4 °C until the time of analysis.

Crude protein content: A sample of about 0.25 g was taken, and the nitrogen ratio was determined using the Kjeldahl method. The resultant nitrogen value was multiplied by 6.25 ($N \times 6.25$) to get the sample crude protein ratio (AOAC, 1990).

Total dietary fiber: The Total Dietary Fiber Assay Kit for the analysis of Total, Soluble, and Insoluble Dietary Fiber according to AOAC and AACC-approved methods was used to determine the total dietary fiber of 1 g samples.

Crude ash content: About 1 g of dry sample was ashed in a muffle furnace at 550 ºC for eight hours to get the crude ash content of the samples.

Resistant, non-resistant, and total starch content: Megazyme Resistant Starch Assay (catalog number K-RSTAR, Megazyme International Ireland Ltd. Co. Wicklow, Ireland) kit developed following AOAC

Official Method 2002.02 and the AACC 32–40 Method was used to determine resistant starch content of 100 mg samples.

Amylose and Amylopectin content: Amylose and amylopectin fractions of the starch were determined using the Megazyme Amylose/Amylopectin Analysis Kit (K-AMYL, Megazyme International Ireland, Wicklow, Ireland).

Statically analysis

First, variance analysis was performed over the combined years using SAS statistical software (SAS Institute 1999). Significant means were compared using the LSD multiple comparison test.

Results

All hulled wheat genotypes have a white auricle color and no hairiness or waxiness. Although the species are primarily erect in growth habitus, some species have also observed a prostrate growth habitus (Supplementary Table 2). The yield and morphological traits of hulled wheat genotypes are provided in Supplementary Table 2, and the average morphological values of the species are provided in Table 1. The differences in yield and morphological traits of the hulled wheat were statistically significant ($p<0.01$). The lowest plant high value was observed in CGN10695 *T. speltoides* with 229.8 cm, and the highest was in CGN13160 *T. turgidum* with 82.8 cm. The shortest spike length was seen in VIR21156 *T. monococcum* at 1.2 cm, and the most extended spike length was in CGN21069 *T. turgidum* at 8.1 cm. CGN10695 *T. speltoides* was observed as the species with the shortest length of upper internode of 18.4 cm, just like the plant height. CGN12029 *T. monococcum* was determined as the species with the most extended length of upper internode of 53 cm. In terms of biological yield, the species with the highest yield was CGN16099 *T. turgidum* (1166.33 g/m^2), and the species with the lowest yield was CGN10779 *T. speldoides*, with a yield of 86.9 g/m^2. The highest grain yield was obtained from the TRI 18419 T. *monococcum* species with 398.75 g/m^2, and the lowest grain yield was obtained from the TRI 17082 T. *boeoticum* species with 40.75 g/m^2. Among the species, the lowest harvest index was obtained from *T. turgidum* CGN08106 species with 18.15%, and the highest harvest index was obtained from *T. boeticum* TRI 18339 species with 53.96% (Supplementary Table 2).

According to the genotype averages of wheat species, plant height varied between 50.40 cm (*Triticum* sp.) and 74.87 cm (*T. araraticum*), length of upper internode varied between 26.80 cm (*Triticum* sp.) and 36.00 cm (*T. dicoccum*), grain yield varied between 121.16 g/m^2 (*T. speldoides*) and 279.20 g/m^2 (*T. araraticum*), biological yield varied between 313.69 g/m^2 (*T. speldoides*) and 846.96 g/m^2 (*T. araraticum*), and harvest index varied between %33.33 (*T. urartu*) and %40.67 (*T. dicoccum*). Although the difference between species in terms of spike length was insignificant, spike length varied between 4.26 and 5.95 cm. (Table 1).

The nutritional properties of hulled wheat genotypes are provided in Supplementary Table 3, and the average nutritional properties of the species are

Table 1 Yield and morphological properties values of hulled wheat species

Wheat species	Plant height (cm)	Spike length (cm)	Length of upper internode (cm)	Biological yield (g/m^2)	Grain yield (g/m^2)	Harvest index (%)
T. dicoccum	61.11^{bc}	4.26	36.00^{a}	600.89^{c}	221.37^{c}	36.53
T. speldoides	57.77^{cd}	4.44	30.30^{b}	313.69^{f}	121.16^{f}	40.67
T. boeoticum	57.44^{cd}	4.72	29.77^{b}	595.21^{c}	184.51^{d}	37.06
T. araraticum	74.87^{a}	5.25	34.93^{a}	846.96^{a}	279.20^{a}	35.12
Triticum sp.	50.40^{e}	4.66	26.80^{b}	534.23^{d}	181.29^{d}	34.95
T. urartu	59.50^{bc}	5.95	28.40^{b}	410.73^{e}	153.08^{e}	34.84
T. turgidum	66.87^{b}	4.85	31.27^{b}	773.98^{b}	224.54^{b}	31.62
T. monococcum	63.64^{bc}	4.46	35.26^{a}	553.02^{d}	217.18^{c}	40.44

^{abcdef}: The difference between genotypes is statistically significant ($p<0.01$)

provided in Table 2. The differences in the hulled wheat's nutritional properties were highly significant ($p < 0.01$). The lowest protein content was detected in the *T. monococcum* sample TRI18428 with 10.12%, the lowest fiber content was detected in the *T. boeoticum* sample VIR27141 with 2.2%, and the lowest ash content was detected in the *T. monococcum* sample CGN08106 with 1.7%. The highest crude protein content was obtained from CGN08106 *T. turgidum* genotype with 19.48%, the highest fiber content was obtained from 8.29% TRI 17082 T. *boeoticum*, and the highest crude ash content was obtained from CGN06599 *T. monococcum* with 5.10%. Among hulled wheat genotypes, the lowest total starch content was obtained from TRI 18537 T. *araraticum* genotype with 49.50%, and the highest value was obtained from TRI 18332 T. *boeoticum* with 67.98%. Resistant starch content varied between 0.25% (TRI 18521 T. *dicoccum*) and 3.38% (TRI 17070 *T. boeoticum*), and non-resistant starch content varied between 48.08% (TRI 18537 T. *araraticum*) and 64.95% (TRI 18332 T. *boeoticum*). While the lowest amylose content was obtained from TRI 18477 *Triticum* sp. (3.43%), the highest was obtained from TRI 17082 *T. boeoticum* genotype (42.88%). The lowest amylopectin content was observed in TRI 17082 T. *boeoticum* (57.13%), and the highest value was observed in TRI 18477 *Triticum* sp. (96.58%) genotype (Supplementary Table 3).

According to the genotype averages of wheat species, crude protein content ranged from 13.16% (*T. speldoides*) to 18.36% (*T. araraticum*), fiber content from 4.97% (*T. monococcum*) to 5.48% (*Triticum* sp.), ash content 2.89% (*T. dicoccum*) to 4.21% (*T. araraticum*), total starch content 52.68% (*T. araraticum*) to 62.53% (*T. speldoides*), resistant starch content 0.39% (*T. dicoccum*) to 2.98% (*T. boeoticum*), non-resistant starch content 51.01% (*T. araraticum*) to 59.85% (*T. speldoides*), amylose content ranged from 12.17% (*Triticum* sp.) to 22.24% (*T.* araraticum). Amylopectin content ranged from 77.76% (*T. araraticum*) to 87.52% (*Triticum* sp.) (Table 2).

GT biplot graph was generated using mutual relationships between investigated yield, morphological, and nutritional traits to obtain trait separation power from yield, morphological, and nutritional vector images (Fig. 1). According to these graphs for hulled wheat genotypes, total starch, non-resistant starch, plant height, grain yield, biological product, crude protein content, crude ash content were identified as the significant traits. On the contrary, resistant starch, harvest index, dietary fiber, amylopectin, amylose, spike length, and length of upper internode had low separation power for hulled wheat genotypes. Biplot vector images reveal valuable information about the relationships among the examinate traits. Positive correlations were among total and non-resistant starch and spike length, plant height, length of upper internode and amylose, grain yield, biological yield,

Table 2 Nutritional properties of hulled wheat species

Wheat species	Crude protein (%)	Dietary fiber	Crude Ash	Total starch	Resistant starch	Non-resistant Starch	Amylose	Amylopectin
T. dicoccum	14.50 ± 0.30^{de}	5.42 ± 0.28^{ab}	2.89 ± 0.12^{b}	59.67 ± 0.50^{b}	0.39 ± 0.014^{a}	59.29 ± 0.50^{a}	18.85 ± 1.42^{ab}	79.69 ± 1.32^{b}
T. speldoides	13.16 ± 0.372^{e}	5.45 ± 0.10^{b}	2.94 ± 0.11^{b}	62.53 ± 0.59^{a}	2.67 ± 0.059^{b}	59.85 ± 0.54^{a}	21.88 ± 2.01^{a}	78.12 ± 2.10^{b}
T. boeoticum	15.18 ± 0.22^{cde}	5.29 ± 0.18^{ab}	3.39 ± 0.10^{c}	58.84 ± 0.53^{b}	2.98 ± 0.029^{c}	55.86 ± 0.51^{b}	21.83 ± 0.98^{a}	78.18 ± 0.98^{b}
T. araraticum	18.36 ± 0.43^{a}	5.31 ± 0.10^{ab}	4.21 ± 0.03^{a}	52.68 ± 0.94^{c}	1.67 ± 0.109^{d}	51.01 ± 0.84^{c}	22.24 ± 2.65^{ab}	77.76 ± 2.65^{ab}
Triticum sp.	17.27 ± 0.55^{ab}	5.48 ± 0.22^{ab}	3.95 ± 0.25^{ac}	53.41 ± 1.43^{c}	0.76 ± 0.025^{e}	52.65 ± 1.45^{bc}	12.17 ± 1.62^{b}	87.52 ± 1.73^{a}
T. urartu	16.80 ± 0.57^{abc}	5.30 ± 0.47^{ab}	4.17 ± 0.26^{ac}	58.33 ± 2.04^{abc}	1.09 ± 0.019^{f}	57.24 ± 2.02^{abc}	16.11 ± 3.11^{ab}	$83.89 \pm 3.11^{a.b}$
T. turgidum	16.19 ± 0.31^{bcd}	5.36 ± 0.15^{ab}	3.58 ± 0.14^{c}	56.55 ± 0.45^{c}	0.66 ± 0.018^{e}	55.89 ± 0.44^{b}	21.04 ± 1.46^{a}	78.70 ± 1.47^{b}
T. monococcum	15.45 ± 0.24^{bcd}	4.97 ± 0.09^{a}	3.66 ± 0.08^{c}	58.84 ± 0.42^{b}	1.30 ± 0.042^{d}	57.53 ± 0.39^{ab}	21.87 ± 0.99^{a}	78.60 ± 0.99^{b}

^{abcdef}: The difference between genotypes is statistically significant ($p < 0.01$)

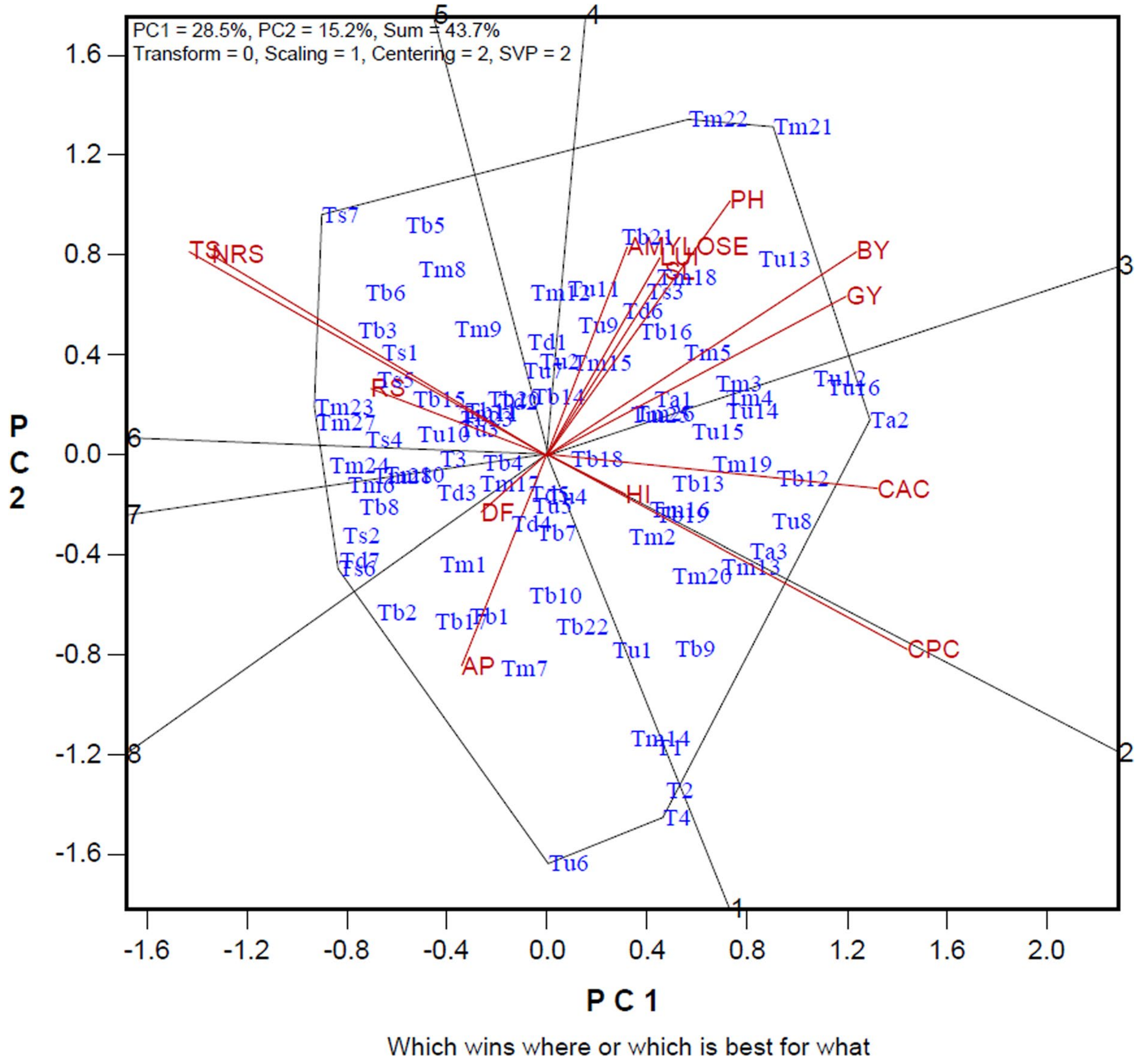

Fig. 1 Polygon views of the genotype group-by-trait (GGT)-biplot based on symmetrical scaling for the which-won-what pattern for genotypes and yield, morphological and nutritional properties. Details of hulled wheat genotypes are presented in Tables 1 and 2 and Supplementary Tables 2 and 3 *(PH: plant height, CPC: crude protein content, CAC: crude ash content, Ap: amylopectin, DF: dietary fiber, RS: resistant starch, TS: total starch, NRS: non-resistant starch, SL: spike length, LUI: length of upper internode, BY: biological yield, GY: grain yield, HI: harvest index, Ta: T. araraticum, Tm: T. monococcum, Td: T. dicoccum, Ts: T. speldoides, Tb: T. boeoticum, Tu: T. urartu)*

and amylopectin and dietary fiber traits. There was a negative correlation between total starch, non-resistant starch, and harvest index crude protein content between dietary fiber, amylopectin, plant height, spike length, and amylopectin.

Hulled wheat genotypes of Ts1, Ts7, Tm23, Tm27, and Tb3, Tb6, and Tb15 were found to be prominent for resistant starch, non-resistant starch and total starch, genotype Tm21, Tm21, Tb21, Tm18 Tu13, Ts3 for plant high, length of upper internode, amylose and spike length, genotypeTu12, Tu16 and Ta2 for grain yield and biological yield, genotype Tb12, Tu8 and Ta3 and Tm13 for crude ash and protein content, genotype Tb1, Tb17 and

Tm7 for amylopectin, genotype Tm 17and Td3 for dietary fiber (Fig. 1).

Discussion

Yield and quality of wheat are significantly influenced by environment, genotype, and genotype x environment interaction (Akcura 2011). Additionally, summer and winter sowing, rainfall volume and distribution, plant density and tillering (Kaplan et al. 2014), and grain development are other factors that may impact the yield and quality of wheat genotypes (Akgün et al. 2007). Previous research observed significant differences between yield and harvest index values in hulled wheat (Troccoli & Codianni 2005; Konvalina et al. 2011; Shewry et al. 2013). The primary source of these variations is the germplasm's varied genetic backgrounds (Feil 1992).

Reports of wheat grain quality characteristics are crucial for the milling industry and the design and management of breeding strategies to increase grain quality (Kulathunga et al. 2021). Differences in climatic characteristics, agricultural applications, genotypes, soil fertility, disease and weed control, and growth locations cause quality features of cereal grains variations (Kaplan et al. 2014). One of the most essential criteria for the assessment of quality in nutrients is crude protein content. The protein content of hulled whole grain flour was determined by Kulathunga et al. (2021) as 13.6–15.8%, by Geisslitz et al. (2019) as 11.1–11.6%, and by Kaplan et al. (2014) as 6.69–16.22%. Brandolini et al. (2008) reported that it varied between 15.4 and 18.7%. The data supported these researchers. In addition, whole wheat flour from ancient wheat is known to have a higher protein content than flour from modern wheat (Abdel-Aal & Wood 2004). Differences in plant grain filling times result in changes in the concentrations of starch and amylose. The impact of year and cultivar is vital on starch content, rate of amylose, and amylopectin (Kardes et al. 2021). It has been reported by Singh et al. (2010) that starch content is affected positively by warm weather, especially during the ripening period. Variations in the dates of harvest time of different wheat species cause changes in the biochemical characteristics of the seed. The grain's amylose content varies based on nitrogen fertilization, genotype, and environment. Similarly, the amylopectin content varies depending on the botanical source, climate, soil conditions, and grain growth (Kaplan et al. 2020). The results of our study align with previous research conducted by Kulathunga et al. (2021) and Abdel-Aal et al. (1997), who indicated that the total starch concentration in spelts ranged from 61.2 to 66.9% and 62.3 to 65.0%, respectively. Ash content is a significant indicator of the mineral composition of foods.

Ash content in the grain may vary based on agronomic application, soil, climate conditions, and crop species. In the literature, the crude ash content of hulled wheat was in the range of 2.0–2.3% (Kulathunga et al. 2021), 2.06–2.80% (Brandolini et al. 2008), 1.9–2.4% (Løje et al. 2003) and 4.23–5.22% (Kaplan et al. 2014). These results were found to be similar to those stated by other researchers.

Foods with dietary fiber generally have a lower glycemic index than other carbohydrate-rich foods. The dietary fiber content of modern wheat was found to be high in some research, while in others, it was found to be low (Frølich et al. 2013). In previous research, the dietary fiber content of hulled wheat was reported to be between 13 and 22.2%, which was higher than our results (Kulathunga et al. 2021).

Biplot analysis can be applied to all genotypes equally by inputting genotype properties like two-way data (Akcura et al. 2021). Biplot analysis can identify ideal genotypes for attributes under investigation and screen genotypes for various properties (Karaman et al. 2022). Users can also evaluate the correlations between the properties graphically via biplot analysis. This biplot perspective is the most effective for illustrating the relationships between the qualities since the cosine of the angle between the vectors of any two properties approximates the correlation coefficient between them (Kaplan et al. 2023).

Conclusion

Health-conscious consumers are looking for alternative flour instead of modern wheat flour. For this reason, the popularity of hulled wheat is increasing daily. This study revealed that hulled wheat species and genotypes have very different yield and nutritional properties and characteristics, and their yield, morphological characteristics, and nutritional values are high. Using genotypes with yield and superior nutritional properties in developing different food products will contribute significantly to producers and consumers.

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Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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