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Determination of Yield and Some Quality Characteristics of Bread Wheat (*Triticum aestivum* L.) Genotypes in Different Environmental Conditions

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ABSTRACT

This study was conducted in 2 regions (Samsun-Bafra and Tokat) in the Central Black Sea Region, depending on rainfall, during the 2021-2022 production period. The trial consists of 21 lines and 4 standard varieties in the regional yield stage within the scope of the bread wheat breeding program conducted by the Black Sea Agricultural Research Institute. The aim of the study is to determine the lines superior to the varieties in terms of grain yield and quality. The trial was conducted in randomized block design in 6 m^2 (5 m x 1.2 m) plots with 4 replications. In the study, yield and some quality traits (thousand grain weight, hectoliter weight, protein ratio, zeleny sedimentation, alveograph energy value, grain hardness and water absorption (Farinograph) value) were examined. According to the obtained results, grain yield was 476.6 - 1125.8 kg/da, thousand grain weight was 31.9 - 54.1 g, hectoliter weight was 68.0 - 80.8 kg/hl, protein content was 10.8 - 15.3%, zeleny sedimentation was 32 - 75 ml, alveograph energy value (W) was 105 -385 Joule, grain hardness (PSI) was 34.4 - 88.6 and water absorption (Farinograph) value was 56.9 - 67.5%. Significant ($p<0.01$) differences were found among the genotypes in terms of grain yield, thousand grain weight and hectoliter weight. The highest grain yield with 1125.8 kg/da was obtained from line 1 in Bafra location, hectoliter weight value with 80.8 kg/hl was obtained from line 12 in Bafra location, thousand grain weight value with 54.1 g was obtained from line 18 in Bafra location and protein value with 15.3% was obtained from line 18 in Bafra location, grain hardness (PSI) value with 88.6 was obtained from line 4 in Tokat location, zeleny sedimentation value with 75 ml was obtained from Altındane standard variety in Bafra location, alveograph energy value with 385 Joule was obtained from line 22 in Tokat location and water absorption (Farinograph) with 67.5% was obtained from line 9 in Bafra location. According to the results obtained from the trial, it was concluded that lines 1, 4, 9, 12, 18 and 22 could be evaluated as variety candidates in the future and therefore should be included in the next breeding program.

Keywords: Bread wheat, line, breeding, quality, region yield

Introduction

Wheat (*Triticum* spp.) has been cultivated and improved by humans for approximately 10,000 years, beginning with the advent of settled agriculture. Today, wheat constitutes a significant portion of the global food supply. More than 720 million people around the world are currently under the threat of hunger, making wheat production and accessibility critically important for global food security (Ibba MI et al., 2022). Wheat is a vital cereal crop with global production exceeding 770 million tons annually (Anonymous, 2022). It is cultivated on more than 217 million hectares worldwide and plays a key role in global food security (Erenstein, 2022).

In Türkiye, wheat was cultivated on 6.8 million hectares with a total production of 20.8 million tons during the 2023-2024 growing season (Anonymous, 2024). Approximately 95% of the wheat grown globally is bread wheat (hexaploid), while the remaining 5% is mostly durum wheat (tetraploid), which is used primarily for pasta production (Shewry, 2009). Wheat provides about 21% of daily caloric intake, approximately 55% of carbohydrates, and 13% of proteins consumed by humans (Riaz et al., 2021; Ali et al., 2012). The global population is projected to reach around 9 billion by 2050, leading to an expected 60% increase in wheat demand (Anonymous, 2025). One of the most effective ways to increase wheat production is by improving grain yield per unit area. Yield is influenced by the plant's genetic potential, environmental factors, and agronomic practices. Variations in grain yield are largely attributable to the genetic characteristics of wheat varieties (Kırtok et al., 1988; Sharma, 1992; Öztürk & Akkaya, 1996; Ağdağ et al., 1997; Dokuyucu et al., 1997; Anıl, 2000). In addition to yield, bread-making quality is another crucial parameter in wheat production. In particular, both the quantity and quality of protein are among the most important traits affecting bread-making performance. The demand for high-quality flour in the food industry naturally drives producers to seek wheat varieties that are both high-yielding and of superior quality. For an ideal bread wheat variety, the required quality parameters include a minimum protein content of 11.5%, a hectoliter weight of 77-78 kg/hl, a Zeleny sedimentation value of at least 30 ml, and high energy and water absorption values, along with a hard grain texture. Pastry products (such as pasta, biscuits, and buns) require an even higher protein content, preferably 12-12.5%, and a baking strength (alveograph energy value) of 220–300 joules (W), which is higher than that of typical bread dough (Anonymous, 2022).

Climate change may negatively affect wheat production due to temperature increase, water scarcity and extreme weather events. This situation necessitates the development of new wheat varieties and the implementation of sustainable agricultural techniques (Asseng et al., 2015). This study was conducted in 2022 in different regions of Türkiye (Bafra/Samsun and Merkez/Tokat) under rainfed conditions. The aim is to comparatively evaluate the grain yield, yield components and certain quality traits of some advanced bread wheat lines. In this context, it is aimed to determine genotypes with high adaptability and increased yield and quality traits together. It also aims to obtain important data that will contribute to both producers and the food industry for sustainable wheat production. The data obtained will contribute to wheat breeding studies in regions with similar ecological conditions.

Materials and Methods

Materials

This study was conducted under rainfed conditions during the 2021–2022 growing season at two experimental sites: the Black Sea Agricultural Research Institute in Bafra (Samsun) and the Transitional Zone Agricultural Research Institute located in the Central Black Sea Region in Tokat (Figure 1). The experimental material comprised 20 advanced bread wheat lines along with 5 standard check varieties. The check varieties included Altındane, Kirve, and Nevzatbey (registered by the Black Sea Agricultural Research Institute), the SİTAP-14/21 line, and Flamura 85 (registered by TAREKS Inc.) (Table 1). Climatic data for the experimental locations are presented in Table 2, while soil analysis results are provided in Table 3.

Methods

The experiment was conducted using a randomized complete block design (RCBD) with four replications. Sowing was carried out using a plot drill with six rows, with each plot measuring 7.7 m². Sowing dates were November 4, 2021, in Tokat and November 18, 2021, in Bafra. The seeding rate was adjusted to establish a target plant population of 550 plants per square meter. Harvesting was performed using a plot combine harvester on July 4, 2022, in Tokat and July 6, 2022, in Bafra, with a harvested area of 6 m² per plot.

Fertilization at sowing included the application of 6 kg/da of pure nitrogen and 6 kg/da of pure phosphorus at both locations. In Bafra, an additional 10 kg/da of nitrogen was applied at the stem elongation stage, followed by 4 kg/da at the heading stage. In Tokat, only 10 kg/da of nitrogen was applied at the stem elongation stage. Weed control was achieved through the application of a herbicide containing Halauxifen-methyl, 25% Pyroxsulam, and 35.4% Cloquintocet-acid as active ingredients, applied at the recommended doses to control both narrow- and broad-leaved weeds.

The primary traits evaluated included grain yield (kg/da), hectoliter weight (kg/hl), and thousand kernel weight (g). Quality traits assessed were moisture content (%), protein content (%), SDS sedimentation value (ml), grain hardness, Alveograph energy value (W), and water absorption (Farinograph, %). These analyses were conducted at the Quality Laboratory of the Bahri Dağdaş International Agricultural Research Institute. Grain yield was calculated by extrapolating the grain weight obtained from the 6 m² plots to a per-decare (da) basis.

For quality analyses, grain samples were ground using a Perten 3100 mill (Perten Instruments AB, Sweden) with a 0.8 mm sieve. Protein content was determined by multiplying the nitrogen content, measured via the Dumas method using a Leco FP 528 analyzer, by a factor of 5.7, according to AOAC 992.23 (Anonymous, 2000a). Grain hardness was assessed using a Foss DS2500 F NIR instrument, calibrated according to the Single Kernel Characterization System

(SKCS) standard (AACC 55-31) (Anonymous, 2000b). For flour production, 1 kg of cleaned wheat grain was tempered to 14.5% moisture (w/w) and rested for 12 hours before milling with a Yücebaş YM1 laboratory mill (Yücebaş Machinery Analytical Equipment, İzmir, Türkiye), following AACC methods 26-95 and 26-50 (Anonymous, 2000b).

Thousand kernel weight (g/1000 seeds) and hectoliter weight (kg/100 L) were measured according to the method of Williams et al., (1988), and results were reported on a dry matter basis. Zeleny sedimentation was assessed using ICC Standard Method No. 116 (Anonymous, 1981), while grain protein content was also evaluated with the Foss 1241 Infratec Grain Analyzer (NIT) (Anonymous, 2002b). Flour yield was determined following ICC Standard Method No. 137/1 (Anonymous, 2002a).

Statistical analyses were performed using JMP software version 7.0. Differences among treatment means were evaluated using the Least Significant Difference (LSD) test at significance levels of $p \leq 0.01$ and $p \leq 0.05$ (Kalaycı, 2005).

Results and Discussion

The grain yield (Table 4), hectoliter weight (Table 5), thousand kernel weight (Table 6), and selected quality parameters (Tables 7-8) of the genotypes evaluated at the Bafra and Tokat locations are presented. Statistically significant differences among genotypes were observed for grain yield, hectoliter weight, and thousand kernel weight at the $p \leq 0.01$ level.

Grain Yield

When both locations were evaluated together, the overall average grain yield was 830.5 kg/da, with values among genotypes ranging from 476.6 to 1125.8 kg/da. The highest yield was recorded for genotype No. 24 (972.0 kg/da), while the lowest yield was observed in genotype No. 22 (573.4 kg/da).

The average grain yield was higher at the Bafra location (876.5 kg/da) compared to Tokat (784.6 kg/da). However, some genotypes exhibited higher grain yields in Tokat. This discrepancy is primarily attributed to the higher rainfall and humidity levels in Bafra, which, while beneficial for crop growth in general, also create favorable conditions for the development of fungal diseases such as rusts, Fusarium, and powdery mildew, and increase the risk of pre-harvest sprouting. Consequently, certain genotypes (Nos. 11, 20, 22, and 25) experienced yield losses in Bafra due to yellow rust infection.

Aydın et al., (2005) reported that grain yields of genotypes ranged from 165 to 381 kg/da under the conditions of Samsun and Amasya, noting that lower-than-expected yields in Samsun were primarily caused by lodging and disease outbreaks associated with excessive rainfall. Similarly, Mut et al., (2005), in a study involving 25 bread wheat genotypes conducted in the same regions, reported grain yields ranging from 284.4 to 490.6 kg/da and observed statistically significant differences among the genotypes. In another multi-environment trial conducted by Mut et al., (2009) across seven locations in Samsun and Amasya, grain yields ranged between 350.3 and 550.6 kg/da.

Karaman and Aktaş (2020) reported grain yields ranging from 581.1 to 777.3 kg/da under Diyarbakır conditions during the 2011–2012 growing season. Similarly, Erkul (2006), in a trial conducted during the 2004-2005 season at the experimental fields of the Department of Field Crops, Faculty of Agriculture, Adnan Menderes University, reported grain yields ranging from 378.12 to 522.40 kg/da.

Yazar et al., (2013), in a bread wheat breeding study conducted in the Central Anatolia Region during the 2010-2011 growing season, found grain yields ranging from 379 to 551 kg/da. Karaman et al., (2017), in trials carried out under rainfed conditions in Diyarbakır, Ceylanpınar, and Hazro during the 2014-2015 season, observed grain yields ranging from 564 to 678 kg/da. Likewise, Aydoğan and Soylu (2017) reported grain yields between 447.42 and 709.08 kg/da in a study conducted at the Bahri Dağdaş International Agricultural Research Institute in Konya during the 2014-2015 season.

Naneli (2022), in a study conducted at the Kaynarca and Taraklı locations during the 2020-2021 growing season, found that grain yields varied significantly ($p \leq 0.01$), ranging from 481 to 727 kg/da in Kaynarca and from 426 to 791 kg/da in Taraklı. The average yields were 617 kg/da and 595 kg/da for Kaynarca and Taraklı, respectively.

Aktaş and Gökdere (2025), in a regional study conducted across the Aegean, Marmara, Mediterranean, Southeastern Anatolia, and Central Anatolia Regions during the 2016-2017 and 2017-2018 growing seasons, reported grain yields ranging from 4260 to 8137 kg/ha.

Ersöz and Budak Başçiftçi (2024) determined that grain yields ranged between 237.91 and 491.20 kg/da in a trial conducted at the research and trial area of the Faculty of Agriculture, Eskişehir Osmangazi University, during the 2021-2022 growing season. Similarly, Doğan (2024), in a study carried out at the Eskişehir Transitional Zone Agricultural Research Institute during the 2021-2022 production season, reported grain yields ranging from 259 to 506 kg/da. Demir (2024), in a trial conducted at the S.S. Akşehir-

Ilgın Sugar Beet Growers Cooperative field during the 2022–2023 growing season, reported grain yields ranging from 436 to 711 kg/da.

Hectoliter Weight (HLW)

Hectoliter weight is a key physical quality parameter in wheat, providing insights into potential flour yield and widely used by the grain industry. Values of 78 kg/hl and above are generally considered favorable by millers. This trait is influenced by both genetic factors (genotype) and environmental conditions.

The hectoliter weight values of the genotypes included in the trial are presented in Table 5. According to the results, the overall mean across locations was 76.1 kg/hl. At the Bafra location, the highest hectoliter weight was observed in genotype No. 12 (80.8 kg/hl), while the lowest was recorded for genotype No. 22 (68.0 kg/hl). In the Tokat location, the highest value was recorded for the standard variety Nevzatbey (79.5 kg/hl), and the lowest for genotype No. 23 (69.7 kg/hl).

Hectoliter weight is significantly affected by environmental variables such as temperature, humidity, and precipitation. When comparing the locations, it is evident that the hectoliter weight values in Tokat were generally lower than those in Bafra. This difference is attributed to Tokat's lower precipitation and higher temperatures. Regular precipitation, particularly during the grain filling period, and hot, dry conditions can promote grain filling and increase weight. Conversely, excessive heat or stress can negatively impact grain development (Slafer & Andrade, 1991).

In a study conducted under Samsun and Amasya conditions, Aydın et al., (2005) reported an average hectoliter weight of 62 kg/hl in the Samsun location, attributing the low values to lodging and disease outbreaks resulting from excessive rainfall. Similarly, Mut et al., (2005), evaluating 25 bread wheat genotypes in the same regions, reported hectoliter weight values ranging from 68.4 to 74.9 kg/hl. In another study across seven environments in Samsun and Amasya, Mut et al., (2010) found an average hectoliter weight of 71.4 kg/hl.

Karaman and Aktaş (2020) reported hectoliter weight values ranging between 76.5 and 85.4 kg/hl in a study conducted in Diyarbakır during the 2011-2012 growing season. Erkul (2006), in a trial carried out during the 2004–2005 season at the Field Crops Department of the Faculty of Agriculture, Adnan Menderes University, reported hectoliter weight values ranging from 75.87 to 81.40 kg/hl.

Karaman et al., (2017), in a study conducted under rainfed conditions in Diyarbakır, Ceylanpınar, and Hazro during the 2014–2015 season, observed hectoliter weight values between 78.2 and 82.7 kg/hl. Likewise, Aydoğan and Soylu (2017), in a trial conducted at the Bahri Dağdaş International Agricultural Research Institute in Konya during the 2014–2015 growing season, reported hectoliter weight values ranging from 73.32 to 78.35 kg/hl.

Aktaş and Gökdere (2025), in a regional study conducted across the Aegean, Marmara, Mediterranean, Southeastern Anatolia, and Central Anatolia regions during the 2016–2017 and 2017-2018 seasons, reported hectoliter weight values ranging from 77.2 to 79.2 kg/hl. Naneli (2022), in a study carried out in Kaynarca and Taraklı during the 2020–2021 growing season, found that genotype differences in hectoliter weight at both locations were statistically significant at the 1% level. Hectoliter weight ranged between 71 and 81 kg/hl in Kaynarca and between 70 and 81 kg/hl in Taraklı. The mean hectoliter weight was 76.6 kg/hl in Kaynarca and 75.3 kg/hl in Taraklı, with the difference between the two locations also statistically significant at the 1% level.

Aydoğan et al., (2019), in their study at the Bahri Dağdaş International Agricultural Research Institute during the 2013–2014 production year, reported hectoliter weight values for bread wheat varieties ranging from 72.38 to 78.48 kg/hl. Demir (2024), in a study conducted during the 2022–2023 growing season at the trial field of the S.S. Akşehir-Ilgın Sugar Beet Growers Cooperative, found hectoliter weight values ranging from 65.7 to 76.2 kg/hl.

Thousand Kernel Weight (TKW)

Thousand kernel weight is one of the key technological quality parameters in wheat production. In addition to genetic factors, environmental conditions significantly affect thousand kernel weight. High temperature stress during the grain filling period negatively impacts thousand kernel weight by shrinking the grains, while adequate water availability supports grain filling and increases kernel weight. In the present study, the average thousand kernel weight across locations was recorded as 41.7 g. The highest value was obtained from genotype number 18 with 48.2 g, while the lowest was observed in genotype number 7 with 31.1 g. The average thousand kernel weight was 45.7 g at the Bafra location and 37.7 g at the Tokat location.

In a study conducted under rainfed conditions during the 2011-2012 growing season in Diyarbakır, Türkiye, Karaman and Aktaş (2020) reported thousand kernel weight values ranging from 28.3 to 53.5 g while identifying superior wheat lines in terms of yield and quality. Similarly, Yazar et al., (2013), in a study conducted within the scope of bread wheat breeding programs in Central Anatolia during the 2010-2011 growing season, reported a maximum thousand kernel weight of 38.6 g. Aydın et al., (2005) observed an average thousand kernel weight of 26.1 g under Samsun and Amasya conditions, attributing the low values to lodging and disease epidemics caused by seasonal rainfall.

Aktaş and Gökdere (2025) reported regional thousand kernel weight values ranging between 35.3 and 39.9 g in their study conducted across the Aegean, Marmara, Mediterranean, Southeastern Anatolia, and Central Anatolia regions during the 2016-2018 period. Yıldırım and Deger (2021) found thousand kernel weight values ranging from 35.48 to 42.71 g in commonly cultivated bread wheat varieties in the Mardin region in 2018. Similarly, Aydoğan et al., (2019), in their study conducted during the 2013-2014 production season at the Bahri Dağdaş International Agricultural Research Institute, reported a thousand kernel weight range of 31.10-41.31 g.

Erbaş Köse et al., (2023), in their study conducted under Bilecik ecological conditions in the 2019-2021 seasons, reported an average thousand kernel weight of 42.5 g. Ersöz and Budak Başçiftçi (2024) found thousand kernel weight values ranging from 37.9 to 44.3 g in their 2021–2022 study conducted at Eskişehir Osmangazi University, Faculty of Agriculture. Similarly, Doğan (2024), in a study carried out during the same season at the Eskişehir Transitional Zone Agricultural Research Institute, reported thousand kernel weight values between 36.2 and 51.25 g. Demir (2024) reported thousand kernel weight values ranging from 31.21 to 45.08 g in a study conducted in the 2022-2023 season at the trial field of the S.S. Akşehir-Ilgın Sugar Beet Growers Cooperative.

Mut et al., (2005) evaluated 25 bread wheat genotypes under Samsun and Amasya conditions and reported thousand kernel weight values ranging from 28.4 to 38.9 g. In another study by Mut et al., (2010), which included seven different environments within the same region, the average thousand kernel weight was found to be 48.4 g. Karaman et al., (2017), in their rainfed trials conducted in Diyarbakır, Ceylanpınar, and Hazro during the 2014-2015 season, reported thousand kernel weight values ranging from 30.0 to 41.4 g. Similarly, Aydoğan and Soylu (2017), in their study conducted during the 2014-2015 growing period at the Bahri Dağdaş International Agricultural Research Institute in Konya, reported thousand kernel weight values between 30.90 and 46.46 g.

Protein Content (%)

Protein content is known to be affected by genotype, but primarily by environmental conditions (Baenziger et al., 1985). High temperatures during ripening can reduce starch accumulation and subsequently increase protein content. Similarly, insufficient rainfall or drought conditions may restrict grain development, thereby increasing the relative protein concentration (Rharrabti et al., 2001). In our study, the Tokat location experienced higher temperatures and lower rainfall compared to the Bafra location. Accordingly, the higher protein content observed in the genotypes grown in Tokat supports the findings reported in both aforementioned studies.

In the present study, the highest protein content in the Bafra location was recorded in genotype 18, with a value of 15.3%, while the lowest values were observed in genotypes 1 and 7, both with 10.8%. At the Tokat location, the highest protein content was found in the control cultivar Flamura-85 with 15.2%, whereas the lowest values were recorded in genotypes 8-11 and 16, with 12.6%.

Previous studies have reported comparable results across various regions and environmental conditions in Türkiye. Aydın et al., (2005) reported an average protein content of 10.9% under Samsun conditions. Mut et al., (2005) evaluated 25 bread wheat genotypes in Samsun and Amasya, reporting protein contents ranging from 10.4% to 13.6%. Similarly, Mut et al., (2010) reported an average protein content of 12.4% across seven different environments under Samsun and Amasya conditions. Karaman and Aktaş (2020) found protein content ranged from 12.4% to 15.4% during the 2011–2012 growing season in Diyarbakır. Sevim and Erekul (2020) reported a range of 9.1% to 14.6%. Erkul (2006), in a study at the Adnan Menderes University during the 2004-2005 season, recorded protein content between 10.39% and 13.33%.

Aktaş and Gökdere (2025) determined regional protein contents between 13.4% and 14.7% in the Aegean, Marmara, Mediterranean, Southeastern Anatolia, and Central Anatolia regions during the 2016-2017 and 2017–2018 seasons. Yıldırım and Değer (2021) observed protein content ranging from 11.50% to 13.25% in bread wheat varieties grown in Mardin in 2018. Aydoğan et al., (2019), in a study at the Bahri Dağdaş International Agricultural Research Institute during the 2013-2014 production year, reported average protein values ranging between 14.16% and 16.09%.

Erbaş Köse et al., (2023), under Bilecik ecological conditions in the 2019-2020 and 2020–2021 seasons, found an average protein content of 13.5%. Doğan (2024) reported protein content ranging from 11.33% to 16.29% in a study at the Eskişehir Transitional Zone Agricultural Research Institute during the 2021-2022 growing season.

Demir (2024) recorded protein values between 11.5% and 14.8% in trials conducted in the S.S. Akşehir-Ilgın Sugar Beet Growers Cooperative experimental field during the 2022-2023 season.

Yazar et al., (2013) reported a maximum protein content of 13.4% in their Central Anatolia Region study during the 2010-2011 growing season. Karaman et al., (2017), under rain-fed conditions in Diyarbakır, Ceylanpınar, and Hazro during the 2014-2015 season, reported protein content ranging from 12.1% to 13.9%. Aydoğan and Soylu (2017), at the Konya Bahri Dağdaş International Agricultural Research Institute during the 2014-2015 season, recorded protein content values between 11.93% and 13.44%.

Alveograph Energy Value (W)

At the Bafra location, the highest alveograph energy value was recorded in the control variety Altındane, with a value of 335 Joules, while the lowest value was observed in genotype 23, with 105 Joules. In the Tokat location, the highest energy value was 385 Joules, obtained from genotype 22, whereas the lowest was recorded in genotype 16, with 141 Joules.

Aktaş and Gökdere (2025) reported that alveograph energy values ranged between 191.2 and 276.4 Joules on a regional basis in their study conducted across the Aegean, Marmara, Mediterranean, Southeastern Anatolia, and Central Anatolia regions during the 2016-2017 and 2017-2018 growing seasons.

Similarly, Kılıç et al., (2014) found that, in their study conducted during the 2004-2005 season at the Diyarbakır GAP International Agricultural Research and Training Center and the Ceylanpınar TİGEM trial site, the average alveograph energy values of genotypes ranged from 37 to 233 Joules.

Water Absorption (Farinograph) (%)

At the Bafra location, the highest water absorption value was recorded in genotype 9 at 67.5%, while the lowest value, 56.9%, was observed in both the Flamura 85 control variety and genotype 23. At the Tokat location, the highest water absorption value was found in genotype 13 at 66.0%, and the lowest was recorded in genotype 11, also at 56.9%.

Sevim and Erekul (2020), in their study conducted at the Aegean Agricultural Research Institute's Menemen trial site, reported water absorption values ranging from 57.6% to 66.6%. Similarly, Aydoğan et al., (2019), in their research conducted during the 2013-2014 production year at the Bahri Dağdaş International Agricultural Research Institute, found that the farinograph water absorption of bread wheat varieties ranged from 62.50% to 68.20%.

Grain Hardness (PSI)

At the Bafra location, the highest grain hardness value was recorded in genotype 13 with a value of 80.0, while the lowest was observed in genotype 1 at 34.4. In the Tokat location, genotype 4 showed the highest grain hardness at 88.6, whereas the lowest value, 57.0, was recorded in genotype 11.

Aydoğan and Soylu (2017), in their study conducted during the 2014-2015 growing season at the Konya Bahri Dağdaş International Agricultural Research Institute, reported that grain hardness values (PSI) ranged from 41.27 to 64.82. Similarly, Doğan (2024), in a study conducted at the Eskişehir Transitional Zone Agricultural Research Institute during the 2021-2022 production season, reported grain hardness values for bread wheat ranging from 19.33 to 64.18 PSI.

Zeleny Sedimentation (ml)

According to Elgün et al., (2002), genotypes with Zeleny sedimentation values below 15 ml have very poor gluten quality; values between 16-24 ml indicate poor quality, 25-36 ml reflect good quality, and values above 36 ml represent very good gluten quality. In the present study, the average Zeleny sedimentation value was 51.8 ml at the Bafra location and 54.0 ml at the Tokat location (Tables 7 and 8).

At the Bafra location, the highest Zeleny sedimentation value was recorded in the Altındane standard variety at 75 ml, while the lowest was observed in genotype 12 at 32 ml. In the Tokat location, genotype 22 exhibited the highest value at 69 ml, and genotype 8 had the lowest at 43 ml.

Aydın et al., (2005) reported that under Samsun and Amasya conditions, Zeleny sedimentation values of genotypes ranged from 27.3 to 50.8 ml, with genotype 22 showing the highest value at both locations -this genotype was later registered as Altındane in 2012. These results are in agreement with our findings. Similarly, Mut et al., (2005) found sedimentation values between 25.0 and 50.6 ml in their study involving 25 bread wheat genotypes under the same regional conditions. Mut et al., (2010) reported an average value of 44.7 ml in seven different environments in Samsun and Amasya.

In Diyarbakır, Karaman and Aktaş (2020) recorded Zeleny sedimentation values ranging from 22.0 to 37.0 ml during the 2011-2012 growing season. Sevim and Erekul (2020) found a range of 14 to 45 ml, while Erkul (2006), in a study conducted at Adnan Menderes University during the 2004-2005 growing season, reported values between 16.33 and 24.33 ml.

Aktaş and Gökdere (2025) reported regional Zeleny sedimentation values ranging from 43.2 to 53.3 ml in their study covering the Aegean, Marmara, Mediterranean, Southeastern Anatolia, and Central

Anatolia regions during the 2016-2017 and 2017-2018 production seasons. In Mardin, Yıldırım and Değer (2021) found values between 26.0 and 43.5 ml among commonly cultivated bread wheat varieties.

Erbaş Köse et al., (2023), in a study conducted under Bilecik ecological conditions during the 2019-2020 and 2020-2021 seasons, reported an average sedimentation value of 29.8 ml. Similarly, Doğan (2024) recorded sedimentation values ranging from 10 to 50 ml at the Eskişehir Transitional Zone Agricultural Research Institute during the 2021-2022 production season. Demir (2024) reported values between 35 and 65 ml in a trial conducted in the experimental field of the S.S. Akşehir-Ilgın Sugar Beet Growers Cooperative in the 2022-2023 growing season.

Yazar et al., (2013), in a study on bread wheat breeding in the Central Anatolia Region during the 2010-2011 growing season, found Zeleny sedimentation values between 12.3 and 48.5 ml. Karaman et al., (2017) reported values ranging from 25.8 to 41.5 ml in a study conducted under rain-fed conditions during the 2014-2015 growing season in Diyarbakır, Ceylanpınar, and Hazro. Finally, Aydoğan and Soylu (2017), in their research at the Konya Bahri Dağdaş International Agricultural Research Institute during the 2014-2015 season, reported values ranging from 26.0 to 39.5 ml.

Conclusions

As a result of the study conducted under rainfed conditions during the 2021-2022 production season in the Samsun and Tokat ecological regions, significant differences were observed among the genotypes. In terms of grain yield, genotype 1 at the Bafra location demonstrated superior performance. Regarding protein content, genotype 18 at the Bafra location had the highest value. The highest hectoliter weight was recorded in genotype 12, and the highest thousand-grain weight was also found in genotype 18, both at the Bafra location.

For Zeleny sedimentation value, the highest result was obtained from the standard cultivar Altındane at the Bafra location. In the Tokat location, genotype 22 showed the highest alveograph energy value. The highest water absorption was observed in genotype 9 at the Bafra location, while genotype 4 at the Tokat location had the highest grain hardness value.

These findings indicate that the aforementioned genotypes exhibit promising technological and agronomic characteristics. Therefore, they are considered potential candidates for inclusion in future wheat breeding programs and will be evaluated in the next breeding cycle.

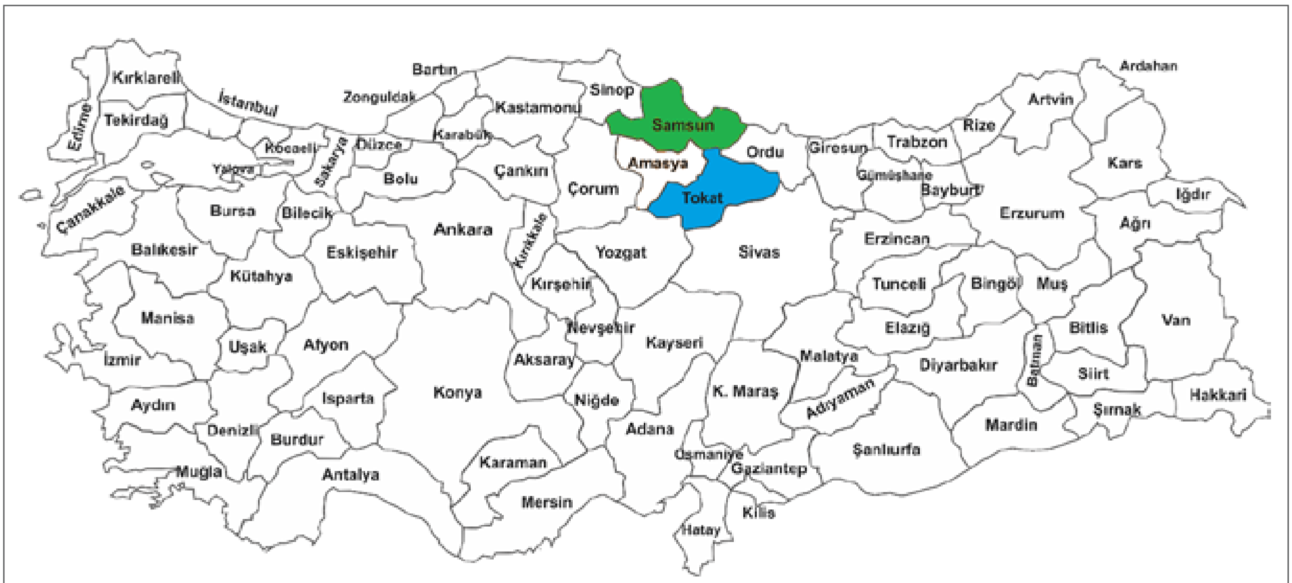

Figure 1. The Location of the Experimental Fields on the Map of Türkiye.

Table 1. Pedigree Information of Bread Wheat Lines and Varieties Used in the Experiment.

Genotype No	Cross/Pedigree	Breeding Instit
1	KS040477K-12/GALLAGHER	CIMMYT
2	KS050255K-6/KANMARK	CIMMYT
3	DONSKAYA YUBILEYNAYA	CIMMYT
4	(ATTILA*2/ESDA//MASON)/(HBK0935-7-4/…	CIMMYT
Altındane	Standard	KTAE
6	KS13DH002722	CIMMYT
7	KS14DH0013-19	CIMMYT
8	CUPRA1/3/CROC1/AE.SQUARROSA(224)//2*…	CIMMYT
9	WEAVER/4/NAC/TH.AC//3*PVN/3/MIRLO/….	CIMMYT
Nevzatbey	Standard	KTAE
11	DH01-29-33*R/3/VORONA/KAUZ//1D13.1/MLT	CIMMYT
12	CNDO/R143//ENTE/MEXI_2/3/AE.SQ.(TAUS)/4/…	CIMMYT
13	53/3/ABL/1113//K92/4/JAG/5/KS89180B/6/RSK/…	CIMMYT
14	CA8055/4/ROMTAST/BON/3/DIBO//SU92/CI13645/…	CIMMYT
Kirve	Standard	KTAE
16	WHEAR//INQALAB 91*2/TUKURU/3/PYN/BAU//…	CIMMYT
17	TACUPETO F2001/BRAMBLING//KIRITATI/3/…	CIMMYT
18	FRANCOLIN#1/BLOUK#1/3/KINGBIRD#1//….	CIMMYT
19	BABAX/LR42//BABAX*2/3/KUKUNA/4/….	CIMMYT
20	WHEAR//INQALAB 91*2/TUKURU/3/PYN/BAU/…	CIMMYT
Flamura 85	Standard	TAREKS
21	ATTILA/3*BCN//BAV92/3/TILHI/4/SUP152/5/…	CIMMYT
22	KMU/KTAE-21/100	KMU
23	KMU/KTAE-21/200	KMU
24	MUTUS*2/MUU/6/ATTILA/3*BCN//BAV92/3/…	CIMMYT
SİTAP-14/21	BABAX/LR42/BABAX*2/3/PAVON....	KTAE

CIMMYT: International Maize and Wheat Improvement Center, TAREKS Inc.: Agricultural Credit Cooperative Seed Company, KTAE : Black Sea Agricultural Research Institute, KMU: Karamanoğlu Mehmetbey University.

Table 2. Precipitation, Temperature, and Relative Humidity Values for the Experimental Locations During the 2021-2022 Growing Season.

Locations	Samsun/Bafra			Tokat		
Month-Year	Precipitation (mm)	Temperature (°C)	Humidity (%)	Precipitation (mm)	Temperature (°C)	Humidity (%)
October	169.2	14.8	81.4	10.5	13.0	65.6
November	75.0	12.6	80.3	0.1	15.2	68.8
December	50.3	10.5	76.7	45.1	3.7	69.1
January	164.2	5.5	70.1	51.3	1.7	71.0
February	61.0	8.1	67.6	35.3	5.4	65.0
March	115.4	5.1	73.0	54.0	3.3	65.1
April	39.8	12.5	70.5	30.2	15.1	51.3
May	44.8	15.1	71.4	34.6	15.3	59.8
June	73.4	20.9	74.9	83.2	20.9	64.2
July	4.6	22.9	68.6	0.1	21.0	59.8
Total	**797.7**			**344.4**		

Table 3. Soil Characteristics of Experimental Fields in 2021.

Location	Soil Texture Class	Total Salt (%)	pH	Lime ($CaCO_3$, %)	Phosphorus (kg/da)	Organic Matter (%)	Field Capacity (%)
Samsun/Bafra	Clay-Loam	0.028	7.13	8.29	6.13	1.73	64
Tokat	Clay-Silty	0.025	7.85	11.0	3.50	1.60	62

Table 4. Mean Grain Yields of Genotypes and Duncan's Multiple Range Grouping (kg/da).

Genotype No	Bafra	Tokat	Average
1	1125.8 a	803.6 a-g	964.7 a
2	974.2 c-f	726.9 f-h	850.5 c-f
3	793.0 h-k	757.1 c-h	775.0 f-i
4	1045.7 a-c	847.0 a-d	946.4 ab
5	757.9 ı-k	740.8 d-h	749.3 g-i
6	924.7 d-g	902.0 a	913.3 a-c
7	1105.2 ab	741.4 d-h	923.3 a-c
8	998.6 b-e	862.9 a-c	930.7 a-c
9	822.8 g-j	797.0 a-g	809.9 d-h
10	882.3 e-h	832.0 a-f	857.2 c-e
11	780.7 h-k	810.3 a-g	795.5 e-h
12	1017.3 a-d	836.2 a-f	926.7 a-c
13	783.3 h-k	762.7 c-h	773.0 f-i
14	1034.6 a-d	800.2 a-g	917.4 a-c
15	776.9 h-k	713.5 gh	745.2 h-j
16	931.3 c-g	793.6 a-g	862.4 c-e
17	675.1 kl	732.1 e-h	703.6 ı-j
18	740.7 jk	764.1 c-h	752.4 g-i
19	977.5 c-f	723.7 f-h	850.6 c-f
20	573.3 lm	761.5 c-h	667.4 j
21	976.1 c-f	778.6 b-h	877.3 b-d
22	476.6 m	670.2 h	573.4 k
23	865.6 f-ı	730.7 f-h	798.1 d-h
24	1099.6 ab	844.4 a-e	972.0 a
25	773.3 h-k	882.5 ab	827.9 d-g
Location Mean	876.5	784.6	830.5
CV (%)	9.6	10.2	9.9
Significance	**	**	**

CV: Coefficient of Variation (%), Significance: Statistical significance level, ** Significant at the 1% level.

Table 5. Mean Hectoliter Weight Values of Genotypes and Duncan Grouping (kg/hl).

Genotype No	Bafra	Tokat	Average
1	76.3 e–g	75.2 d–i	75.8 h–j
2	79.8 a–c	75.3 d–h	77.6 d–f
3	76.8 d–f	76.8 b–e	76.8 fg
4	80.7 a	75.3 d–h	78.0 c–e
5	70.5 i	74.3 f–i	72.4 m
6	80.7 a	77.8 a–c	79.3 ab
7	78.5 b–d	76.5 b–f	77.5 d–f
8	76.3 e–g	73.7 hi	75.0 j–l
9	77.2 de	76.8 b–e	77.0 e–g
10	78.5 b–d	79.5 a	76.0 a–c
11	75.0 f–h	74.3 f–i	74.7 kl
12	80.8 a	78.7 ab	79.8 a
13	73.8 h	74.3 f–i	74.1 l
14	77.8 c–e	74.7 e–i	76.3 g–i
15	78.5 b–d	78.5 ab	78.5 b–d
16	75.0 f–h	74.0 g–i	74.5 kl
17	76.7 d–f	77.2 b–d	76.9 fg
18	78.0 c–e	75.3 d–h	76.7 f–h
19	76.8 d–f	74.7 e–i	75.8 h–j
20	73.3 h	76.0 c–g	74.7 kl
21	77.8 c–e	73.0 i	75.4 i–k
22	68.0 j	74.8 e–i	71.4 m
23	74.3 gh	69.7 j	72.0 m
24	80.3 ab	75.7 c–h	78.0 c–e
25	76.7 d–f	74.3 f–i	75.5 i–k
Location Mean	76.7	75.5	76.1
CV (%)	1.6	1.8	1.4
Significance	**	**	**

CV: Coefficient of Variation (%), Significance: Level of statistical significance, **: Significant at the 1% level.

Table 6. Average Values and Duncan Grouping for Thousand Kernel Weight of Genotypes (g).

Genotype No	Bafra		Tokat		Average	
1	43,7	f -ı	33,8	mn	38,8	f-h
2	42,1	h-j	31,9	n	37,0	hı
3	44,6	e-h	40,4	c-g	42,5	c-e
4	46,0	d-f	36,2	j-m	41,1	c-e
5	41,1	ı-j	36,1	j-m	38,6	gh
6	46,5	d-f	36,6	ı-l	41,5	c-e
7	36,1	k	26,0	o	31,1	j
8	46,7	d-f	35,2	k-m	40,9	d-f
9	45,9	d-f	37,6	h-k	41,7	c-e
10	46,5	d-f	39,4	d-h	43,0	c-d
11	38,7	jk	34,0	l-n	36,4	ı
12	47,2	de	38,7	e-j	42,9	c-d
13	44,4	e-ı	38,9	e-ı	41,6	c-e
14	47,7	c-e	38,3	f-j	43	c-d
15	48,7	b-d	43,6	ab	46,1	ab
16	45,7	d-g	37,5	h-k	41,6	c-e
17	50,9	a-c	44,6	a	47,7	ab
18	54,1	a	42,3	a-c	48,2	a
19	52,8	a	41,1	b-e	46,9	ab
20	44,4	e-ı	42,1	a-d	43,2	c
21	53,6	a	38,0	g-j	45,8	b
22	36,6	k	41,1	b-e	38,8	f-h
23	42,3	g-ı	32,3	n	37,3	hı
24	51,7	ab	40,7	c-f	46,2	a-b
25	45	e-h	36,1	j-m	40,6	e-g
Location Mean	45,7		37,7		41,7	
CV (%)	5,4		5,1		5,3	
Significance			**		**	

CV: Coefficient of Variation (%), Significance: Level of statistical significance, **: Significant at the 1% level.

Table 7. Quality Values of Genotypes in the BVD at the Bafra Location.

Genotype No	Moisture (%)	Protein (%)	Zeleny SDS (ml)	Grain Hardness (PSI)	Alveograph Energy (W)	Water Absorption (%)
1	10.1	10.8	45	34.4	158	57.5
2	9.7	13.4	40	56.9	208	58.1
3	9.7	12.4	47	53.6	261	58.5
4	9.6	12.5	52	59.8	229	60.6
5	10.1	12.9	75	54.3	335	60.0
6	10.5	12.0	65	62.3	260	61.7
7	9.7	10.8	38	74.9	157	60.9
8	9.7	11.6	46	69.2	215	59.6
9	10.1	12.7	51	72.0	203	67.5
10	9.9	12.8	50	61.4	223	62.5
11	9.6	10.9	54	45.9	147	58.1
12	9.9	10.9	32	71.7	142	57.1
13	9.8	14.0	63	80.0	308	59.9
14	9.9	11.3	45	47.0	144	58.2
15	10.2	12.6	55	59.4	167	60.5
16	10.1	11.4	51	59.0	127	62.6
17	9.8	15.1	61	62.4	296	59.8
18	9.8	15.3	59	71.4	311	63.9
19	9.8	12.5	48	70.0	276	60.8
20	10.7	11.4	44	54.0	200	56.9
21	10.5	11.8	52	57.8	175	58.7
22	10.0	11.6	60	49.8	248	58.3
23	9.8	10.8	52	48.9	105	56.9
24	9.7	12.2	57	65.7	195	58.6
25	10.0	12.0	53	59.8	204	59.6

Table 8. Quality Values of Genotypes in the BVD at the Tokat Location.

Genotype No	Moisture (%)	Protein (%)	Zeleny SDS (ml)	Grain Hardness (PSI)	Alveograph Energy (W)	Water Absorption (%)
1	9.5	13.8	48	58.7	204	62.5
2	9.3	14.3	44	60.3	230	59.3
3	9.4	13.6	61	84.9	303	61.4
4	9.1	12.9	55	88.6	368	63.4
5	9.8	14.0	65	72.4	374	62.8
6	9.5	13.4	58	79.9	222	62.4
7	9.3	13.1	49	79.0	288	61.0
8	9.3	12.6	43	81.0	212	63.0
9	9.2	14.1	44	84.6	249	65.2
10	9.4	12.8	52	74.6	266	63.6
11	9.5	12.6	55	57.0	155	56.9
12	9.1	13.0	58	64.9	164	61.2
13	9.6	13.6	55	78.0	356	66.0
14	9.6	13.8	48	73.3	196	61.8
15	10.3	13.9	52	71.7	228	62.1
16	9.2	12.6	50	59.8	141	57.5
17	9.3	13.0	64	64.3	291	59.3
18	9.3	13.2	53	61.8	318	61.9
19	9.2	12.9	46	57.1	210	58.6
20	9.3	15.2	61	66.7	277	62.0
21	9.1	14.1	65	74.3	313	61.9
22	9.2	14.0	69	67.9	385	60.4
23	9.4	14.2	48	67.0	315	62.4
24	10.1	13.6	52	66.2	199	60.1
25	9.1	14.1	55	70.4	262	58.6

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