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Effect of Temperature on Yield and Quality Parameters of Bread Wheat Cultivars at Different Growth Stages under Rainfed Conditions

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ABSTRACT

High temperature and its fluctuation influence bread wheat (*Triticum aestivum* L.) yield and quality before and after the grain filling stage in the Trakya region of Türkiye. Effect of the temperature between the Z24 and Z89 growth stages on yield, quality and some agronomic characters in bread wheat cultivars were investigated. This research was established with 25 genotypes in a randomised complete block design (RCBD) with 4 replications in Edirne and Tekirdağ locations, from 2010-2011 (E1) to 2015-2016 (E6) growing seasons. 5 common checks varieties were examined for their grain yield (GY), 1000-kernel weight (TKW), test weight (TW), protein ratio (PRT), wet gluten content (GLT), gluten index (IND), grain hardness (HARD), sedimentation value (SED), plant height (PH) and days of heading (DH). There were various relationships among environment, cultivar and temperature. The mean grain yield was in the range of 4454-8158 kg/ha^{-1} across six environments, in the Edirne location and E4 was the highest yielding environment while E6 was the lowest. As a result of the environmental effect, there was a 83.2% difference between the highest and lowest yield. The highest TKW (47.2 g) was in E4 and the lowest (34.3 g) was in E1. Test weight varied across six environments the lowest was in E3 and the highest in E2. Environment E1 had a higher protein ratio and wet gluten content, and E4 had the lowest protein ratio and wet gluten content. The gluten index varied from the lowest in E6 (71.3%), and the highest was 93.3 in E4. There was high variation in sedimentation value across six environments. The lowest value was in E4 (40.0 ml) and the highest was in 64.8 ml in E1. In the Tekirdağ location, the mean grain yield was in the range of 5485-8283 kg/ha^{-1}, so there was a 51.0% difference between the highest and lowest yield. The highest (46.6 g) and lowest (39.5 g) TKW were in environments E2 and E1. Test weight varied across six environments the lowest was 81.1 kg in E4 and the highest was 85.2 kg in E2. Environment E3 had the lowest protein ratio, E1 had the lowest wet gluten content and E2 had the highest protein ratio and wet gluten content. Across six environments, the gluten index varied from the lowest in E2 (74.8%), and the highest was 94.5 in E1. The lowest sedimentation was in E4 (42.2 ml) and the highest was in 47.0 ml in E5.

***Keywords*:** Bread wheat, environment, temperature, yield, quality characters

Introduction

Global climate change is one of the most important factors threatening world food security. The weakest aspect of agricultural production is that it is very susceptible to the effects of changes in climate factors. At the beginning of climate change in the world and in our country, increasing air temperatures and drought generated attention. Wheat has the maximum cultivated area among cereals and is mostly grown in rain-fed areas. Global climate change and consequent environmental stress factors cause significant yield losses in wheat (Ayrancı and Bağcı, 2020). Wheat is one of the most important cereal crops in the world. The widespread cultivation of the crop all along the globe is mainly due to the high versatility of evolution, which enables its adaptation to different agro-climatic conditions and the unique property of wheat flour and dough which allows its processing into a range of food products (Kant et al., 2014).

Improving crop yields is essential to meet the increasing pressure of global food demands. The loss of high-quality land, the slowing in annual yield increases of major cereals, increasing fertilizer use, and the effect of this on the environment all indicate that we need to develop new strategies to increase grain yields with less impact on the environment (Chapagain and Good, 2015). Environmental factors play a main role in the expression of genotype characteristics (Peterson et al., 1998). In wheat, grain yield and baking quality are dependent on the environment, genetic factors and the interaction between them (Yan and Holland, 2010; Coventry et al., 2011). Environmental factors, such as nitrogen fertilization, water and temperature, influence protein content (Sissons et al., 2005). In contrast, the protein quality is largely under genetic control (Lerner et al., 2006; Rogers et al., 2006). The physical characteristics of grain are important as they are indicative of potential processing quality. Grain hardness, which is largely genetically determined (Pena, 2008). Grain protein content in the mature grain is largely determined by environmental and farm management factors, with genetics playing a minor role in being either low or high in protein content. By contrast, the protein quality is determined by the genetic composition of the wheat variety and also how the environment influences genetic expression (Blakeney et al., 2009). Heat and drought stress are currently the leading threat to the world's food supply, limiting wheat yield. The extent and severity of stress-affected agricultural land are predicted to worsen as a result of inadequate irrigation resources, declining water tables and global warming. Drought/heat tolerance is crucial to stabilize and increase food production since domestication has limited the genetic diversity of crops including wild wheat, leading to cultivated species, adapted to artificial environments, and losing tolerance to stress episodes (Arya et al., 2012; Kaur et al., 2016). Climate change threatens to impact wheat productivity, quality and global food security. Heat stress events at the post-anthesis stage impacted wheat grain yield mostly at the grain filling stage, whilst the effect on physical and chemical quality was varied. The overall effect of post-anthesis heat on wheat yield and quality was genotype-specific (Fernie et al., 2022).

The knowledge about the nature and extent of genotype × environment interaction can help the plant breeders a great deal in formulating their breeding plans in the selection of varieties for location-specific responses and general adaptation. Consistently good performance over a range of environments (phenotypically stable) must be one of the important criteria while evaluating any wheat genotype or variety, where great variations occur in environmental conditions, locations and seasons. Besides this identification of phenotypical stable genotypes, it is also essential to identify genotypes suitable for the specific favourable and unfavourable environments for commercial production. Thus, the identification of stable genotypes, adaptable to a wide range of environments has considerable significance in bread wheat improvements (Kant et al., 2014). The success of a wheat breeding program depends on the regional adaptability of the cultivars improved and the adaptability of such cultivars in the target environments determined by their tolerance to biotic and abiotic stresses (Altay, 2012). Therefore the aim of this study was revealing the effects of genotype, environment, and GE interaction on yield, and quality parameters under different environmental conditions.

Materials and Methods

The experiment was carried out in the Trakya region of Türkiye from 2010-2011 to 2015-2016 growing cycles. Twenty-five winter wheat genotypes were examined under rainfed conditions with a randomized complete block design (RCBD) with four replications at 2 locations in Edirne (latitude 41° 38' 57'' N, longitude 26° 35' 59'' E and altitude 41 m), and Tekirdağ (latitude 40° 58' 27'' N, longitude 27° 27' 58'' E and altitude 43 m) provinces. Each plot had 6 meters length, in 6 rows, spaced 0.17 meters apart. A seed rate of 500 seeds m^2 was used. In this study, five commonly cultivated bread wheat cultivars Pehlivan, Gelibolu, Aldane, Selimiye and Bereket were evaluated. Grain yield, 1000-kernel and test weights, protein ratio, gluten, gluten index, hardness, sedimentation, plant height and days of heading were investigated (Perten, 1990; Anonymous, 2002; Anonymous, 1990)

The quality analysis of the Zeleny sedimentation test and wet gluten content were determined according to ICC standard methods No. 116/1 and 106/2, respectively (Anonymous, 1972; Anonymous, 1984).

The mean and maximum temperature in Edirne and Tekirdağ locations in March (Z24-30), April (Z31-49), May (Z51-75), and June (Z77-Z89) from shooting up to ripening period were taken from 2011 up to 2016 growing cycles in experimental field area (Table 1 and 2). The Zadoks Decimal Code (Z) was used to describe the plant growth stages of cereals. There were significant differences in average and maximum temperatures over the years. Due to this difference, there were significant differences in the parameters examined.

To determination of the regression equations R^2 were calculated (Finlay and Wilkinson, 1963; Eberhart and Russell, 1969). Data were analysed statistically for

analysis of variance the method described by Gomez and Gomez (1984). The significance of differences among means was compared by using Least Significant Difference (L.S.D. at a 5%). Stability analysis of 5 wheat cultivars for all traits was also done using the model proposed by Eberhart and Russel (1966).

Results and Discussion

Combined analysis of variance (ANOVA) across the 6 environments revealed highly significant variation among growing cycles and wheat cultivars for yield, days of heading, plant height and quality characters in the Edirne location (Table 3). Grain yield, 1000-kernels weight, test weight, protein and gluten value, gluten index, hardiness, sedimentation days of heading and plant height of wheat genotypes grown in two different environments and during 6 growing cycles are shown in Tables 3 and 4. At the Edirne location, across the 6 years environments, the mean grain yield was in the range of 4454- 8158 kg/ha^{-1}, and the mean grain yield was 6525 and 2013-2014 was the highest yielding growing cycle. Across 6 environments, the highest mean 1000-kernel weight (TKW) and test weight (TW) for all genotypes were in 2013-2014 and 2011-2012 while the lowest values were in 2010-2011 and 2012-2013 cycles, respectively. Test weight is the weight of a specific volume of grain and is an indication of the bulk density of the grain. It reflects the extent of grain filling and the potential for flour yield (Blakeney et al., 2009). The results revealed significant differences ($P<0.01$) in the protein content among growing cycles. The crude protein ratio was found to be in the range of 9.6-14.6% for the growing environments in 2013-2014 and 2010-2011, respectively. Mean values of wet gluten of wheat genotypes grown in six environments were significantly varied ($P<0.01$) depending on the differences in the genotypes and environments as well as the protein content. The highest wet gluten was determined in the 2010-2011 cycles and the lowest was in the 2013-2014 cycle. Across six environments minimum, sedimentation value was 40.0 ml in 2013-2014, and the maximum was 64.8 ml in the 2010-2011 cycles (Table 3).

According to cultivars, at the Edirne location, Gelibolu had the highest yielding cultivar. The highest TKW and TW were observed for Pehlivan and Selimiye, while the lowest values were obtained for Bereket, respectively. The highest protein ratio and sedimentation value were determined in cultivar Aldane. The highest mean value for wet gluten was obtained for Selimiye (36.9%) and Aldane (36.7%) grown at the Edirne location, while the lowest value was recorded for Gelibolu (27.3%) cultivated at Edirne location.

In the research carried out in six varies environments, Aldane was determined to be the best quality variety (Table 4).

A combined analysis of variance across the six environments in the Tekirdağ location revealed highly significant variation among years and cultivars for yield, days of heading, plant height and quality parameters (Table 5). At the Tekirdağ location, across six environments, the mean grain yield was in the range of 5485 – 8283 kg/ha^{-1}, and the mean grain yield was 6837 kg/ha^{-1}. The highest yielding cycle was 2011-2012. Based on years, the highest mean values of TKW, TW, protein ratio and gluten value for all genotypes were in 2011-2012. Across six environments minimum, sedimentation value was 42.2 ml in 2013-2014, and the maximum was 47.0 ml in the 2014-2015 cycles (Table 5).

At the Tekirdağ location, the minimum grain yield of 6415 kg/ha^{-1} was produced by the wheat cultivar Aldane. In contrast, a maximum grain yield of 7142 kg/ha^{-1} was produced by the cultivar Gelibolu, both varieties released by Trakya Agriculture Research Institute (Table 6). In the study, the TKW of wheat cultivars ranged from 40.2 g (cv Bereket) to 46.2 g (cv Pehlivan). Across six environments cultivar Selimiye had the highest test weight (84.1 kg). Cultivar Aldane had the highest protein ratio (12.4%), gluten index (93.0%), and sedimentation value (58.2 ml). The highest wet gluten content (34.5%) was determined in cv Pehlivan (Table 5). The highest mean value for wet gluten was obtained for Pehlivan (34.5%) and Aldane (33.2%) grown at Tekirdağ, while the lowest value was recorded for Gelibolu (26.2%) cultivated at the Tekirdağ location.

Correlation coefficients among temperature and the tested characters in the Edirne location were given in Table 7. Various relations among investigated parameters were found based on temperature with yield and quality parameters. The effect of the mean and maximum temperature on the quality parameters and yield of the correlations parameters were determined by Pearson's correlation analysis (Table 7). The results of the Edirne location showed that higher temperature from shooting up to the grain filling stage negatively affected protein ratio, gluten value, hardness and sedimentation in cultivars. Also, 1000-kernel weight was positively affected by mean and maximum temperature from shooting to the maturating stage in Edirne. Increasing in mean and maximum temperature during Z24 and Z89 reduced plant height and shortened in days of heading (Table 7).

Mean temperature during the Z51-75 growth stage had a significant effect and increased grain yield ($r=0.492$). An increase in maximum temperature during

the shooting and grain filling period more negatively affected grain yield than the heading stage. So, there was a negative relation between grain yield with maximum temperature during Z31-49 (r=-0.390), and Z77-89 (r=-0.753) growth stage. Thousand kernel weight was positively affected by increasing in mean temperature during Z24-30 (r=0.473), Z31-49 (r=0.445), Z51-75 (r=0.594), and Z77-89 (r=0.459) growth stage. The mean and maximum temperature during the Z51-75 growth stage had a significant effect and reduced test weight (r=-0.479 and r=-0.618). During the grain-filling period, the mean and maximum temperature had a significant effect on test weight (r=0.667; r=0.597). The higher mean and maximum temperature during the Z24 up to Z89 growth stage led to various levels of reductions in protein ratio and gluten value. The mean temperature during Z24-30 (r=-0.955**), Z31-49 (r=-0.615), Z51-75 (r=-0.311), and Z77-89 (r=-0.298) growth stage had negatively effect and caused various level of decline on protein ratio. An increase in maximum temperature during Z31-49 and Z51-75 negatively affected protein ratio and gluten value. The mean temperature during Z24-30 (r=-0.931**), Z31-49 (r=-0.546), Z51-75 (r=-0.325), and Z77-89 (r=-0.142) growth stage had a negative effect and caused a various level of decline on gluten value. The higher temperature during Z31-49 (r=-0.827*) and Z77-89 (r=-0.979**) growth stage had significant reductions in gluten index. Grain hardness and sedimentation in cultivars were negatively affected by mean and maximum temperature during the Z24 and Z89 growth stages. Hardness in cultivars was negatively affected by increasing in mean temperature during Z24-30 (r=-0.955**), Z31-49 (r=-0.575), Z51-75 (r=-0.342), and Z77-89 (r=-0.129) growth stage. Also, the mean temperature negatively affected sedimentation value of cultivars during Z24-30 (r=-0.861**), Z31-49 (r=-0.676), and Z77-89 (r=-0.670) growth stage. Maximum temperature had negatively effect during Z24-30 (r=-0.489), Z31-49 (r=-0.699), and Z77-89 (r=-0.405) growth stage (Table 7).

The correlation coefficients between the quality parameters in the Edirne location are given in Table 8. Grain yield was positively correlated (r=0.739) with 1000-kernel weight, and gluten index (r=0.805) but negatively correlated with test weight (r=-0.481). Protein content was significantly positively correlated with wet gluten content (r=0.987, $p<0.01$), grain hardness (r=0.970, $p<0.01$), and sedimentation value (r=0.862, $p<0.05$). TKW showed a negative correlation with protein ratio, wet gluten content, grain hardness, and sedimentation value. Test weight was positively correlated with protein ratio, wet gluten content and grain hardness, negatively correlated with gluten index (Table 8).

Correlation coefficients among temperature and the tested characters in the Tekirdağ location were given in Table 9. There were various relations among investigated parameters based on mean and maximum temperature. Increasing in mean temperature during Z24-30 (r=-0.517) negatively affected grain yield but positively affected during Z31-49 (r=0.559) and Z51-75 (r=0.648) growth stage. An increase in maximum temperature during Z77-89 (r=-0.651) growth stages negatively affected grain yield. In the study, 1000-kernel weight was positively affected by increasing in mean temperature during Z31-49 (r=0.912*), Z51-75 (r=0.672), and Z77-89 (r=0.369) growth stage. Mean and maximum temperature during Z31-49 (r=0.638), Z51-75 (r=0.545), and (r=0.818*) growth stage had positive effect and increased test weight. The results of Tekirdağ location showed that mean temperature from Z31 up to Z89 growth stage had a positive effect on grain yield, 1000-kernel weight, and test weight. But, increasing in maximum temperature during Z77-89 reduced grain yield, 1000-kernel weight, and test weight. The gluten index in cultivars was negatively affected by mean and maximum temperature from shooting up to the physiological maturating stage. Protein ratio, hardness and gluten value was positively affected by mean temperature during the Z31-49 and Z77-89 stage.

During Z31-49 growth stage mean temperature had significant effect protein ratio (r=0.572), wet gluten value (r=0.582) and grain hardness (r=0.566). Also, there was a positive relationship between mean temperature with protein ratio (r=0.450), gluten value (r=0.601) and hardness (r=0.474) during the Z77-89 growth stage. Gluten index was negatively affected by mean and maximum temperature during all growth stages investigated in the study. The higher mean and maximum temperature during Z24-30, Z31-49 (r=-0.538), and Z89-89 (r=-0.457), growth stage caused various levels of reductions in sedimentation value. The maximum temperature during Z24-30 (r=-0.906*) growth stage caused a significant effect and reduced sedimentation in cultivars. Increases in mean and maximum temperature during Z24 and Z89 caused various effects and reduced plant height and shortened days of heading to the Tekirdağ location (Table 9).

The correlation coefficients between the quality parameters in the Tekirdağ location are given in Table 10. Grain yield was significantly positively correlated (r=0.839*, $p<0.05$) with 1000-kernel weight, and positively correlated with TW, grain hardness. Protein content was significantly positively correlated

with wet gluten content (r=0.917, p<0.01), grain hardness (r=0.861, p<0.05), and negatively correlated with sedimentation value (r=0.588). TKW had a positive effect on TW, protein ratio, wet gluten content, and hardness. Test weight was positively correlated with protein ratio, wet gluten content and grain hardness, and negatively correlated with gluten index. It was found highly significant negative correlation between wet gluten content and gluten index (r=-0.939, p<0.01) (Table 10).

Conclusions

According to the results there were various relations between environment, cultivar and temperature. In the Edirne location, environment E4 was the highest yielding environment and E6 was the lowest. There was a 45.4% difference between the highest and lowest yield for the environmental effect. The highest TKW was in E4 and the lowest was in E1. Test weight varied across six environments the lowest was in E3 and the highest in E2. Environment E1 had a higher protein ratio and wet gluten content, and E4 had the lowest protein ratio and wet gluten content. The gluten index varied from the lowest in E6 and the highest in E4. There was high variation in sedimentation value across six environments. The lowest value was in E4 and the highest was in E1. The Edirne location showed that higher temperature from tillering up to the grain filling phase had a negatively effect on protein ratio, gluten value, hardness and sedimentation. Also, 1000-kernel weight was positively affected by mean and maximum temperature from the shooting to the maturating stage. An increase in mean and maximum temperature during Z24 and Z89 reduced plant height and shortened in days of heading.

In the Tekirdağ location, there was a 33.8% difference between the highest and lowest yield. The highest and lowest TKW was in environments E2 and E1. Test weight varied across six environments the lowest was in E4 and the highest in E2. Environment E3 had lowest protein ratio, E1 had lowest wet gluten content, E2 had the highest protein ratio and wet gluten content. Across six environments, the gluten index varied from the lowest in E2, and the highest in E1. The lowest sedimentation was in E4 and the highest was in E5. The Tekirdağ location mean temperature during Z31-75 positively affected and increased grain yield. Increasing in maximum temperature negatively affected and decreased grain yield during Z77-89 growth phase. The Tekirdağ location showed that higher temperature grain filling phase had a negatively effect on TKW, TW and sedimentation value. An increase in mean and maximum temperature during Z24 and Z89 reduced plant height and shortened in days of heading.

Table 1. The mean and maximum temperature from Zadoks 24 to Zadoks 89 growth stages (in March, April, May and June) in the Edirne location.

Year	Mean Temperature (°C)				Maximum Temperature (°C)			
	Z24-30	Z31-49	Z51-75	Z77-Z89	Z24-30	Z31-49	Z51-75	Z77-Z89
2011 (E1)	7.4	10.5	17.4	21.9	23.7	24.1	31.8	34.4
2012 (E2)	8.9	15.5	19.1	25.3	24.4	30.2	31.7	36.9
2013 (E3)	9.8	20.3	20.8	23.3	23.6	32.0	32.9	36.2
2014 (E4)	10.1	13.6	18.6	22.9	23.7	25.5	32.1	33.6
2015 (E5)	9.0	13.1	20.4	22.5	19.9	25.7	33.3	35.3
2016 (E6)	10.2	15.5	17.4	23.9	23.3	31.8	32.2	38.4
Mean	9.2	14.8	19.0	23.3	23.1	28.2	32.3	35.8

Table 2. The mean and maximum temperature from Zadoks 24 to Zadoks 89 growth stages (in March, April, May and June) in the Tekirdağ location.

Year	Mean Temperature (°C)				Maximum Temperature (°C)			
	Z24-30	Z31-49	Z51-75	Z77-Z89	Z24-30	Z31-49	Z51-75	Z77-Z89
2011 (E1)	8.1	10.5	16.5	21.9	22.3	24.1	26.1	34.0
2012 (E2)	7.9	14.1	18.1	24.1	21.6	25.0	28.1	33.5
2013 (E3)	9.6	13.5	19.5	22.4	21.6	23.5	33.6	32.6
2014 (E4)	9.9	13.4	17.5	21.8	24.0	22.8	27.0	36.9
2015 (E5)	8.5	11.4	18.2	21.3	18.3	24.6	28.0	33.3
2016 (E6)	10.4	11.4	17.9	23.6	20.7	26.3	31.7	34.4
Mean	9.1	12.4	18.0	22.5	21.4	24.4	29.1	34.1

Table 3. Mean yield and quality parameters across six environments in Edirne location.

Environments	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH	PH
2010-2011 (E1)	6552^{b}	34.3^{c}	82.5^{bc}	14.6^{a}	43.4^{a}	86.7^{ab}	54.6^{a}	64.8^{a}	131.2^{a}	117.8^{a}
2011-2012 (E2)	7149^{b}	46.4^{a}	85.2^{a}	12.2^{b}	37.2^{b}	79.5^{bc}	51.6^{ab}	43.4^{b}	121.0^{b}	87.0^{d}
2012-2013 (E3)	7272^{b}	44.2^{ab}	80.1^{d}	10.5^{cd}	29.3^{de}	80.8^{abc}	47.0^{cd}	42.6^{b}	115.4^{c}	117.4^{a}
2013-2014 (E4)	8158^{a}	47.2^{a}	80.4^{d}	9.6^{d}	25.4^{e}	93.3^{a}	45.8^{d}	40.0^{b}	109.2^{d}	114.8^{a}
2014-2015 (E5)	6766^{b}	41.6^{b}	81.3^{cd}	12.3^{b}	34.7^{bc}	87.2^{ab}	49.4^{bc}	59.8^{a}	122.2^{b}	92.4^{c}
2015-2016 (E6)	4454^{c}	36.5^{c}	83.7^{b}	11.0^{c}	31.5^{cd}	71.3^{c}	47.6^{cd}	40.6^{b}	103.8^{e}	98.6^{b}
Mean	6725	41.7	82.2	11.7	33.6	83.1	49.3	48.5	117.1	104.7
LSD (0.05)	75.9^{**}	3.9^{**}	1.3^{**}	1.0^{**}	4.0^{**}	12.3^{**}	2.9^{**}	6.3^{**}	2.3^{**}	4.8^{**}

Significance at **: P<0.01; *: P<0.05; GY: Grain yield (kg/ha^{-1}), TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), GLT: Wet gluten value (%), IND: Gluten index (%), HARD: Hardness (PSI), SED: Sedimentation value (ml)

Table 4. Mean yield and quality characters in genotypes in Edirne location.

Cultivars	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH	PH
Pehlivan	6649^{ab}	44.7^{a}	82.7^{ab}	11.3^{bc}	35.3^{ab}	60.3^{b}	50.5^{a}	41.8^{c}	118.7^{a}	108.0^{a}
Gelibolu	7116^{a}	39.6^{ab}	81.7^{ab}	10.8^{c}	27.3^{c}	92.2^{a}	48.8^{a}	43.5^{c}	117.3^{a}	100.3^{b}
Aldane	6394^{b}	42.9^{ab}	82.1^{ab}	13.0^{a}	36.7^{a}	92.4^{a}	48.7^{a}	61.0^{a}	114.5^{b}	104.5^{ab}
Selimiye	6800^{ab}	41.9^{ab}	82.9^{a}	12.1^{ab}	36.9^{a}	82.5^{a}	50.3^{a}	50.5^{b}	117.2^{a}	101.5^{b}
Bereket	6668^{ab}	39.4^{b}	81.5^{b}	11.3^{bc}	31.6^{b}	88.2^{a}	48.3^{a}	45.8^{bc}	118.0^{a}	109.0^{a}
Mean	6725	41.7	82.2	11.7	33.6	83.1	49.3	48.5	117.1	104.7
LSD $_{(0.05)}$	66.4ns	3.6^{*}	1.2ns	0.9^{**}	3.7^{**}	11.2^{*}	2.6ns	5.8^{**}	2.0^{**}	4.4^{**}

Significance at **: P<0.01; * :P<0.05; GY: Grain yield (kg/h^{-1}), TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), GLT: Wet gluten content (%), IND: Gluten index (%), HARD: Hardness (PSI), SED: Sedimentation value (ml)

Table 5. Mean yield and quality parameters across six environments in Tekirdağ location.

Environments	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH	PH
2010-2011 (E1)	5852^{b}	39.5^{c}	81.4^{d}	10.5^{b}	26.0^{e}	94.5^{a}	47.6^{b}	44.2^{ab}	137.6^{a}	111.0^{a}
2011-2012 (E2)	8283^{a}	48.0^{a}	85.2^{a}	12.1^{a}	36.6^{a}	74.8^{c}	53.6^{a}	43.0^{ab}	124.2^{b}	102.0^{c}
2012-2013 (E3)	7821^{a}	46.6^{a}	83.8^{b}	10.1^{b}	26.6^{de}	87.7^{abc}	46.2^{b}	44.4^{ab}	125.4^{b}	105.6^{bc}
2013-2014 (E4)	5902^{b}	43.2^{b}	81.1^{d}	11.5^{a}	32.9^{b}	81.1^{bc}	48.0^{b}	42.2^{b}	109.4^{c}	109.8^{ab}
2014-2015 (E5)	7678^{a}	42.4^{b}	81.4^{d}	10.6^{b}	29.6^{cd}	88.1^{ab}	46.8^{b}	47.0^{a}	125.8^{b}	102.4^{c}
2015-2016 (E6)	5485^{b}	40.0^{c}	82.7^{c}	10.6^{b}	31.4^{bc}	80.3^{bc}	45.2^{b}	44.0^{ab}	106.2^{d}	100.8^{c}
Mean	6837	43.3	82.6	10.9	30.5	84.4	47.9	44.1	121.4	105.3
LSD (0.05)	60.2**	2.2**	1.0**	0.9**	2.9**	12.9**	4.2**	4.8ns	1.8**	4.9**

Significance at **: P<0.01; * :P<0.05; GY: Grain yield (kg/h^{-1}), TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), GLT: Wet gluten content (%), IND: Gluten index (%), HARD: Hardness (PSI), SED: Sedimentation value (ml)

Table 6. Mean yield and investigated characters in cultivars in Tekirdağ location.

Cultivars	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH	PH
Pehlivan	6729^{ab}	46.2^{a}	82.6^{b}	10.9^{b}	34.5^{a}	64.4^{b}	47.8^{a}	37.8^{c}	123.0^{a}	111.5^{a}
Gelibolu	7142^{a}	40.7^{b}	82.9^{b}	10.2^{cd}	26.2^{c}	90.8^{a}	47.8^{a}	40.0^{c}	121.5^{ab}	100.3^{b}
Aldane	6415^{b}	44.9^{a}	82.1^{bc}	12.4^{a}	33.2^{ab}	93.0^{a}	45.7^{a}	58.2^{a}	119.7^{c}	100.7^{b}
Selimiye	7023^{a}	44.6^{a}	84.1^{a}	10.9^{bc}	31.3^{b}	87.8^{a}	49.5^{a}	44.8^{b}	121.0^{bc}	102.8^{b}
Bereket	6876^{ab}	40.2^{b}	81.3^{c}	10.1^{d}	27.3^{c}	86.1^{a}	48.7^{a}	39.8^{c}	122.0^{ab}	111.0^{a}
Mean	6837	43.3	82.6	10.9	30.5	84.4	47.9	44.1	121.4	105.3
LSD (0.05)	55.0ns	2.0**	0.9**	0.6**	2.7**	11.8ns	3.9ns	4.3**	1.6**	4.3**

Significance at **: P<0.01; * :P<0.05; GY: Grain yield (kg/h^{-1}), TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), GLT: Wet gluten content (%), IND: Gluten index (%), HARD: Hardness (PSI), SED: Sedimentation value (ml)

Table 7. Correlation coefficients among investigated parameters and mean-max temperature in Edirne location.

Parameter	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH	PH
MT (Z24-30)	-0.073	0.473	-0.252	-0.955**	-0.931**	-0.255	-0.955**	-0.861*	-0.949**	-0.072
MT (Z31-49)	0.033	0.445	-0.183	-0.615	-0.546	-0.463	-0.575	-0.676	-0.469	0.025
MT (Z51-75)	0.492	0.594	-0.479	-0.311	-0.325	0.186	-0.342	-0.068	0.090	-0.115
MT (Z77-89)	-0.119	0.459	0.667	-0.298	-0.142	-0.586	-0.129	-0.670	-0.356	-0.632
MXT(Z24-30)	0.100	0.129	0.321	-0.109	-0.009	-0.212	0.086	-0.489	-0.140	0.322
MXT(Z31-49)	-0.390	0.171	0.266	-0.448	-0.337	-0.827*	-0.395	-0.699	-0.555	-0.247
MXT(Z51-75)	0.036	0.101	-0.618	-0.248	-0.333	0.091	-0.427	0.150	-0.077	-0.046
MXT(Z77-89)	-0.753	-0.196	0.597	-0.098	0.010	-0.979**	-0.090	-0.405	-0.419	-0.542

Significance at **: P<0.01 and * :P<0.05; GY: Grain yield, TKW: 1000-kernel weight, TW: Test weight, PRT: Protein ratio, GLT: Wet gluten content, IND: Gluten index, HARD: Hardiness, SED: Sedimentation value, DH: Days of heading, PH: Plant height, MT: Mean Temperature, MXT: Maximum Temperature, Z: Zadoks

Table 8. Correlation coefficients among yield quality characters in Edirne location.

Traits	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH
TKW	0.739								
TW	-0.481	-0.208							
PRT	-0.215	-0.648	0.406						
GLT	-0.241	-0.600	0.530	0.987**					
IND	0.805	0.335	-0.588	0.011	-0.092				
HARD	-0.115	-0.513	0.520	0.970**	0.987**	0.007			
SED	-0.030	-0.578	-0.044	0.862*	0.773	0.346	0.745		
DH	0.285	-0.250	0.094	0.858*	0.830*	0.368	0.859*	0.844*	
PH	0.294	-0.165	-0.676	-0.087	-0.170	0.395	-0.119	0.070	0.049

Significance at **: P<0.01 and *: P<0.05; GY: Grain yield, TKW: 1000-kernel weight, TW: Test weight, PRT: Protein, GLT: Wet gluten content, IND: Gluten index, HARD: Hardiness, SED: Sedimentation, DH: Days of heading, PH: Plant height

Table 9. Correlation coefficients among investigated parameters and mean-max temperature in Tekirdağ location.

Traits	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH	PH
MT (Z24-30)	-0.517	-0.226	-0.197	-0.303	-0.055	-0.196	-0.661	-0.238	-0.819*	-0.095
MT (Z31-49)	0.559	0.912*	0.638	0.572	0.582	-0.677	0.566	-0.538	-0.267	-0.134
MT (Z51-75)	0.648	0.672	0.545	-0.222	0.002	-0.243	-0.105	0.218	-0.168	-0.514
MT (Z77-89)	0.144	0.369	0.818*	0.450	0.601	-0.734	0.474	-0.457	-0.299	-0.564
MXT(Z24-30)	-0.391	0.093	-0.037	0.345	0.127	-0.141	0.218	-0.906*	-0.166	0.701
MXT(Z31-49)	-0.084	-0.252	0.320	-0.007	0.254	-0.315	-0.026	0.248	-0.219	-0.773
MXT(Z51-75)	0.194	0.282	0.467	-0.488	-0.203	-0.133	-0.427	0.113	-0.309	-0.485
MXT(Z77-89)	-0.651	-0.309	-0.528	0.421	0.346	-0.260	-0.022	-0.612	-0.584	0.452

Significance at **: P<0.01 and * :P<0.05; GY: Grain yield, TKW: 1000-kernel weight, TW: Test weight, PRT: Protein, GLT: Wet gluten content, IND: Gluten index, HARD: Hardiness, SED: Sedimentation, DH: Days of heading, PH: Plant height, MT: Mean Temperature MXT: Maximum Temperature, Z: Zadoks

Table 10. Correlation coefficients among yield quality characters in Tekirdağ location.

Traits	GY	TKW	TW	PRT	GLT	IND	HARD	SED	DH
TKW	0.839*								
TW	0.641	0.771							
PRT	0.206	0.446	0.340						
GLT	0.213	0.443	0.433	0.917**					
IND	-0.207	-0.514	-0.576	-0.766	-0.939**				
HARD	0.525	0.632	0.580	0.861*	0.700	-0.545			
SED	0.297	-0.237	-0.244	-0.588	-0.477	0.523	-0.410		
DH	0.386	0.061	0.040	-0.236	-0.505	0.655	0.227	0.386	
PH	-0.406	-0.259	-0.535	-0.097	-0.437	0.551	-0.082	-0.348	0.343

Significance at **: P<0.01 and *: P<0.05; GY: Grain yield, TKW: 1000-kernel weight, TW: Test weight, PRT: Protein, GLT: Wet gluten content, IND: Gluten index, HARD: Hardiness, SED: Sedimentation, DH: Days of heading, PH: Plant height

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