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Research Article

Selection of Advanced Mutant Wheat (*Triticum aestivum* L.) Lines Based on Yield and Quality Parameters

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Abstract

In the presented research, conventional gamma ray mutagenesis was used to develop new mutant line(s), which have such characters moderate and/or high yielding, semi dwarf and early maturing. Thus, Selimiye cultivar, TCI2066 and three sisters' line of TCI2021 were irradiated with 200 Gy gamma rays and segregated up to sixth generations. 15 advanced mutant lines from M_6 generation and their parent and five commercial wheat cultivars, which have superior characters than others were evaluated according to some agronomic parameters, such as grain yield (GY), thousand kernel weight (TKW), test weight (TW), protein content (PRT), hardness (HARD), days of heading and plant height, under field condition during 2012-2014 growing years in Edirne, Turkey. As a result of study, the highest grain yield was determined from the mutant lines derived from Selimiye wheat cultivar than commercial cultivars. The mutant lines of TCI2021-21M4-2 and TCI2021-23M5-2 were given the highest value in terms of protein content, and the highest hardness values were determined from the mutant lines of TCI2066-9M2-3, TCI2066-9M2-1 and TCI2021-21M4-2, respectively. The mutant line of TCI2021-12M3-8 was measured the shortest one among them. Additionally, a strong positive correlation was determined between GY and TKW, and TW in both growing season. In conclusion, gamma ray mutagenesis had efficiently used in local bread wheat improving programmes to develop mutant lines with superior characters, and TKW and TW could be used as selection criteria for maintaining grain yield under divers rainfall conditions of Trakya Region.

Key words: Bread wheat, gamma ray mutagenesis, grain yield, quality characters.

İleri Kademe Ekmeklik Buğday (*Triticum aestivum* L.) Mutant Hatlarının Verim ve Kalite Parametrelerine Göre Seleksiyonu

Özet

Araştırmada, orta veya yüksek verimli, yarı cüce ve erken olgunlaşmaya sahip olan yeni mutant hatlar geliştirmek için geleneksel gamma ışını mutagenesi kullanılmıştır. Selimiye çeşidi, TCI2066 ve TCI2021'in üç hattı 200 Gy gama ışınları ile ışınlanmış ve M_6 generasyonu elde edilmiştir. M6 generasyonundan seçilen on beş ileri kademe mutant hattı ve ebeveyn hatları ve beş buğday çeşidi dane verimi, bin tane ağırlığı, hektolitre ağırlığı, protein, sertlik, başaklanma gün sayısı ve bitki boyu gibi agronomik parametrelere göre Edirne'de 2012-2014 yılları arasında tarla koşullarında değerlendirilmiştir. Araştırma sonucuna göre en yüksek verim Selimiye çeşidinin mutant hatlarında belirlenmiştir. TCI2021-21M4-2 ve TCI2021-23M5-2 hatlarında en yüksek protein oranı, tane sertliği ise TCI2066-9M2-3, TCI2066-9M2-1 ve TCI2021-21M4-2 hatlarında belirlenmiştir. TCI2021-12M3-8 mutant hattında en kısa bitki boyu ölçülmüştür. Tane verimi ile bin tane ağırlığı ve hektolitre ağırlığı arasında her iki ekim yılında da olumlu ve önemli ilişki belirlenmiştir. Sonuç olarak gamma ışını mutagenesi ekmeklik buğday programında iyi karakterlere sahip mutant hatları geliştirmede etkili bir şekilde kullanılmıştır. Bin tane ağırlığı ve hektolitre ağırlığı Trakya Bölgesinde farklı yağış koşullarında tane verimi için seleksiyon kriteri olarak kullanılabilen karakterler olmuştur.

Anahtar kelimeler: Ekmeklik buğday, gama ışını mutagenesi, tane verimi, kalite karakterleri.

Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world due to adapting to diverse environments from -35 ºC in the vegetative stage to 40 ºC during grain filling period (Shewry, 2009). Turkey is among one of the ten wheat producer countries. Wheat production has over 20 million tons by annually in Turkey and about 10% of this production is compensated by Trakya Region (Sağlam et al., 2015). Grain yield is an important trait as it measures the economic productivity in wheat. Yield quantity and grain quality in elite wheat cultivars are divers throughout the region depending on cropping season due to environmental conditions (Öztürk and Korkut, 2011; Öztürk and Korkut, 2018). For example, the amount of annual rainfall is one of the restricted factors in this region. Although, the average annual rainfall is enough during the cropping season, distribution of this rainfall mostly is not regular. Due to this fluctuation of rainfall in some growing years cause to decrease in grain yield and quality of annual wheat production. Thereby, to manage the sustainable wheat production in Trakya Region should be based on developing new elite bread wheat cultivar(s), which maintain yield stability under the climatic conditions in the region. There is considerable variation of what yields among years and they are mainly result of weather impacts, particularly precipitation quantities and their distribution as well as temperature regimes. However, precise connections are impossible to explain based on their monthly values only although there are indications that the higher precipitation and the lower temperatures during winter period could be negative influencing factors (Öztürk and Korkut, 2011; Sostaric et al., 2014).

Mutation is a heritable change in genes and chromosomes, and occurs at random, either spontaneous or induced with mutagenic agents (Şen et al., 2017). Induced mutations are necessary to enhance rate of genetic variability since spontaneous mutation rate is very low and that prevents breeders to exploit them in plant breeding programmes. Selecting new cultivar(s) against tolerance to drought stress is generally evaluated using phenotypic observations. Thus, effective stress related biomarkers are needed to identify and implement in breeding programmes for screening of drought tolerant genotypes (Şen and Öztürk, 2018). Mutation breeding is one of the breeding tools based on artificially inducing hereditary changes in plants using either physical or chemical mutagen, which has been successfully used to develop diverse and valuable materials in several crops with agronomical important traits (Thapa, 2004; Borzouei et al., 2010; Shah et al., 2012). Therefore, mutagenesis is applied to amend few blemishes in a cultivar that has several agronomic traits preferable by farmer. In wheat breeding, Sakin et al., (2004, and 2005) obtained superior mutant types having better agronomic values in term of yield and yield components. Gamma rays in particular, is well known physical mutagen and often used in mutation breeding program to induce desirable mutants with different genotypes (Konzak, 1987; Knott, 1991). To predict the selection effects precisely, heritability accompanied by genetic advance is more useful than heritability alone. Genotypic differences were highly significant for grain yield and all quality characters except particle size index (Akçura, 2009). The genotypic correlation values were slightly higher than their corresponding phenotypic values, which might have been due to the modified effect of growing seasons on character association at genetic level (Akçura, 2009). Significant differences among cultivars for characters in bread wheat genotypes and significant and positive correlations between grain yield and plant height, grain number per spike, grain weight per spike, 1000-kernel weight and test weight were found while insignificant but positive correlations between spike length, heading period and vegetative period were observed (Kara et al., 2016). In addition, previous studies carried out for both bread wheat cultivars and landraces generally showed a negative relationship between thousand kernel weight with protein content and sedimentation (Akcura, 2011). The genetic correlation analysis indicated that positive and important relations were found between grain yield and grain weight/spike, test weight, plant weight, grains/spike, spikelets/spike, 1000 grain weight and spike length. Days to 50% flowering showed negative and important correlation coefficient with grain yield (Bilgin et al., 2011).

The objectives of this work were to apply gamma ray irradiation to obtain mutant wheat populations (i) and to select new mutant bread wheat line(s) from among these populations, which have superior characters, such as moderate or high yielding, semi dwarf, early maturing, etc. (ii).

Materials and Methods

Experimental Design:

In this study; Selimiye cultivar, TCI2066 and three sisters' line pedigree number of TCI2021 genotypes (Table 2) were irradiated with 200 Gy gamma rays installed at Turkish Atomic Energy

Authority in Ankara, in 2005. Irradiated seeds were grown in rows spacing of 30 cm up to obtain the M_6 mutant wheat populations in the experimental field of Trakya Agriculture Research Institute, Edirne, Turkey, which is located in geographic latitude of 41°40' N and longitude of 26°34' S, altitude is 48 m. During the two-year trial, the mean annual rainfall for this region was measured to be 614.9 mm (high rainfall condition) in 2012-2013 wheat growing season and to be 486.2 mm (low rainfall condition) in 2013-2014 wheat growing season. The mean values of humidity and temperature recorded at similar values in both cropping years, even if the distributions between the months were different. The experiment carried out under rainfed condition and did not irrigate (Table 1). Then, 15 advanced mutant lines from M_6 generation and their parent (as a control) and five commercial wheat cultivars, which have superior characters than others and, thus, are widely growth in this region were evaluated based on agronomical parameters, such as GY, TKW, TW, PRT, HARD, DH and PH under field condition during 2012-2013 and 2013-2014 wheat growing seasons. For each cropping season, the experiment was carried out a randomized complete block design with four replications. Trial plots were 5 m x 1.2 m sizes with 6 rows and sowing density was 500 seed/m^2. Agronomic parameters were recorded along the plant growth.

Table 1. Some climatic parameters during the wheat growing season in 2012-2013 and 2013-2014 cropping years in Edirne.

Months	**Rainfall (mm)**		**Relative humidity (%)**		**Mean temperature (°C)**	
	2012-2013	**2013-2014**	**2012-2013**	**2013-2014**	**2012-2013**	**2013-2014**
October	46.1	30.7	73.3	77.5	18.9	12.8
November	12.4	73.9	83.4	86.7	12.2	11.0
December	165.8	2.3	95.6	82.2	3.6	2.7
January	134.6	74.9	90.2	87.4	4.2	5.5
February	104.5	3.8	88.3	86.0	6.8	7.6
March	62.9	124.5	77.0	81.4	9.8	10.1
April	51.0	36.8	71.1	81.6	16.3	13.6
May	11.0	61.7	66.7	76.6	20.8	18.6
June	26.6	68.8	70.1	73.8	23.3	22.9
Total/Mean	614.9	486.2	79.5	78.8	12.9	12.6

Table 2. Cross and pedigree number of the parent genotypes used in this study.

No	**Parents Genotypes**	**Pedigree**
1	Selimiye	Lau/Agd/3/Odes95//Olv/B16 TE5402-4T-1T-2T-0T
2	LAGOS-10/MIRLEBEN// BLUEGIL-2	TCI2066-030YE-30YE-3T-2T-0T
3	SARKA/3/AGRI/NAC//MLT/4/BLUEGIL-2	TCI2021-030YE-030YE-9T-2T-2T-0T
4	SARKA/3/AGRI/NAC//MLT/4/BLUEGIL-2	TCI2021-030YE-030YE-4T-3T-2T-0T
5	SARKA/3/AGRI/NAC//MLT/4/BLUEGIL-2	TCI2021-030YE-030YE-9T-2T-1T-0T

Measurement of Agronomic Parameters:

Agronomical attributes addressed in this study TKW, TW, HARD, PRT was measured according to Peterson et al., (1998) and Köksel et al., (2000), Pena (2008), Tosun et al., (2006), Elgün et al., (2001). Days of heading and plant height were also measured (Tosun et al., 2006).

Statistical Analysis:

The data for the four replications were combined and statistically analyzed using analysis of variance (Gomez and Gomez, 1984). The significance of differences among means was compared by using Least Significant Difference test (L.S.D.) at P<0.05 (Kalaycı, 2005). Coefficients of the regression equations were calculated according to (Finlay and Wilkinson, 1963; Eberhart and Russell, 1969). Regression graphs were drawn to predict adaptability of genotypes.

Results and Discussion

The aim of wheat breeding programs is to improve the genotypes adaptation to target environment(s). In most case, grain yield and yield-related traits are the most important economic traits in wheat improvement. Thus, they constitute the major selection criteria in breeding programs. However, yield is a polygenic trait with low inheritance. Induced genetic variability with mutation technique brings about heritable changes in plants and offer new genetic varieties to plant breeders. Kenzhebayeva et al., (2017) used gamma radiation to generate genetic variation in wheat and tested the linkage between various important grain parameters in fifth generation mutants. In this study, we have created the mutant wheat populations using 200 Gy gamma irradiation and promising mutant lines were successfully selected under target environment from M_6 generation of the mutant populations. The ANOVA results for grain yield, agronomic, physiological and quality characteristics of wheat genotypes were given in Table 3 and 4. Analysis of variance for two seasons indicated statistically significant differences ($P<0.01$ and $P<0.05$) for all traits measured in presented study (Table 3 and 4). These results have also addressed us to proceed further analysis such as correlation and regression using entire data. To compare commercial cultivars, the highest grain yield were determined from the mutant lines of Selimiye M1-2, Selimiye M1-3, Selimiye M1-11, and Selimiye M1-6 derived from Selimiye cultivar with yield of 822.9, 810.4, 805.2 and 802.5 kg da^{-1}, respectively (Table 3). The traits such as 1000-kernel weight, days of heading and plant height are among the several contributing factors of grain yield. In presented work, there was no promising results that mutant lines have improved in terms of TKW and DH traits, whereas the mutant line of TCI2021-12M3-8 was measured the shortest one among them. Grain protein ratio and hardness are important factors affecting grain quality and thus a key determinant of both end use and market value in bread wheat (Atlı, 1999; Tosun et al., 2006; Mızrak, 2011; Niu et al., 2010). The mutant lines of TCI2021-21M4-2 and TCI2021-23M5-2 were given the highest value in terms of protein ratio (11.5%) and the highest hardness value were determined from the mutant lines of TCI2066-9M2-3, TCI2066-9M2-1 and TCI2021-21M4-2, respectively (Table 4). Kenzhebayeva et al., (2017) reported that gamma ray mutagenesis increased the protein content in some advanced mutant lines than parents. To reveal the relationship between each pair of the traits from all genotypes was calculated simple correlation analysis and the results of correlation analysis were summarized in Table 5 and 6, respectively. Correlation studies are useful in measuring the strength and direction of the relationships among the different agronomic characters Grain yield is one of the major important characters. Güngör and Akgöl, (2015) and Bilgin et al., (2008) revealed that a high significant correlation of 1000 grain weight with grain yield implies that 1000 grain weight plays a very important role in the possible increase of the grain yield of new wheat genotypes in the Thrace Region. Öztürk and Korkut, (2017) and Tekdal et al., (2014) reported that TKW and TW had a positive effect on grain yield. The higher grain yields were found in examined varieties with the higher 1000-grain weight. In the present study a strong positive correlation was determined, in this study, between GY and TKW (r=0.551**, r=0.776**), and TW (r=0.701**, r=0.833**) in both cropping season under high and low rainfall conditions, respectively. These results are accordance with those of Bilgin et al., (2008), and Yağdı and Sözen, (2009). TKW and TW can be used to determine the potential flour yield in wheat grain, which accepted as the main quality factors by the milling industry (Boz et al., 2012). Grain protein content is another important factor affecting of both end use and market value in wheat. However, it is known that grain protein is negatively correlated with grain yield (Atlı, 1987; Atlı, 1999; Aydoğan and Soylu, 2017). This result was confirmed with in our study, as well. Hardness is among the major components affecting the quality of wheat and related to the protein content (especially gluten) of the grain. The increase in protein content results in increasing rigidity or hardness (Atlı, 1999; D'Egidio, 2001). Öztürk and Korkut, (2017) and Boz et al., (2012) indicated that hardness was positively correlated with protein content in wheat. The correlation ratios in this study were calculated as 0.313 in 2012-2013 growing year and as 0.388 in 2013-2014 growing year. These results showed that high and low rainfall conditions did not create huge correlation differences between grain hardness and protein content. According to result of the study grain yield was shown significant negative correlation with days of heading in 2012-2013 (r=-0.575**) under high rainfall condition, and in 2013-2014 (r=-0.845**) under low rainfall condition in our study. This result showed that early genotypes had higher grain yield. These results are substantiated with those of Bilgin et al., (2008), and Yağdı and Sözen, (2009). Plant height is a major agronomic trait in wheat breeding because of its association with lodging, seedling growth capacity, and weed control. Aydın et al., (2010) reported that plant height had the greatest direct effect on grain yield and they, thus, suggested that it was a one of the primarily selection criteria for improving grain yield in wheat under high and low rainfall conditions. However, we found low positive correlation between GY and PH in both cropping seasons to be r=0.137 (in 2012-2013) and r=0.130 (in 2013-2014), respectively. These results revealed that how the target environment and genotype have the determinative effect on the selection, which was done using yield components.

Table 3. The mean grain yield of the genotypes in terms of growing years.

No	Genotypes	2012-2013 Growing year	2013-2014 Growing year	Mean grain yield (kg da^{-1})
1	Aldane (Local check)	720.5 a-d	789.5 b-f	755.0 cde
2	Selimiye M1-2	764.6 a	881.2 a	822.9 a
3	Selimiye M1-3	749.9 ab	871.0 ab	810.4 ab
4	Selimiye M1-6	739.5 abc	865.5 ab	802.5 a-d
5	Selimiye (Parent-Local Check)	680.6 d-g	825.5 abc	753.0 def
6	Selimiye M1-9	683.8 c-g	864.7 ab	774.2 a-e
7	Selimiye M1-11	745.8 ab	864.6 ab	805.2 abc
8	TCI2066-9M2-1	657.0 f-ı	588.6 jk	622.8 kl
9	TCI2066-9 (Parent-Local Check)	609.2 ıj	573.3 k	591.3 lm
10	Bereket (Local Check)	738.8 abc	794.3 b-e	766.6 b-e
11	TCI2066-9M2-3	638.0 g-j	672.3 hıj	655.2 h-k
12	TCI2021-12 (Parent- Local Check)	645.8 f-ı	705.0 fgh	675.4 hıj
13	TCI2021-12M3-3	699.3 b-f	728.4 d-h	703.5 fgh
14	TCI2021-12M3-4	664.0 e-ı	701.1 f-ı	670.2 h-k
15	Pehlivan (Local Check)	719.1 a-e	779.3 c-g	749.2 ef
16	TCI2021-12M3-5	668.6 d-h	698.4 ghı	683.5 hı
17	TCI2021-12M3-6	657.6 f-ı	662.7 hıj	660.2 h-k
18	TCI2021-12M3-8	654.0 f-ı	725.7 e-h	689.9 ghı
19	TCI2021-12M3-10	651.0 f-ı	720.2 e-h	685.6 ghı
20	Gelibolu (Local Check)	648.3 f-ı	885.6 a	767.0 b-e
21	TCI2021-21(Parent-Local Check)	623.2 hıj	657.6 h-k	640.4 ı-l
22	TCI2021-21M4-2	582.6 jk	668.7 hıj	625.7 jkl
23	TCI2021-23 (Parent-Local Check)	538.1 kl	588.6 jk	563.4 m
24	TCI2021-23M5-2	526.0 l	604.7 ıjk	565.3 m
25	Kate A-1 (Local Check)	652.9 f-ı	815.4 a-d	734.1 efg
Mean		666.3	742.1	702.9
LSD (0.05)		56.4	84.8	50.2**
CV (%)		6.0	8.1	7.2
F		9.51**	11.24**	18.18**

Note: * and ** represented significance at: P<0.05 and: P<0.01, respectively.

The results of regression equation (R^2) were given in Figure 1 and 2. In presented study, the highest significant association was found between TW and TKW (R^2=0.888). On the other hand, regression analysis indicated that TW was the trait most related to GY (R^2=0.697). TKW was followed it with the rate of (R^2=0.552). The positive association between these traits could be emphasized that by increasing the amount of TW and TKW would be increased the amount of GY under changing rainfall conditions of Trakya Region. In this study, it was found negatively relationship between DH with TW (R^2=0.820), TKW (R^2=0.732), and GY (R^2=0.634). These results suggested that early genotypes had higher amount of test weight, 1000-kernel weight and grain yield.

Conclusions

In conclusion, the presented data based on a two-year trial revealed that the highest grain yield was determined from the mutant lines derived from Selimiye wheat cultivar. The mutant lines of TCI2021-21M4-2 and TCI2021-23M5-2 were given the highest value in terms of protein ratio and the highest hardness value were determined from the mutant lines of TCI2066-9M2-3, TCI2066-9M2-1 and TCI2021-21M4-2, respectively. The mutant line of TCI2021-12M3-8 was measured the shortest one among others. Additionally, a strong positive correlation was determined between GY and TKW, and TW in both cropping season. The data obtained from this study also showed that gamma-irradiated mutation recourses could be successfully integrated in local wheat breeding programs to improve yield and yield related components (i) and TKW and TW could be used as selection criteria for maintaining grain yield content under the climate conditions of Trakya Region (ii).

Table 4. The mean values of the genotypes in terms of agronomic, and quality characters.

No	Genotypes	TKW	TW	PRT	HARD	DH	PH
1	Aldane (Local check)	48.6^{a}	80.0^{abc}	11.4^{ab}	45.5^{cde}	112.5^{de}	115.0^{de}
2	Selimiye M1-2	46.6^{abc}	80.8^{a}	10.2^{ag}	44.5^{de}	112.5^{de}	116.0^{cde}
3	Selimiye M1-3	46.6^{ab}	80.9^{a}	10.4^{ag}	46.0^{be}	112.0^{e}	116.5^{cde}
4	Selimiye M1-6	47.6^{ab}	80.1^{abc}	10.1^{ah}	46.0^{be}	112.0^{e}	114.5^{de}
5	Selimiye (Parent- Local Check)	49.4^{a}	80.1^{abc}	9.8^{dh}	46.5^{bcd}	112.0^{e}	115.0^{de}
6	Selimiye M1-9	49.4^{a}	80.3^{ab}	9.6^{eh}	47.0^{bcd}	111.5^{e}	115.5^{de}
7	Selimiye M1-11	47.5^{ab}	80.5^{ab}	9.3^{gh}	46.5^{bcd}	112.0^{e}	114.5^{de}
8	TCI2066-9M2-1	34.0^{hi}	74.4^{fg}	9.7^{eh}	49.0^{ab}	125.5^{ab}	108.5^{e}
9	TCI2066-9 (Parent-Local Check)	33.5^{i}	74.9^{fg}	10.2^{ag}	48.5^{abc}	125.0^{abc}	110.0^{e}
10	Bereket (Local check)	43.1^{bcd}	79.6^{abc}	9.1^{gh}	44.5^{de}	115.0^{d}	121.0^{ad}
11	TCI2066-9M2-3	34.9^{ghi}	74.4^{fg}	11.0^{ae}	50.5^{a}	125.0^{abc}	113.5^{de}
12	TCI2021-12 (Parent- Local Check)	37.1^{fi}	76.1^{d-g}	10.8^{af}	48.5^{abc}	125.5^{ab}	96.5^{f}
13	TCI2021-12M3-3	36.5^{fi}	75.7^{efg}	10.9^{ae}	48.0^{abc}	126.0^{a}	96.0^{f}
14	TCI2021-12M3-4	37.6^{ei}	76.5^{def}	10.3^{ag}	48.5^{abc}	125.5^{ab}	95.5^{f}
15	Pehlivan (Local check)	49.4^{a}	80.2^{abc}	9.3^{fgh}	46.5^{bcd}	115.0^{d}	120.0^{bcd}
16	TCI2021-12M3-5	36.7^{fi}	75.2^{fg}	10.4^{ag}	47.0^{bcd}	126.0^{a}	95.5^{f}
17	TCI2021-12M3-6	34.4^{hi}	74.0^{g}	11.3^{abc}	47.5^{ad}	126.0^{a}	95.5^{f}
18	TCI2021-12M3-8	37.1^{fi}	76.8^{def}	10.0^{bh}	47.0^{bcd}	125.5^{ab}	94.0^{f}
19	TCI2021-12M3-10	38.1^{eh}	76.6^{def}	10.4^{ag}	48.0^{abc}	126.0^{a}	95.0^{f}
20	Gelibolu (Local check)	45.5^{abc}	80.1^{abc}	8.6^{h}	43.0^{e}	111.5^{e}	109.0^{e}
21	TCI2021-21(Parent-Local Check)	36.7^{fi}	74.5^{fg}	10.6^{ag}	48.5^{abc}	127.0^{a}	99.0^{f}
22	TCI2021-21M4-2	35.2^{ghi}	75.1^{fg}	11.5^{ab}	49.0^{ab}	126.5^{a}	98.0^{f}
23	TCI2021-23 (Parent-Local Check)	42.0^{cde}	77.8^{cde}	11.3^{ad}	39.5^{f}	123.0^{bc}	129.5^{a}
24	TCI2021-23M5-2	40.4^{def}	75.4^{efg}	11.5^{a}	37.5^{f}	122.5^{c}	126.5^{ab}
25	Kate A-1 (Local check)	39.1^{dg}	78.3^{bcd}	9.8^{ch}	45.5^{cde}	108.0^{f}	124.5^{abc}
Mean		41.1	77.5	10.3	46.3	119.6	109.4
CV (%)		5.4	1.5	7.1	3.4	1.1	3.9
LSD (0.05)		4.4	1.6	1.5	3.3	2.8	8.8
F		13.03**	8.64**	2.34*	6.36**	49.94**	13.64**

Note: * and ** represented significance at: P<0.05 and: P<0.01, respectively. TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), HARD: Hardness (PSI), DH: Days of heading, PH: Plant height (cm).

Table 5. The correlation coefficients among tested parameters in 2012-2013 season.

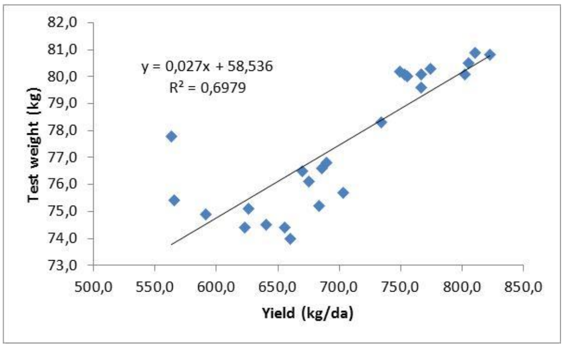
Traits	GY	TKW	TW	PRT	HARD	DH
TKW	0.551**					
TW	0.701**	0.904**				
PRT	-0.549**	-0.679**	-0.683**			
HARD	0.288	-0.398*	-0.273	0.313		
DH	-0.575**	-0.754**	-0.768**	0.683**	0.203	
PH	0.137	0.502**	0.417*	-0.321	-0.365	-0.660**

Note: * and ** represented significance at: P<0.05 and: P<0.01, respectively. GY: Grain yield (kg da^{-1}), TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), HARD: Hardness (PSI), DH: Days of heading, PH: Plant height (cm).

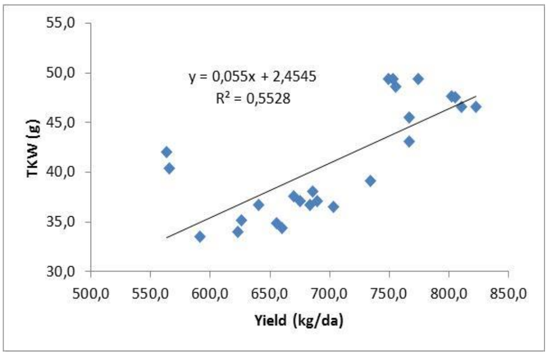
Table 6. The correlation coefficients among tested parameters in 2013-2014 season.

Traits	GY	TKW	TW	PRT	HARD	DH
TKW	0.776**					
TW	0.833**	0.941**				
PRT	-0.285	-0.154	-0.299			
HARD	-0.039	-0.360	-0.353	0,388		
DH	-0.845**	-0.890**	-0.930**	0.196	0.404*	
PH	0.130	0.519**	0.521**	0.177	-0.804**	-0.589**

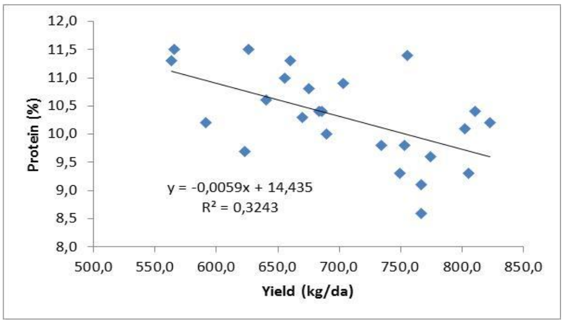
Note: * and ** represented significance at: P<0.05 and: P<0.01, respectively. GY: Grain yield (kg da^{-1}), TKW: 1000-kernel weight (g), TW: Test weight (kg), PRT: Protein ratio (%), HARD: Hardness (PSI), DH: Days of heading, PH: Plant height (cm).



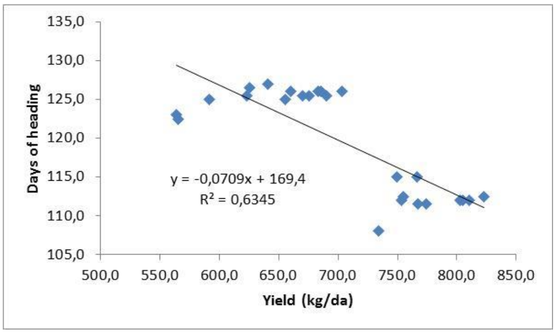
Grain yield and test weight



Grain yield and 1000-kernel weight

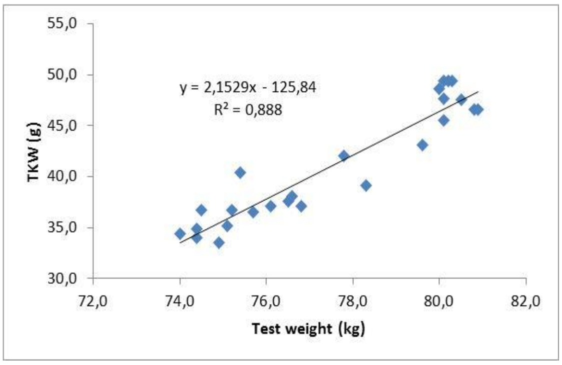


Grain yield and protein ratio

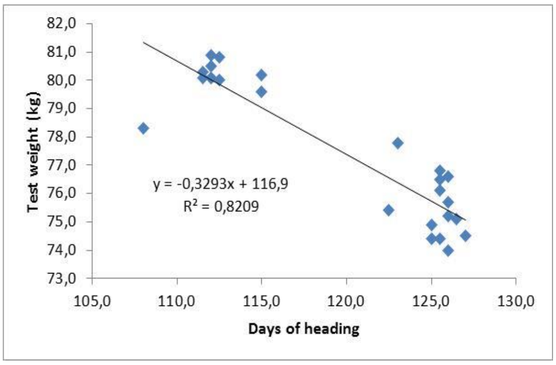


Grain yield and days of heading

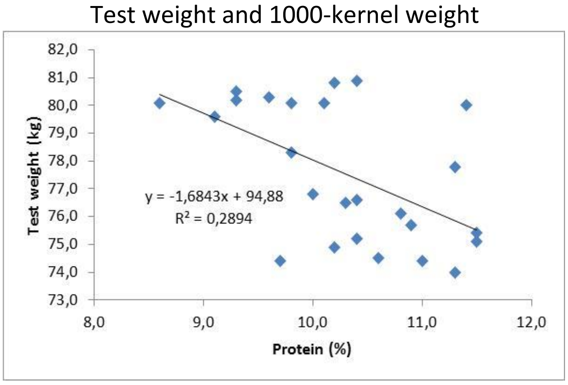
Figure 1. Relationship between grain yield and quality parameters and days of heading.



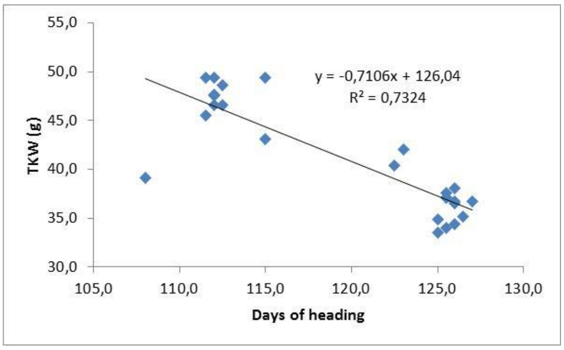
Test weight and 1000-kernel weight



Test weight and days of heading



Test weight and protein ratio



1000-kernel weight and days of heading

Figure 2. Regression analysis among quality and other parameters in two-year trial.

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