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QUALITY PERFORMANCE OF DURUM WHEAT (*Triticum durum* L.) GERMPLASM UNDER RAINFED AND IRRIGATED FIELD CONDITIONS

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ABSTRACT

Wheat is usually grown as a rainfed crop and no irrigation is applied in most production fields. This study was undertaken to evaluate the quality characteristics of durum wheat germplasm in under rainfed and irrigated field conditions during 2019-2020 and 2021-2022 growing seasons. The experiments were laid out in 12x12 alpha lattice block design with two replicates for rainfed and irrigated experiments. Grain protein content, starch content, wet gluten content and test weight were examined for 125 genotypes which consisted of fifty local cultivars, nineteen foreign cultivars used in Turkey, forty two gene bank landraces *(ex situ)* and fourteen local landraces (*in situ*). Supplemental irrigation resulted in a decrease in grain protein content and wet gluten content but an increase in starch content. *Ex situ* landraces (17.48%) and *in situ* landraces (16.62%) had higher grain protein content mean values under both rainfed and irrigated conditions. The correlation coefficient was 0.82 between grain protein content-wet gluten content whereas it was -0.77 and -0.65 between grain protein content-starch content and wet gluten content-starch content, respectively. The decrease in protein and gluten content in local and foreign cultivars was more dramatic in both years compared to landraces. Our results indicated that *ex situ* landraces have a great potential in terms of grain quality characteristics. The high genotypic diversity and improved quality characteristics in landraces provided extensive insights for future studies to improve crop quality in areas with limited irrigation opportunities.

Keywords: Gluten, protein, starch, supplemental irrigation, test weight

INTRODUCTION

Turkey ranks 3rd in the world in durum production that accounts for 17% of the total wheat production in Turkey (FAO, 2021). Factors such as global warming, decreases in usable water resources, pests, diseases, soil salinity, lack of plant nutrients in the soil, drought, and high temperatures threaten the sustainability of agricultural production (Lobell et al., 2011). GPC (grain protein content) is an important determinant of durum wheat end use (Sissons et al., 2021; Sarkar and Fu, 2022). Because the endosperm structure of durum wheat is hard, and the glassiness ratio in the grain is high, semolina yields and semolina shine values are higher than those of bread wheat (Troccoli, 2000). GPC is a complex trait strongly affected by environmental factors (Manai–Djebali et al., 2021). The grain quality of durum wheat is related to GPC because of its direct association with the production of high-quality pasta (Dalla Marta et al., 2011). The GPC of wheat plays an important role in determining its quality. When the GPC exceeds 13%, the grain is desirable for making pasta with its increased tolerance to overcooking, and high GPC significantly increases the water absorption in the grain and extends the shelf life of the final product (Suprayogi et al., 2009; Mefleh et al., 2019). Breeders generally select for high GPC, as it plays a crucial role in determining the value of grain (Sissons et al., 2020). Starch is the main component of flour as it makes up approximately 80% of durum flour and acts as an energy source (Lafiandra et al., 2010; Mastrangelo and Cattivelli, 2021). Starch is an important component of the human diet, as it is a major ingredient of pasta, noodles, and bread. Therefore, the quality of pasta and noodles depends on their SC (starch content) (Saini et al., 2022). WGC (wet gluten content) in the kernel is an important indicator of the pasta quality of durum wheat and an elastic protein that shows the suitability of the flour structure for making pasta and couscous (Modenes et al., 2009). Test weight may vary depending on genetic structure, environmental conditions, and cultural practices (Samaan et al., 2006; Protic et al., 2007). Test weights of durum wheats are usually higher than wheat varieties (Morris, 2004; Sissons, 2004).

It is widely accepted that there is a negative correlation between GPC and grain yield in bread and durum wheat (Thorwarth et al., 2019). Although irrigation of wheat generally results in an increase in grain yield, it can have negative effects on grain quality. The quality of the end product is highly linked to the grain structure, which is affected by the genotype, environment, and genotype x environment (Schulthess et al., 2013). Various environmental parameters such as soil properties and agricultural practices, have an important influence on the industrial quality parameters of durum wheat grains (Calzarano et al., 2018; Manai–Djebali et al., 2021).

Wheat plants require water during all stages of development, but in some periods, the effect of water deficiency is critical and may lead to vital yield and quality losses (Yavas et al., 2016). Water deficiency during grain filling causes early senescence, reduces photosynthesis, and shortens the grain filling stage (Farooq et al., 2014; Zhang et al., 2019). Supplemented irrigation may be required during the bolting and seed-filling stages (Oweis and Hachum, 2009; Moradi et al., 2022). Insufficient and irregular rainfall in terms of optimum plant growth in regions located in arid and semi-arid climatic zones poses a great risk to wheat farming (Langridge and Reynolds, 2021).

This study aimed to explore the potential of some quality traits in 125 durum wheat (*Triticum durum* L.) genotypes, evaluated under rainfed and irrigated field conditions during two growing seasons.

This study included almost all modern cultivars, *ex situ* and *in situ* landraces used in Turkey. Hence, this is the first study to examine quality characteristics in in this region.

MATERIALS AND METHODS

Plant materials and growing conditions

The study was conducted using 125 durum wheat genotypes (*Triticum durum* L.) including fifty local cultivars (local CVs), nineteen foreign cultivars (foreign CVs), forty two gene bank landraces (*ex situ* LDs) obtained from the Genebank in Aegean Agricultural Research Institute in İzmir/Turkey and fourteen landraces (*in situ* LDs) (Table 1.)

The field experiments were carried out in the Application and Research Fields at Nigde Omer Halisdemir University, Nigde, Turkey in the growing season of 2019/2020, 2021/2022 under rainfed and irrigation conditions. Field experiments were planned for two years in the 2019-2020 and 2020/2021 growing seasons, but there were problems in the emergence rates in the trial conducted in the 2020/2021 growing season. Considering that the data to be obtained from the experiment would not be healthy, it was decided to repeat the field experiment in the 2021/2022 growing season. The experimental site (37°56'31.6"N 34°37'58.7"E) was located in the central part of Turkey, similar to continental climate. The experiments were laid out in 12x12 alpha lattice block design with two replications for rainfed and irrigated experiments. Each plot consisted of 3 rows of 3 m and each row was 0.2 m apart. The soil of the experimental area has a clay-loam structure, alkaline character, and an organic matter content of 1.91% (Caliskan et al., 2021). The sowing dates were 15/11/2019 and 07/11/2021 for 2019/20 and 2021/2022 growing seasons, respectively. The average vegetative period for 2019/20 and 2021/2022 growing seasons experiments were, 228 and 233 days, respectively. The emergence dates of the plots were followed up after sowing and germination rates are observed. The differences between the genotypes were not found to be significant.

In this study, a total of 160 kg of pure N and 80 kg of P_2O_5 were fertilized per ha, and 20-20-20 compound fertilizer was applied to 80 kg pure N and 80 kg P_2O_5 per ha before planting. The other half of the nitrogen was given as urea fertilizer during the tillering period. Weed control was carried out regularly in the trial areas and agronomic and plant protection measures were taken according to Anderson and Grainge (2000).

Supplemental Irrigation

After sowing, the experimental fields were irrigated with a sprinkler irrigation system to support germination and emergence. For the rainfed experiments, the plants received only water from natural rainfall. Supplementary irrigation (SI) is defined as the addition of a limited amount of water to rainfed crops to improve and stabilize yields when rainfall cannot provide the moisture required for normal plant growth (Oweis et al., 2000). For irrigated experiments, two supplemental irrigations were applied in both years (Table 2).

Supplemental irrigation was provided on two occasions during at the boot stage (Z45) and at flowering (Z65) (Zadoks et al., 1974), which is one of the periods when plants need water the most (Wang et al., 2013). The amount and duration of irrigation were determined by measuring the field capacity of samples taken from the soil at regular intervals (Cassel and Nielsen, 1986). When the field capacity fell below 60%, the plants were irrigated with the drip irrigation system to reach their field capacity.

Observations and measurements

One hundered and twenty five durum wheat genotypes were studied for grain quality traits. After harvesting the plots, 500 g of the sample from each plot was saved for quality analyses. Grain protein content (%), starch content (%), wet gluten content (%) and test weight (kg/hl) were examined. Near-infrared spectroscopy (NIRS) offers a more comprehensive measurement of the entire sample by analyzing a larger portion of the wheat sample compared to conventional methods. Conventional methods may involve sampling from specific regions or parts of the sample, which can introduce sampling bias and potentially underestimate protein and wet gluten content (Zhang et al., 2022).

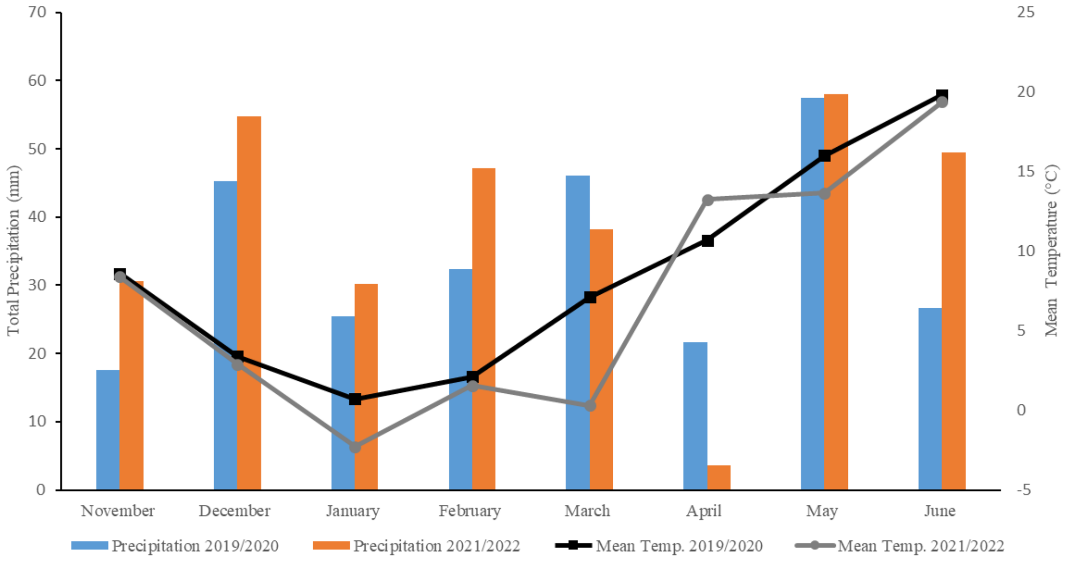
Table 1. Genotypes used in the study and their registration countries/years

No	Genotype Name	Registered Country	Registered Year	No	Genotype Name	Registered Country	Registered Year
1	Fatasel-185/1	Turkey	1964	**64**	Creco	Israel	1974
2	Kunduru-1149	Turkey	1967	**65**	Iride	Italy	1996
3	Akbasak-073144	Turkey	1970	**66**	Dylan	Italy	2002
4	Saribasak	Turkey	1970	**67**	Ofanto	Italy	1990
5	Vatan	Turkey	1978	**68**	Cham-1	Syria	1984
6	Cakmak-79	Turkey	1979	**69**	Cham-9	Syria	2010
7	Gokgol-79	Turkey	1979	**70**	TR 31887 - Elazig		
8	Tunca-79	Turkey	1979	**71**	TR 31893 - Malatya		
9	Diyarbakir-81	Turkey	1981	**72**	TR 31902 - Malatya		
10	Sham-1	Turkey	1984	**73**	TR 31930 - Malatya		
11	Balcali-85	Turkey	1985	**74**	TR 32015 - Malatya		
12	Ege-88	Turkey	1988	**75**	TR 32090 - Ankara		
13	Kiziltan-91	Turkey	1991	**76**	TR 32167 - Yozgat		
14	Salihli-92	Turkey	1992	**77**	TR 35148 - Yozgat		
15	Aydin-93	Turkey	1993	**78**	TR 35150 - Yozgat		
16	Altinbac-95	Turkey	1995	**79**	TR 45305 - Yozgat		
17	Harran-95	Turkey	1995	**80**	TR 46881 - Erzincan		
18	Ceylan-95	Turkey	1995	**81**	TR 47949 - Kars		
19	Selcuklu-97	Turkey	1997	**82**	TR 53860 - Yozgat		
20	Amanos 97	Turkey	1997	**83**	TR 53861 - Yozgat		
21	Yilmaz-98	Turkey	1998	**84**	TR 54969 - Yozgat		
22	Altin 40-98	Turkey	1998	**85**	TR 54973 - Yozgat		
23	Altintoprak-98	Turkey	1998	**86**	TR 54977 - Yozgat		
24	Ankara-98	Turkey	1998	**87**	TR 56128 - Eskisehir		
25	Saricanak-98	Turkey	1998	**88**	TR 56135 - Eskisehir		
26	Cesit-1252	Turkey	1999	**89**	TR 56206 - Eskisehir		
27	Yelken-2000	Turkey	2000	**90**	TR 63315 - Konya		
28	Kumbet-2000	Turkey	2000	**91**	TR 71914 - Konya		
29	Balcali-2000	Turkey	2000	**92**	TR 72025 - Konya		
30	Fuatbey-2000	Turkey	2000	**93**	TR 80984 - Eskisehir		
31	Mirzabey-2000	Turkey	2000	**94**	TR 81238 - Erzincan		
32	Meram-2002	Turkey	2002	**95**	TR 81249 - Elazig		
33	Sölen-2002	Turkey	2002	**96**	TR 81258 - Malatya		
34	Tuten-2002	Turkey	2002	**97**	TR 81259 - Malatya		
35	Akçakale-2000	Turkey	2002	**98**	TR 81273 - Ankara		
36	Turabi	Turkey	2004	**99**	TR 81277 - Ankara		
37	Gap	Turkey	2004	**100**	TR 81278 - Ankara		
38	Ozberk	Turkey	2005	**101**	TR 81283 - Ankara		
39	Urfa-2005	Turkey	2005	**102**	TR 81284 - Ankara		
40	Dumlupinar	Turkey	2006	**103**	TR 81323 - Ankara		
41	Eminbey	Turkey	2007	**104**	TR 81356 - Konya		
42	Artuklu	Turkey	2008	**105**	TR 81367 - Konya		
43	Eyyubi	Turkey	2008	**106**	TR 81369 - Nigde		
44	Sahinbey	Turkey	2008	**107**	TR 81371 - Nigde		
45	Imren	Turkey	2009	**108**	TR 81374 - Konya		
46	Guney yıldızı	Turkey	2010	**109**	TR 81381 - Sivas		
47	Ali baba	Turkey	2010	**110**	TR 81544 - Nigde		
48	Zuhre	Turkey	2011	**111**	TR 81550 - Nigde		
49	Gundas	Turkey	2012	**112**	Bagacak	Turkey	
50	Soylu	Turkey	2012	**113**	Beyaziye	Turkey	
51	Zenit	Italy	1992	**114**	Hacihalil	Turkey	
52	Svevo	Italy	1996	**115**	Havrani	Turkey	
53	Baio	Italy	1998	**116**	Hevidi	Turkey	
54	Pathfinder	Canada	1999	**117**	Iskenderiye	Turkey	
55	Nevigator	Canada	1999	**118**	Karadere	Turkey	
56	Floradur	Austria	2003	**119**	Kurtulan	Turkey	
57	Saragolia	Italy	2004	**120**	Levante alike	Turkey	
58	Uc.1113	USA	2005	**121**	Menceki	Turkey	
59	UN Darwin	USA	2006	**122**	Mersiniye	Turkey	
60	Clavdio	Italy	2011	**123**	Misri	Turkey	
61	C9	Israel		**124**	Sivaslan	Turkey	
62	C43	Israel		**125**	Sirnak Alkaya	Turkey	
63	Inbar	Israel					

Table 2. Treatment groups

Growing Season	Growing season precipitation (mm)	Supplement irrigation (mm)	Total water consumption (mm)
2019-2020	272.6	-	272.6
	272.6	SI* = 65 SI**= 60	397.6
2021-2022	312.1	-	312.1
	312.1	SI* = 50 SI**= 50	412.1

SI*: first supplemental irrigation; SI**: second supplemental irrigation



Climate data provided from Nigde Meteorology Services General Directorate
Figure 1. Climate parameters of the research field (2019/2020, 2021/2022)

NIRS is a low-cost, fast and simple assessment method. Recently, many researchers have published advanced research studies using NIRS for wheat quality assessment (Du et al., 2022). Grain quality traits (protein content (%), starch content (%), wet gluten content (%) and test weight (kg/hl) of one hundred and twenty five durum wheat genotypes were determined using a Near infrared spectrometer IM 9500 (Perten Instruments, Stockholm, Sweden) according to the manufacturer's instructions with the wavelength ranging from 570-1100 nm.

Statistical analyses

Analyses of variance (ANOVA) for all examined traits were performed according to Jonas and Sall (2011) using the JMP Pro 14.0 software. Tukey's post-hoc test was performed to compare the means at the 5% probability level (Abdi and Williams, 2010). In addition, Pearson correlation coefficients (r) between quality traits and the significance of each correlation coefficient were obtained using the same software. Comparison of the means between the rainfed and irrigated treatments were performed by using the LSD. (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Analysis of variance was performed on the four traits for the growing seasons 2019-2020 and 2021-2022. Genotypes are listed in four groups according to their origins as local cultivars, foreign cultivars, *ex situ* landraces and *in situ* landraces. The aim of this study is to compare quality characteristics in durum wheat population in rainfed and irrigated conditions. Therefore, supplemental irrigation was not considered as a factor, and rainfed-irrigated trials were subjected to analysis of variance separately. Results of statistical analysis for the effects of experimental factors [Year (Y) and Population (P)] on quality parameters of durum wheat with P values were given in Table 3.

Table 3. Analysis of variance for grain protein content (GPC), starch content (SC), wet gluten content (WGC) and test weight (TW)

Experimental Factors	**Rainfed**				**Irrigated**			
	GPC	**SC**	**WGC**	**TW**	**GPC**	**SC**	**WGC**	**TW**
Population (P)	0,0002**	0,295^{ns}	0,0036**	0,023*	<,0001**	0,0472*	0,3491^{ns}	<,0001**
Year (Y)	<,0001**	0,0464*	0,0003**	<,0001**	<,0001**	0,0471*	0,0043**	<,0001**
P × Y	0,0047**	0,4825^{ns}	0,0194*	0,197^{ns}	0,002**	0,6829^{ns}	0,6294^{ns}	<,0001**

*: significant at 0.05 level, **: significant at 0.01 level

Table 4. Pearson's correlation coefficients among quality characteristics calculated from the mean of two environments for 125 durum wheat genotypes

Traits^{+}	**TW**	**WGC**	**SC**
WGC	-0,08		
SC	0,21	-0,65**	
GPC	-0,20	0,82**	-0,77**

*: significant at 0.05 level, **: significant at 0.01 level, ns: non-significant
$^{+}$WGC: Wet gluten content (WGC), Starch content (SC), grain protein content (GPC), Test weight (TW)

Protein content

The proportion of protein within the grain varies depending on the specific region, generally ranges between %8 and %20 of the entire grain composition (De Santis et al., 2021). In our study, the average grain protein content (GPC) in both years varied from 10.95% to 22.35% with an average of 16.66%. Year and population had significant effect on GPC in both rainfed and irrigated conditions (Table 3). The mean values of GPC for the *ex situ* landraces were significantly higher than other populations in first year of experiment. Irrigated treatments had lower mean GPC values compared to rainfed treatments in both years (Table 5). Since the total precipitation was higher in second year, the difference between rainfed and irrigated treatments did not appear as expected (Figure 1). Tatar et al. (2020) found that protein content of grains was increased due to drought conditions. In this study the mean values of GPC for rainfed treatments also gave higher average GPC values than the irrigated treatments in both years. Supplemental irrigation resulted in decrease in GPC in all populations in 2019/2020 and standard cultivars in 2021/2022 growing season. *Ex situ* and *in situ* landraces examined in the study showed significantly higher GPC values compared to standard cultivars in both years. Similarly, Nazco et al. (2012) examined the quality traits in a diverse population of 154 durum wheat genotypes and indicated the overall quality attributes of landraces were higher than standard cultivars. They suggested that landraces could be used as a resource in breeding programs.

GPC (grain protein content) is significantly influenced by genotype, management approaches, and environmental factors (Magallanes-Lopez et al., 2017). Tekdal et al. (2018) investigated the small part of same cultivars and landraces used in this study under different environments which differs in terms of precipitation regime. They reported that the GPC of genotypes was higher at locations with low precipitation than at those with higher precipitation. Their results agreed with ours, while the GPC varied between 13.3% and 16.4% and the highest GPC was obtained from local genotypes. Our results are also in agreement with previous findings that, in addition to genotype, environmental conditions are of great importance in GPC in durum wheat (Sakin et al., 2011; Sayaslan et al., 2012; Yildirim and Atasoy, 2020).

Table 5. Protein content (%) of durum wheat populations under rainfed and irrigated conditions during 2019-2020 and 2021-2022 growing seasons.

Groups	2019/2020			2021/2022			Gen.Mean
	Rainfed*	Irrigated*	Mean*	Rainfed^{ns}	Irrigated*	Mean*	
Local CVs	19.86 bc	17.80 b	**18.83 B**	16.70	15.94 b	**16.32 B**	**17.58**
Foreign CVs	18.63 c	17.50 b	**18.07 C**	16.69	15.85 b	**16.27 B**	**17.17**
Ex Situ LDs	20.29 a	19.08 a	**19.69 A**	17.14	17.13 a	**17.14 A**	**18.41**
In Situ LDs	19.15 b	17.85 b	**18.50 B**	17.04	16.90 a	**16.97 A**	**17.74**
Mean	**19.48**	**18.06**	**18.77**	**16.89**	**16.46**	**16.67**	**17.72**

ns: non-significant, *: significant at 0.05 level.

Starch content

Starch makes up about 70% of the endosperm in wheat grain (Sissons, 2008). The average starch content (SC) in both years varied from 55.7% to 70.1% with an average of 65.87% in our study. Year had significant effect in both rainfed and irrigated conditions. A significant difference was not observed between the populations in the first year of experiment whereas there was a significant difference between the populations in the second year of experiment (Table 6). Local and foreign modern cultivars had higher SC in the second year. Similarly, Boukid et al. (2018) examined modern cultivars and landraces for flour characteristics and noted that modern cultivars have higher starch content due to trends towards increasing yield in the previous breeding processes.

Table 6. Starch content (%) of durum wheat populations under rainfed and irrigated conditions during 2019-2020 and 2021-2022 growing seasons.

Groups	2019/2020			2021/2022			Gen.Mean^{ns}
	Rainfed^{ns}	Irrigated^{ns}	Mean^{ns}	Rainfed^{ns}	Irrigated*	Mean^{ns}	
Local CVs	65.27	66.31	**65.79**	66.33	66.86 a	**66.59**	**66.19**
Foreign CVs	66.13	66.36	**66.25**	66.21	66.77 a	**66.49**	**66.37**
Ex Situ LDs	63.50	65.58	**64.54**	65.99	65.87 b	**65.93**	**65.23**
In Situ LDs	65.11	65.13	**65.12**	66.30	66.20 b	**66.25**	**65.68**
Mean	**65.00**	**65.85**	**65.42**	**66.21**	**66.42**	**66.32**	**65.87**

ns: non-significant, *: significant at 0.05 level.

It has been reported that as the amount of irrigation in durum wheat increases, quality-related characteristics are reduced, whereas dough quantity is like typical dryland durum production (Sissons et al., 2014). The findings of study for SC were comparatively lower than those of some previous studies (Kizilgeci et al., 2019) but in agreement with (Oner and Kendal, 2012) and (El-Khayat et al., 2006) which had average SC between 66.4% - 69.7% and 64.3% - 68.3%, respectively.

Wet gluten content

The average wet gluten content (WGC) in both years varied from 24.7% to 51.85% with an average of 39.92%. Year had a significant effect on WGC in both years, while population had a significant effect in rainfed experiments but not in irrigated experiments. (Table 3). The average values of WGC for the rainfed treatments were significantly higher than irrigated treatments in both years. Standard cultivars showed significantly lower GPC values in both years when compared to both *ex situ* and *in situ* landraces (Table 7).

In a study examining the effect of supplemental irrigation on the quality characteristics of durum wheat, WGC analyzes using the NIRS showed that the WGC was higher in the rainfed group (Flagella et al., 2010). Similarly, Erekul et al. (2012), examined the effect of supplemental irrigation during grain filling stage on wheat and indicated that supplemental irrigation resulted in decrease in WGC. The findings of study for WGC were comparatively higher than some previous studies of Oner and Kendal (2012), Punia et al. (2019) and Yildirim and Atasoy (2020) which ranged between 21.90% - 34.57%, 29.50% - 37.10% and 22.2% - 30.1%, respectively. The results were in agreement with those of Vida et al. (2014) and Ferrari et al. (2014) which ranged from 33.3% to 63.3% with an average of 43.3% and from 21.56% to 49.36% with an average value of 37.61%, respectively.

Table 7. Wet gluten content (%) of durum wheat populations under rainfed and irrigated conditions during 2019-2020 and 2021-2022 growing seasons.

Groups	2019/2020			2021/2022			Gen. Mean
	Rainfed*	Irrigated^{ns}	Mean*	Rainfed*	Irrigated*	Mean*	
Local CVs	44.46 ab	41.54	**43.00 AB**	37.14 c	35.50 b	**36.32 B**	**39.66**
Foreign CVs	41.50 b	41.18	**41.34 B**	39.66 b	38.37 ab	**39.02 AB**	**40.18**
Ex Situ LDs	47.49 a	42.67	**45.08 A**	42.40 a	39.60 a	**41.00 A**	**43.04**
In Situ LDs	42.67 b	41.84	**42.26 AB**	41.68 a	38.13 ab	**39.90 A**	**41.08**
Mean	**44.03**	**41.81**	**42.92**	**40.22**	**37.90**	**39.06**	**40.99**

ns: non-significant, *: significant at 0.05 level.

Test weight

The average value of test weight (TW) for both years varied from 73.75 kg/hl to 85.95 kg/hl with an average of 80.74 kg/hl. Year and population had significant effect on test weight in both rainfed and irrigated experiments (Table 3). *Ex situ* landraces resulted the lowest test weight values in both rainfed and irrigated experiments (Table 8).

Table 8. Test weight (kg/hl) values of durum wheat populations under rainfed and irrigated conditions during 2019-2020 and 2021-2022 growing seasons.

Groups	2019/2020			2021/2022			Gen. Mean
	Rainfed*	Irrigated*	Mean*	Rainfed*	Irrigated*	Mean*	
Local CVs	81.01 b	79.80 b	**80.40 C**	84.00 a	84.35 a	**84.18 A**	**82.29**
Foreign CVs	81.58 ab	80.07 b	**80.82 B**	84.13 a	84.65 a	**84.39 A**	**82.61**
Ex Situ LDs	80.96 b	79.19 c	**80.07 C**	83.03 b	82.92 c	**82.98 C**	**81.52**
In Situ LDs	81.78 a	81.05 a	**81.41 A**	83.80 a	83.65 b	**83.72 B**	**82.57**
Mean	**81.33**	**80.03**	**80.68**	**83.74**	**83.89**	**83.82**	**82.25**

ns: non-significant, *: significant at 0.05 level.

The test weight or the weight per hectoliter (hl) reflects the density and the volume occupied by the grains (Taghouti et al., 2010). The results of our study for TW were in agreement with previous studies Migliorini et al. (2016), Ozturk et al. (2017) and Yildirim and Atasoy (2020) ranged between 71.20 kg/hl -79.46 kg/hl, 77.8 kg/hl - 85.9 kg/hl and 81.75 kg/hl - 85.71 kg/hl, respectively. The results were comparatively higher than Aydogan et al. (2010) which ranged between 74.37-74.95 kg/hl.

Figure 2. GPC, SC, WGC and TW values of durum wheat populations under rainfed and irrigated conditions during 2019-2020 and 2021-2022^{ns} growing seasons.

Previous breeding activities aimed at improving grain yield resulted in a decline in genetic variability for quality-related traits, likely due to the inverse relationship between yield and GPC (Subira et al., 2014). Landraces and old wheat cultivars demonstrate remarkable genetic variation, making a valuable resource for improving modern varieties. especially in terms of quality (Broccanello et al., 2023). The *ex situ* and *in situ* landraces used in our study exhibited higher protein and wet gluten content values compared to the standard cultivars in both years, overlapped with the literature. Supplemental irrigation had significant impacts on the quality characteristics examined in the study in both years (Figure 2). Overall GPC and

WGC means of the rainfed group had significantly values compared to irrigated group in both years according to t-test result. There was no significant difference between the rainfed and irrigated groups in terms of SC in both years according to t-test result. There was a significant difference between the means values of rainfed and irrigated groups in the first year of experiment but not in the second year. In addition to the difference between the treatments, there was also a significant statistical difference between the years (Table 3). GPC and WGC means yielded higher results in the first year of the experiment. The reason for this may be attributed to the irregular and less precipitation regime in the first year compared to the second year (Figure 1).

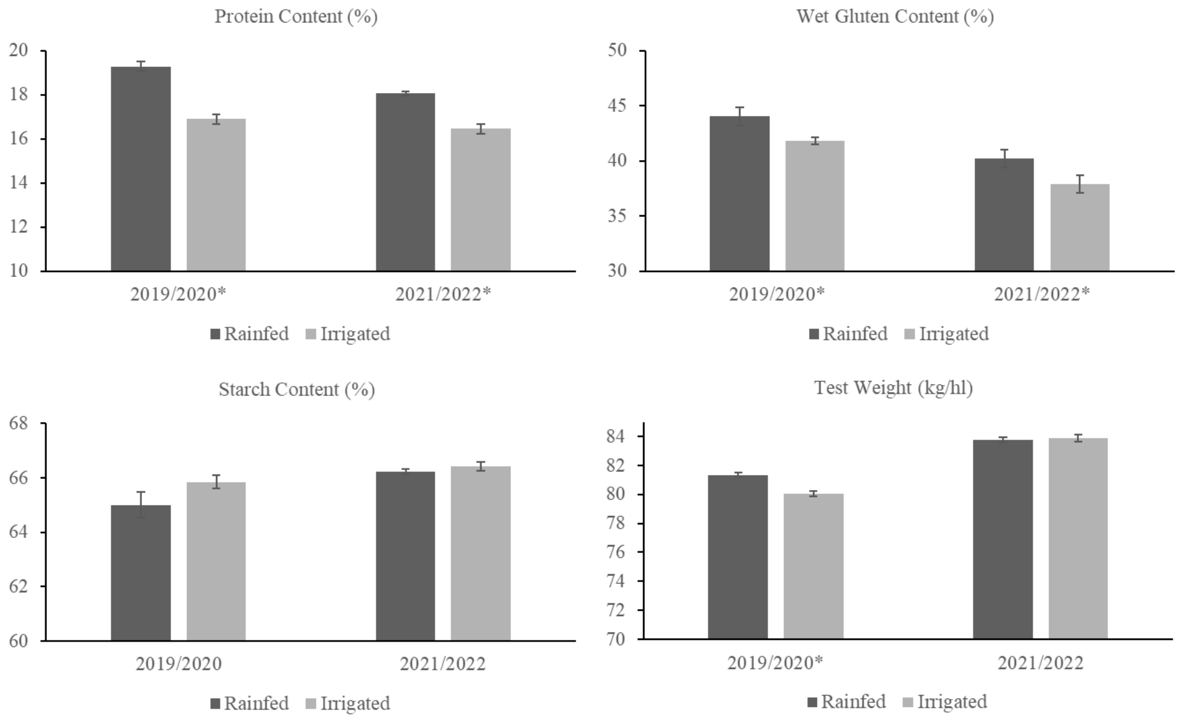


Figure 2. GPC, SC, WGC and TW values of durum wheat populations under rainfed and irrigated conditions during 2019-2020 and 2021-2022 growing seasons. * shows significant difference between rainfed and irrigated treatments at p ≤0,05 as determined by t-test.

Significant correlations were found between the characteristics examined in the study. A strong significant positive correlation (0.82) was observed between GPC - WGC as expected TW (Geisslitz et al., 2019). There was no significant correlation between GPC-TW. The correlation coefficients were -0.77 and -0.65 for SC-GPC and SC-WGC, respectively (Table 4). This finding was expected, as SC and GPC (based on a % of kernel weight) are inherently linked (El-Khayat et al., 2006).

CONCLUSIONS

Given the continuous advancement of people's living standards and the optimization of daily eating habits, there is an increasing demand for a diverse range of high-quality wheat cultivars and cultivation practices. To date, little effort has been made to quantify variations within these cultivars and landraces in terms of durum quality traits. The durum wheat germplasm varied in grain protein content, starch content, wet gluten content and test weight. All examined traits showed continuous distributions indicating that these traits are genetically complex and inherited as quantitative traits. The different rainfall patterns and supplemental irrigation applications differently affected durum wheat quality in both years. In 2019/2020, whole germplasm had significantly higher GPC and WGC values compared to 2021-2022. Among four populations, *ex situ* landraces had the highest GPC mean values (17.48%) under rainfed and irrigated conditions in 2019/2020. Since the GPC is a major decisive for durum wheat quality, our results showed that supplemental irrigation has a major impact on the quality of wheat grain, but this effect may be negative.

The availability of new genetic resources is crucial for breeding programs, as they possess the essential genetic variability required to advance the development of innovative varieties. Our results indicate that *ex situ* landraces have great potential in terms of grain quality characteristics. The high genotypic diversity and improved quality characteristics of landraces provide extensive insights for future studies to improve crop quality in areas with limited irrigation opportunities.

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