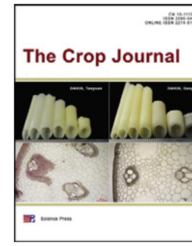
THE CROP JOURNAL 5 (2017) 533–540

Available online at www.sciencedirect.com

ScienceDirect



Genetic gains in wheat in Turkey: Winter wheat for dryland conditions☆

Mesut Keser[a,*], Nurberdy Gummadov[b], Beyhan Akin[b], Savas Belen[c], Zafer Mert[d], Seyfi Taner[e], Ali Topal[f], Selami Yazar[d], Alexey Morgounov[b], Ram Chandra Sharma[g], Fatih Ozdemir[e]

[a]International Center for Agricultural Research in the Dry Areas (ICARDA), Yenimahalle, Ankara 06170, Turkey
[b]International Maize and Wheat Improvement Center (CIMMYT), Yenimahalle, Ankara 06170, Turkey
[c]Transitional Zone Agricultural Research Institute, Tepebasi, Eskisehir 26005, Turkey
[d]Central Research Institute for Field Crops, Ankara 06170, Turkey
[e]Bahri Dagdas International Agricultural Research Institute, Konya 42050, Turkey
[f]Department of Field Crops, Faculty of Agriculture, Selcuk University, Konya 42030, Turkey
[g]International Center for Agricultural Research in the Dry Areas (ICARDA), Tashkent, Uzbekistan

ARTICLE INFO

Article history:
Received 23 February 2017
Received in revised form 9 April 2017
Accepted 18 April 2017
Available online 24 June 2017

Keywords:
Genetic gain
Rainfed wheat production
Winter wheat
Yield

ABSTRACT

Wheat breeders in Turkey have been developing new varieties since the 1920s, but few studies have evaluated the rates of genetic improvement. This study determined wheat genetic gains by evaluating 22 winter/facultative varieties released for rainfed conditions between 1931 and 2006. The study was conducted at three locations in Turkey during 2008–2012, with a total of 21 test sites. The experimental design was a randomized complete block with four replicates in 2008 and 2009 and three replicates in 2010–2012. Regression analysis was conducted to determine genetic progress over time. Mean yield across all 21 locations was 3.34 t ha^{-1}, but varied from 1.11 t ha^{-1} to 6.02 t ha^{-1} and was highly affected by moisture stress. Annual genetic gain was 0.50% compared to Ak-702, or 0.30% compared to the first modern landmark varieties. The genetic gains in drought-affected sites were 0.75% compared to Ak-702 and 0.66% compared to the landmark varieties. Modern varieties had both improved yield potential and tolerance to moisture stress. *Rht* genes and rye translocations were largely absent in the varieties studied. The number of spikes per unit area decreased by 10% over the study period, but grains spike^{-1} and 1000-kernel weight increased by 10%. There were no significant increases in harvest index, grain size, or spike fertility, and no significant decrease in quality over time. Future use of *Rht* genes and rye translocations in breeding programs may increase yield under rainfed conditions.

☆ Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.
* *Corresponding author.*
E-mail address: M.Keser@cgiar.org (M. Keser).

http://dx.doi.org/10.1016/j.cj.2017.04.004

1. Introduction

World demand for wheat is growing at approximately 2% per year [1]. While genetic gains in yield potential of irrigated wheat currently stand at < 1% progress in rainfed environments is even lower [2]. Worldwide, approximately 50% of the area under wheat cultivation is rainfed and periodically affected by drought [3]. These areas provide 50%–90% less wheat yield compared to irrigated conditions. During the 21st century, climate change is likely to increase both the intensity and frequency of droughts [4]. The area planted to wheat in Turkey has declined from 9.5 million hectares (Mha) at the beginning of the 1990s to 7.8 Mha in 2011–2015, but grain yield increased from 2 t ha^{-1} to 2.7 t ha^{-1} during the same period [5]. The highest production was 22 million tons in 2013 while severe droughts during 2007 resulted in production of just 17.2 million metric tons. Eighty percent of the wheat produced in Turkey is cultivated under dry rainfed conditions, primarily in the Central Anatolia and Transitional regions [6]. Thus, in these regions, the most important factors affecting yield are precipitation and its distribution within the wheat cultivation period.

In recent years, there has been a rapid increase in the number of varieties released in Turkey and there are now 201 officially listed bread wheat varieties [7]. Worldwide, fewer experiments have evaluated wheat genetic gains in dryland areas, compared to optimal environments. In a trial conducted in Iran, 81 wheat cultivars released from 1930 to 2006 were examined under irrigated and terminal drought stress conditions at Karaj during 2008–2009 [8]. Grain yields improved by 31 and 20 kg ha^{-1} per year under irrigated and drought stress conditions, respectively. Compared to old cultivars, modern cultivars incurred less yield loss under drought stress. Across all environments, significant genetic changes over time were found for harvest index, grain number m^{-2}, and spike dry weight at anthesis. No changes were observed for above-ground dry matter and 1000-kernel weight. Battenfield et al. [9] studied 30 cultivars comprising two tall cultivars (Kharkof, released in 1919, and Triumph 64, released in 1964) and 28 semi-dwarf cultivars released in the USA during 1971–2008. Cultivars were tested in 2010 and 2011 at 11 rainfed locations in Oklahoma, Kansas, and Texas. Compared to Kharkof, a significant annual yield increase of 14.6 kg ha^{-1} or 0.93% was obtained across all locations (including tall cultivars), although this was reduced to 11.03 kg or 0.40% per year when only semi-dwarf cultivars (released 1971–2008) were considered.

A study conducted in the Brazilian savanna focused on quantifying the genetic progress of dryland wheat released between 1976 and 2005 [10]. Mean estimated genetic progress for grain yield was 37 kg ha^{-1} per year. In another study, eight dryland winter wheat cultivars widely cultivated from 1940 to 2010 in Shaanxi province of China were grown in plots that could be sheltered from rain [11]. Plant height decreased from 140.7 cm to 79.5 cm from the earliest to the most recent cultivar. Yield increased significantly with an annual genetic gain of 0.48% and was consistently and positively associated with increased grain weight and harvest index. Afridi and Khalil [12] evaluated 15 landmark wheat cultivars (registered from 1965 to 2000) under irrigated and rainfed environments in Peshawar, Pakistan, during 2004–2005. Grain yield increased by 48.5 kg ha^{-1} $year^{-1}$ in irrigated environments and 31.28 kg ha^{-1} $year^{-1}$ under rainfed conditions.

A limited number of studies have been conducted on wheat genetic progress in Turkey. During 1992–1996, Avçin et al. [13] studied 14 bread wheat varieties developed during 1933–1991 under Central Anatolian conditions and calculated annual genetic gains of 16.1 kg ha^{-1}. The same researchers documented genetic gains of 10.3 kg ha^{-1} $year^{-1}$ for durum wheat in the region [14]. In another study, 16 cultivars released in Turkey after 1976 were evaluated in the Çukurova region under two nitrogen application levels during 2003–2004 to evaluate yield progress and changes in associated traits [15]. Average genetic gain was 0.64% $year^{-1}$ and was associated with increased harvest index, reduced plant height, and higher grain number. In Konya, Turkey, researchers found no difference in spike number m^{-2} between old and new varieties, but grain number and grain weight per spike in varieties Karahan-99, Demir-2000, and Bağcı-2002 were higher than older germplasm [16]. Another study estimated genetic gain for yield and other traits in winter wheat released in Turkey during 1963–2004 for irrigated environments [6]. Fourteen varieties grown in 16 environments were evaluated from 2008 to 2012 in Konya, Eskişehir, Ankara, and Edirne. The highest yields were obtained from the recent varieties Kinaci-97 (5.48 t ha^{-1}) and Ekiz-2004 (5.42 t ha^{-1}), compared to the old varieties Yektay-406 (4.17 t ha^{-1}) and Bezostaya-1 (4.27 t ha^{-1}). Over a period of 20 years, grain yield increased by 58 kg ha^{-1} $year^{-1}$ (1.37%). This gain was mainly achieved by reducing plant height and increasing harvest index. There was no clear tendency of changes in specific yield components, indicating that new high-yielding varieties reach their yield potential by different avenues.

Periodic evaluation of genetic improvement of crop cultivars is useful, both as a demonstration of the importance of plant breeding to the public and as a way of identifying traits or target environments that may warrant increased efforts by breeders [17]. Evaluating cultivars from different eras in a common environment is the most direct method to estimate breeding progress. This study aimed to document the genetic gains in grain yield and associated changes in agronomic traits in rainfed winter wheat in Turkey to assist development of future breeding strategies.

2. Materials and methods

This study was conducted at the Agricultural Research Institutes of three Turkish provinces (Ankara, Konya, and Eskisehir) over five seasons (2008 to 2012, inclusive), using 22 registered winter bread wheat varieties developed for rainfed conditions (Table 1). Genotypes were classified into five groups according to the year of release:

1) One landrace variety (Ak-702) widely cultivated prior to modern breeding.
2) Three landmark varieties (Kirac-66, Bezostaya-1 from Russia, and Gerek-79) that became popular during the 1970s and were to some degree "Green Revolution" winter wheat varieties with significantly higher yield potential. The area sown to these varieties has declined substantially

Table 1 – Historical set of rainfed winter wheat varieties included in the study of genetic gains during 2008–2012.

No.	Variety	Year of release	Pedigree	Institution [a]	Growth habit [b]
1	Ak-702	1931	Landrace selection	TZARI	F
2	Kiraç-66	1966	Floransa/Yayla-305	TZARI	F
3	Bezostaya-1	1968	Lutescens-17/Skorospelka-2	MRS	W
4	Gerek-79	1979	Mentana/Mayo-48//4-11/3/Yayla-305	TZARI	F
5	Gun-91	1991	F-35-70/Mochis-73	CRIFC	F
6	Kutluk-94	1994	Krasnodarskaya//Inia-66/Lilifen/3/Calibasan	TZARI	F
7	Dagdas-94	1994	Ankara-093-44/Avrora//Sihhe	BDIARI	W
8	Ikizce-96	1996	Arthur*2/Siete-Cerros-66//Brill	CRIFC	W
9	Suzen-97	1997	C-126-15/Collafen/3/Norin-10-Brevor/P-14//P-101/4/Kirac-66	TZARI	F
10	Karahan-99	1999	C-126-15/Collafen/3/Norin-10-Brevor/P-14//P101/4/Kirac-66	BDIARI	F
11	Yakar-99	1999	Es-14/5/63-122/4/66-2/Noroeste-66/3/Lovrin-21//Kavkaz/Hyslop	CRIFC	W
12	Harmankaya-99	1999	Fundulea-29/2*Lovrin-32	TZARI	W
13	Demir-2000	2000	21031/Co-6552142//Mara/Scout/3/Pai-Yu-Pao	CRIFC	F
14	Bayraktar-2000	2000	Chisholm/Gerek-79	CRIFC	W
15	Altay-2000	2000	Es-14//Yektay/Blueboy-2	TZARI	W
16	Izgi-2001	2001	Ca-8055/Kutluk-94	TZARI	F
17	Sonmez-2001	2001	Bezostaya-1*2/Tevere/3/Kremena/Lovrin-29/4/Katya-1	TZARI	F
18	Atli2002	2002	Hyslop/Siete-Cerros-66//Sadovo-1	CRIFC	W
19	Zencirci-2002	2002	Sdt/Kirac-66	CRIFC	W
20	Tosunbey	2004	Ecvd-12/Kirac-66//Crow	CRIFC	F
21	Seval	2004	Bolal-2973/No64/3/Arthur*2/Siete-Cerros-66//Bolal-2973	CRIFC	W
22	Mufitbey	2006	Nongda-146/4/Yamhill/Tobari-66//McDermid/3/Lira/5/F-130-L-1-12	TZARI	W

[a] BDIARI, Bahri Dağdaş International Agricultural Research Institute, Konya; CRIFC, Central Research Institute for Field Crops, Ankara; MRS, Maize Research Station, Adapazari; TZARI, Transitional Zone Agricultural Research Institute, Eskisehir.
[b] W, winter; F, facultative.

but both Bezostaya-1 and Gerek-79 can still be found in production.

3) No varieties were released in Turkey during the 1980s, thus group 3 comprises five varieties (Gun-91, Kutluk-94, Dagdas-94, Ikizce-96, Suzen-97) released during 1991–1997. These derive from winter × spring crosses using local, Eastern European, USA, and Mexican parents.
4) Ten varieties (Karahan-99, Yakar-99, Harmankaya-99, Demir-2000, Bayraktar-2000, Altay-2000, Izgi-2001, Sonmez-2001, Atli-2002, Zencirci-2002) released during 1999–2002, based on diverse winter × winter crosses.
5) Three varieties representing recent germplasm: Seval, Tosunbey, and Mufitbey.

Of the varieties released since 1990 (groups 3–5), nine genotypes originated from the Central Research Institute for Field Crops (Ankara), seven from the Transitional Zone Agricultural Research Institute (Eskisehir), and two from the Bahri Dagdas International Agricultural Research Institute (Konya).

Trials were designed using a randomized complete block with four replications in 2008 and 2009 and three replications in 2010–2012 (Table 2). Plots were planted in six rows measuring 7.0 m × 1.2 m. There was 20 cm distance between rows and 550 seeds m^{-2} were planted with a plot seeder. Plots were fertilized with 40 kg ha^{-1} nitrogen and 70 kg ha^{-1} phosphorus at planting, and 40 kg ha^{-1} nitrogen (ammonium nitrate) was applied at tillering. Weeds were controlled by applying herbicide (1500 mL ha^{-1} 2–4 D) before stem elongation. Plots were harvested using a combine harvester, with a 1 m edge left at both ends of the plot (harvested area = 5.0 m × 1.2 m). Genotypes remaining at the tillering stage when those with the spring habit had headed were classified as winter types (Table 1).

Data were recorded for grain yield, plant height, days to heading, biomass, harvest index, spikes m^{-1}, grains $spike^{-1}$, 1000-kernel weight, test weight, protein content, dry gluten content, and SDS sedimentation, and yield components were determined based on data from ten spikes. Data were processed by variance analysis using the "JMP" statistics package and significance was confirmed using an LSD test. Regression analysis was conducted to determine genetic progress over time, using years as the independent variable (x) and productivity traits as dependent variables (y). Average yield, regression coefficient (b), and total of squares of deviation from the regression were used to determine the stability of the old and new varieties. Correlations between grain yield and other traits were also calculated. Molecular marker data for the 1B.1R and 1A.1R translocations, *Rht-B1*, *Lr*, and *Yr* genes were provided by the CIMMYT Biotechnology group in Mexico.

Ankara, Konya, and Eskişehir provinces are located in the Central Anatolia Plateau; the research sites of this study are described in further detail in [6]. This region generally experiences hot summers (average temperature in July is 22 °C) and cold winters (average temperature in January is –0.7 °C) with average annual temperatures of 10.8 °C. There was not much difference in spring season temperature variation from the long-term data in the three locations during the study period. Precipitation during the wheat season (autumn-spring) at all three sites was higher than the long-term average in 2009 and 2011, and lower than the long-term average in 2008, 2010 (except Konya), and 2012 (Table 2).

Table 2 – Description of environments and average grain yield for all varieties tested during 2008–2012.

Year	Location	Environment	Replications	Number of irrigations	Precipitation fall-winter-spring (mm) [a]	Average air temperature in spring (°C)	Yield (t ha^{-1})	ANOVA F-value
2008	Konya	Rainfed	4	–	278	14.1	4.06	2.02^{*}
	Eskisehir	Rainfed	4	–	271	10.6	3.09	11.56^{**}
	Ankara	Rainfed	4	–	257	10.6	1.11	8.29^{**}
2009	Konya	Rainfed	4	–	386	11.2	4.64	1.76^{*}
	Eskisehir	Rainfed	4	–	354	8.6	4.56	3.77^{**}
	Ankara	Rainfed	4	–	327	8.2	2.67	9.64^{**}
2010	Konya	Irrigated	3	2	310	13.7	4.31	5.16^{**}
		Irrigated	3	1	310	13.7	3.55	1.72^{+}
		Rainfed	3	–	310	13.7	1.07	4.34^{**}
	Eskisehir	Irrigated	3	2	267	10.1	3.90	5.90^{**}
		Rainfed	3	–	267	10.1	1.20	2.19^{*}
	Ankara	Rainfed	3	–	263	10.2	3.11	1.75^{*}
2011	Konya	Rainfed	3	–	429	10.7	3.38	7.58^{**}
	Eskisehir	Irrigated	3	2	426	8.8	4.60	2.29^{*}
		Rainfed	3	–	426	8.8	3.04	6.77^{**}
	Ankara	Rainfed	3	–	354	7.6	3.91	6.65^{**}
2012	Konya	Irrigated	2	1	286	12.0	2.86	1.94^{*}
		Rainfed	2	–	286	12.0	1.49	7.44^{**}
	Eskisehir	Irrigated	3	2	366	9.3	4.39	1.58^{+}
		Rainfed	3	–	366	9.3	3.41	1.99^{*}
	Ankara	Rainfed	3	–	279	9.2	6.06	1.81^{*}

$^{+}$,*, and ** significant at P = 0.10, 0.05, and 0.01, respectively.
[a] Long-term precipitation: Konya, 288 mm; Eskisehir, 298 mm; Ankara, 299 mm. Long-term air temperature in spring: Konya, 11.7 °C; Eskisehir, 9.6 °C; Ankara, 9.7 °C.

3. Results

Environmental conditions and agronomic practices across different sites and years resulted in high grain yield variation. Moisture stress caused low yields of <1.5 t ha^{-1} in Ankara (2008), Konya (2010 and 2012), and Eskisehir (2010). The highest yield exceeded 6 t ha^{-1} in Ankara (2012). No diseases affecting grain yield were observed in any of the trials. Lodging was recorded only in Konya in 2010 and 2011. Overall, the 21 environments used in the study enabled very good and detailed evaluation of the germplasm. ANOVA across all environments (Table 3) demonstrated high significance of all major factors and their interactions. ANOVA for individual trials showed that yield differences between the varieties were significant at $P < 0.05$ for 19 trials; for the remaining two trials (Konya-2010 and Eskisehir-2012) the significance was $P < 0.10$ (Table 1). Data from all 21 trials were used for multi-locational analysis.

Table 3 – Results of an ANOVA for the grain yield of a historical set of wheat varieties across three locations during 2008–2012.

Source of variation	*df*	Mean square	*F* probability
Years	4	103,627,216	<0.001
Locations	5	62,123,967	<0.001
Year × location	11	147,624,523	<0.001
Replication (year location)	46	2,054,830	
Genotype	21	5,764,621	<0.001
Genotype × year	84	1,219,594	<0.001
Genotype × location	105	772,755	<0.001
Genotype × year × location	231	652,856	<0.001
Error	930	331,545	

Table 4 presents grain yield and other agronomic traits for the varieties included in the study. Compared to the landrace variety Ak-702, the modern varieties showed clear genetic superiority. Even the landmark varieties of the 1970s (group 2; Kirac-66, Bezostaya-1, and Gerek-79) exceeded Ak-702 by 24.1% (3.14 t ha^{-1} versus 2.53 t ha^{-1}) when considering yield across all sites. The increase was 14.0% at lower yielding sites below 2 t ha^{-1} (1.06 t ha^{-1} versus 0.93 t ha^{-1}). The annual genetic gain of the varieties developed in 2004–2006 (group 5) compared to Ak-702 was obvious across all environments. For low-yielding sites, gains were 6.1 kg ha^{-1} $year^{-1}$ (0.66%), compared to 18.0 kg ha^{-1} $year^{-1}$ (0.49%) for high yielding sites and 12.5 kg ha^{-1} $year^{-1}$ (0.50%) averaged across all sites.

This study was primarily concerned with the genetic gains achieved by the breeding programs compared to the group 2 landmark varieties (Kirac-66, Bezostaya-1, and Gerek-79). These varieties (especially Bezostaya-1 and Gerek-79) had a large impact on wheat production in Turkey during the 1970s and 1980s and are still cultivated on limited areas. The yield of group 3 varieties (released during 1991–1997) across all sites, exceeded the landmark group by 2.2% (3.21 t ha^{-1} vs. 3.14 t ha^{-1}); group 4 yields (3.52 t ha^{-1}) exceeded the landmarks by 12.1%, and group 5 yields (3.46 t ha^{-1}) were 10.2% higher than the landmark group 2. At the four drought-affected sites with yields <2 t ha^{-1}, the yield gains for groups 3, 4, and 5 compared to group 2 were –2.8%, 25.5%, and 30.2%, respectively. At the six high-yielding sites, yield gains compared to group 2 were 3.5%, 12.2%, and 15.0% for groups 3, 4, and 5, respectively.

Over the 40 years of breeding evaluated in this study, yearly genetic gain compared to landmark varieties was 0.30% across all 21 sites; 0.75% based on data for drought environments and 0.38% for high-yielding sites. The respective coefficients of

Table 4 – Grain yield, agronomic and grain quality data of varieties used in this study.

Variety	Release year	Yield at all sites (t ha^{-1})	Yield at sites <2.0 t ha^{-1}	Yield at sites >4.0 t ha^{-1}	Days to heading #	Height # (cm)	Biomass #	Harvest index #	Spikes m^{-1} #	Grains $spike^{-1}$ #	1000-kernel weight (g)*	Protein # (%)	SDS sedimentation # (mL)
		Number of locations at which the trait was recorded											
		21	4	6	12	16	6	6	6	6	6	6	6
Ak-702	**1931**	**2.53**	**0.93**	**3.66**	**146**	**95**	**1014**	**0.28**	**595**	**30.3**	**29.0**	**12.2**	**10.6**
Kıraç-66	1966	2.91	0.90	3.97	143	100	978	0.28	621	27.9	30.1	12.5	13.0
Bezostaya-1	1968	3.17	1.00	4.64	143	92	993	0.29	452	33.2	36.2	12.6	14.0
Gerek-79	1979	3.33	1.29	4.42	140	91	1085	0.31	698	26.8	30.5	11.8	12.6
Average, 66–79		**3.14**	**1.06**	**4.34**	**142**	**94**	**1019**	**0.29**	**590**	**29.3**	**32.3**	**12.3**	**13.2**
Gun-91	1991	3.17	0.72	4.57	143	89	1027	0.29	472	34.5	33.3	12.4	13.9
Kutluk-94	1994	3.26	0.96	4.40	145	99	1111	0.29	550	28.3	36.8	12.5	13.3
Dagdas-94	1994	3.27	1.10	4.73	145	104	1083	0.29	526	35.8	37.0	11.8	10.5
İkizce-96	1996	2.92	1.20	4.16	140	88	848	0.25	573	28.5	31.0	12.5	14.1
Suzen-97	1997	3.41	1.18	4.59	141	95	1065	0.30	529	33.7	34.2	11.8	12.5
Average, 91–97		**3.21**	**1.03**	**4.49**	**143**	**95**	**1027**	**0.28**	**530**	**32.2**	**34.5**	**12.2**	**12.9**
Karahan-99	1999	3.65	1.73	4.72	141	95	1057	0.31	591	29.5	34.3	12.2	13.6
Yakar-99	1999	3.19	0.85	4.93	141	85	1032	0.29	496	33.9	32.0	12.1	13.5
Harmankaya-99	1999	3.79	1.33	5.01	142	75	889	0.35	446	41.3	35.4	12.2	12.7
Demir-2000	2000	3.49	1.15	4.72	144	101	953	0.28	460	35.1	36.3	12.3	13.5
Bayraktar-2000	2000	3.59	1.75	4.93	135	89	994	0.30	626	27.5	35.5	11.5	11.6
Altay-2000	2000	3.57	1.02	5.01	143	93	1042	0.29	489	36.8	35.0	11.8	12.4
İzgi-2001	2001	3.61	1.54	4.72	138	85	1078	0.32	634	32.7	34.0	12.1	13.8
Sönmez-2001	2001	3.68	1.48	4.93	140	91	1031	0.33	460	36.5	35.6	11.8	13.1
Atlı-2002	2002	3.22	1.09	5.01	145	97	1110	0.30	522	30.2	38.3	12.1	12.4
Zencirci-2002	2002	3.36	1.40	4.72	140	96	1077	0.30	558	31.0	38.0	11.5	13.2
Average, 99-02		**3.52**	**1.33**	**4.87**	**141**	**91**	**1026**	**0.31**	**528**	**33.4**	**35.4**	**12.0**	**13.0**
Tosunbey	2004	3.58	1.33	4.93	139	82	1006	0.34	484	35.0	33.7	11.6	12.8
Seval	2004	3.60	1.73	5.01	139	82	978	0.34	590	31.7	31.7	12.1	12.5
Mufitbey	2006	3.47	1.08	5.02	145	95	1100	0.28	540	32.5	36.2	12.0	11.0
Average, 04–06		**3.46**	**1.38**	**4.99**	**141**	**90**	**1028**	**0.31**	**537**	**32.3**	**35.6**	**11.9**	**12.5**
$LSD_{0.05}$ for genotypes		**0.24**	**0.33**	**0.48**	**3**	**3**	**108**	**0.02**	**44**	**2.4**	**0.94**	**0.4**	**0. 6**

Mean data over years and locations.

determination of grain yield on years of release were 0.36 ($P < 0.01$) for all sites; 0.17 ($P < 0.10$) for low-yielding sites <2 t ha^{-1}, and 0.42 ($P < 0.01$) for high-yielding sites >4 t ha^{-1} (Fig. 1). All three groups demonstrate steep yield increases and gains achieved since 1990. The highest yielding varieties across all sites were Harmankaya (3.79 t ha^{-1}, released in 1999), Sonmez (3.68 t ha^{-1}, 2001), and Karahan (3.65 t ha^{-1}, 1999). At drought sites, the highest yielding varieties were Bayraktar (1.75 t ha^{-1}, 2000), Karahan (1.73 t ha^{-1}, 1999), and Seval (1.73 t ha^{-1}, 2004). The most recently-released varieties, Seval, 2004 and Mufitbey, 2006 were among the highest yielding under favorable conditions. Bi-plot analysis of multi-locational data (Fig. 2) demonstrates the superiority of Sonmez-2001, Karahan-99, Izgi-2001, Bayraktar-2000, Harmankaya-99, and Seval. These cultivars combine higher yield and better yield stability across the environments tested.

Varieties developed at the Ankara and Eskisehir institutes are comparable in terms of average yield and yield at high-yielding sites. At low-yielding sites, varieties developed at Ankara produced 6.5% higher yields (1.31 t ha^{-1} vs. 1.23 t ha^{-1}). The only other notable difference between varieties developed at the two institutes was grains spike^{-1}, which was 9.3% higher for varieties developed at Eskisehir. These institutes are therefore able to provide farmers with a choice of superior varieties.

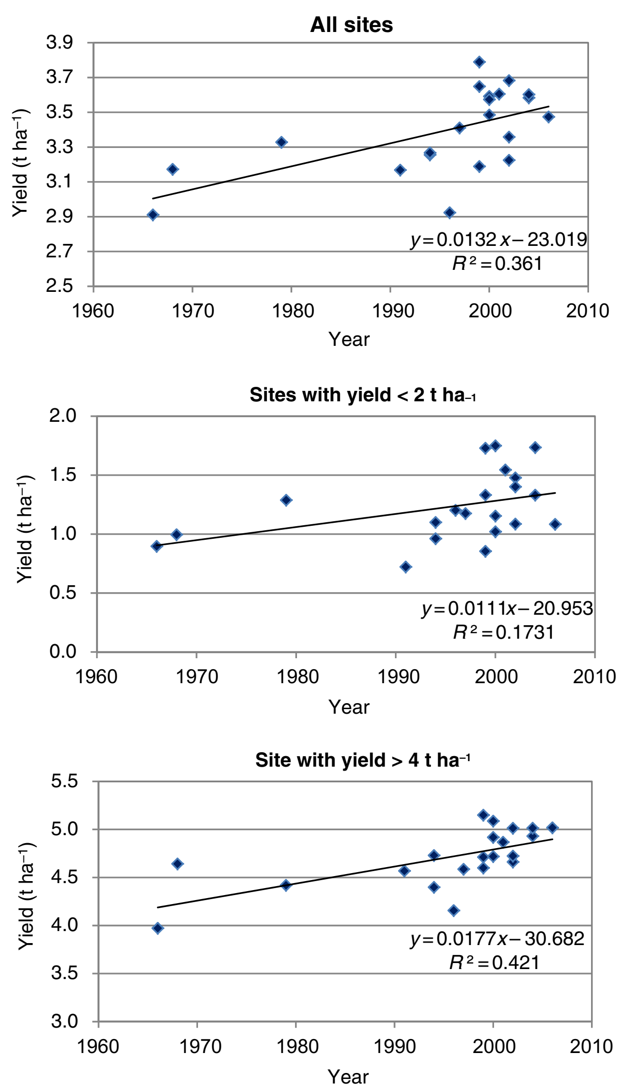


Fig. 1 – Yield gains in a historical set of rainfed wheat varieties developed during 1966–2006.

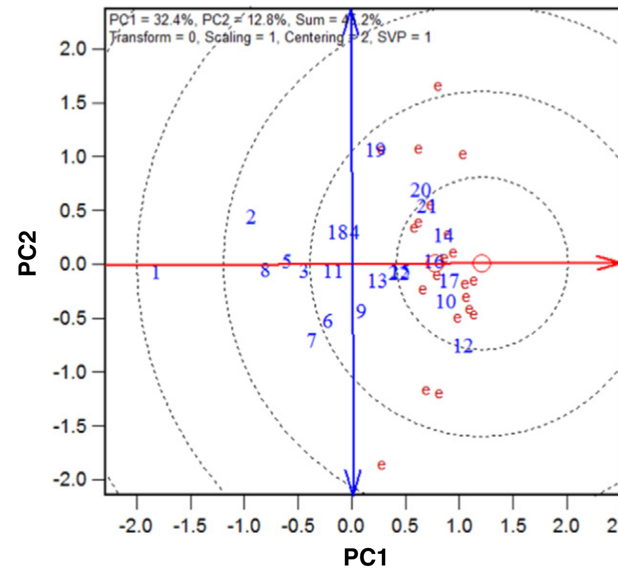


Fig. 2 – Bi-plot analysis of grain yield of a historical set of 22 varieties across 21 environments in Turkey during 2008–2012. Numbers refer to varieties listed in Table 1.

Rates of plant development (indicated by days to heading) did not change over time. Early-maturing cultivar (Bayraktar, released in 2000) reached heading 5–6 days before others, but there was generally no change over the last 40 years of breeding. The frequency of winter or facultative growth habit genotypes did not change over time (Table 1). On average, plant height decreased by 4–5 cm, but only cultivar (Demir-2000) possessed *Rht1* and none had *Rht2*.

Yield components were recorded at all three experimental sites during 2008 and 2009. No substantial increase over time was observed for biomass per unit area. Harvest index was generally low (around 0.3) and underwent a very small increase over time, as determined by comparing the average harvest index for each group. Number of spikes per unit area decreased by an average 10% in all varieties released after 1990, compared to the landmark group. During the same period, grains spike^{-1} and grain size both increased by around 10%, thus spike productivity appears to be a key factor in increasing grain yield over time. Bezostaya-1 is favored by millers and bakers in Turkey for its superior bread-making quality whereas modern varieties have slightly lower protein contents and SDS sedimentation values.

The contribution of plant height and yield components to grain yield were evaluated during 2008 and 2009 using coefficients of correlation (Table 5). A significant positive correlation between plant height and yield was observed only under severe drought in Ankara in 2011. Among the yield components, only harvest index demonstrated a positive significant correlation with grain yield in five of six environments. The two important contributors to yield genetic gain (grains spike^{-1} and 1000-kernel weight) were significantly

Table 5 – Coefficients of correlation between grain yield and key agronomic traits.

Year	Location	Yield (t ha^{-1})	Coefficient of correlation between grain yield and key agronomic traits					
			Height	Biomass	Harvest index	Spikes m^{-1}	Grains spike^{-1}	1000-kernel weight
2008	Konya	4.06	0.01	0.37^{+}	0.62**	0.08	0.34	0.22
2008	Eskisehir	3.09	0.25	0.49*	0.60**	0.45*	−0.34	0.10
2008	Ankara	1.11	0.42*	0.42*	0.78**	0.07	0.34	0.43*
2009	Konya	4.64	−0.24	0.39^{+}	0.01	−0.05	0.06	0.39^{+}
2009	Eskisehir	4.56	−0.14	0.27	0.56**	−0.42*	0.47*	0.65**
2009	Ankara	2.67	−0.35	0.50*	0.79**	0.46*	0.17	0.25

$^{+}$, *, and ** significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

correlated with yield only in one and two environments, respectively. However, as data was available only from six of 21 sites the analysis was limited and might not represent all environmental scenarios.

4. Discussion

This study evaluated 22 Turkish rainfed winter wheat varieties across 21 environments and builds on the previous study of genetic gains in irrigated wheat in Turkey [6]. Gummadov et al. [6] concluded that genetic gains of 1.37% year^{-1} for irrigated wheat over the last 20 years were achieved through introduction of semi-dwarf genes *Rht1* and *Rht2*, with a stable biomass but increased harvest index. Annual genetic gains in rainfed varieties were more modest at 0.50% compared to the landrace selection Ak-702 (released in 1931), or 0.30% compared to the first modern landmark varieties released in the 1970s (Kirac-66, Bezostaya-1, and Gerek-79). However, the genetic gains at four drought-affected sites (<2 t ha^{-1}) were higher in relative terms: 0.75% compared to Ak-702 and 0.66% compared to the landmark varieties. Modern varieties had both improved yield potential and tolerance to moisture stress, resulting in overall higher and stable grain yield. Estimation of the genetic gains in this study was consistent with previous work on this subject in Turkey [16].

The rainfed winter wheat varieties used in this study do not represent semi-dwarf germplasm typical of Green Revolution spring wheat; they do not possess the *Rht1* and *Rht2* genes and there was no substantial reduction in plant height, which conforms with the findings of other studies on *Rht* genes [18] and 1B.1R (or 1A.1R) [19]. Most of the varieties have a height range of 85–95 cm, which is probably optimal for Turkish dryland conditions and controlled by other *Rht* genes. It seems that the development of rainfed wheat germplasm in Turkey followed a more conservative approach and achieved reasonable genetic gains without conversion to semi-dwarf stature and without using rye translocations, typical of CIMMYT semi-arid spring wheat germplasm and varieties from drought-prone areas (India, Pakistan, USA). The semi-dwarf genes (*Rht1* and *Rht2*) and 1B.1R (or 1A.1R) translocation play fundamental roles in wheat adaptation and affect a number of traits including grain yield and its components, and disease resistance [17]. Although parents possessing these genes were relatively widely used in the crosses, selection pressure for good bread-making quality and taller types in dry conditions might have contributed to the absence of these genes. One of the reasons why dwarfing genes and rye translocations have not been found in Turkish rainfed winter wheat cultivars was the breeding methodology and locations used to test advanced lines. Turkish wheat breeding has historically used modified bulk selection in segregating populations, and this may have favored selection of taller types. Regional trials are primarily conducted in yield-limiting environments, which may also have hindered selection of dwarf types. Another consideration is that straw is a valuable animal fodder, especially for small ruminants. Thus farmers tend to favor taller types for the straw, a feature that may affect breeders' decisions during selection.

Trethowan et al. [20] demonstrated that tall isolines have longer coleoptiles. Compared to tall lines genotypes with *Rht1* or *Rht2* alleles have poor seedling emergence in dryland plantings that may result in yield penalties. In order to overcome this problem some breeders have replaced these dwarfing genes with other reduced height genes such as *Rht8* in order to increase coleoptile length and enable deeper planting [21,22]. The genotypes with *Rht* genes in Turkish wheat breeding system may have been inferior to tall types in yield due to poor emergence and subsequent crop establishment. A number of wheat breeding programs maintain semi-tall or tall varieties targeted for drought conditions and still make substantial genetic gains in yield [23]. In the case of Turkish rainfed winter wheat germplasm, it would be worthwhile to investigate optimal plant height and the effects of different *Rht* genes for variable degrees of moisture stress.

Our analysis of yield components demonstrated a gradual decrease of 10% in the number of spikes per unit area, as well as 10% increases in grains spike^{-1} and 1000-kernel weight. Spike size and productivity also tended to be higher in groups 4 and 5 germplasm. However, as with the Gummadov et al. [6] study of irrigated wheat, we also observed substantial diversity in the capacity of individual varieties to increase yield by different means. Some varieties had lower biomass but higher harvest index and larger grains, while others had average grain size but highly fertile spikes. It also illustrates the opportunities for crossing programs targeted to combine optimal traits. Gummadov et al. [6] found a slight deterioration of grain quality associated with breeding progress in yield. In rainfed wheat we found less deterioration compared to the superior grain quality check Bezostaya-1, with varieties such as Demir-2000 and Izgi-2001 almost matching Bezostaya-1 in protein content and sedimentation value.

The breeding strategy for sustaining and enhancing genetic gains for dryland winter wheat in Turkey should consider the following: a) possible utilization of semi-dwarf genes and rye translocations to enhance drought tolerance and yield responses to optimal environments, provided that coleoptile length is not reduced; b) multi-location testing involving the institutes at Ankara, Eskisehir, and Konya would provide an excellent basis for further progress, including new field phenotyping approaches and utilization of physiological tools; c) as yields increase, more attention should be paid to grain quality to meet the requirements of the milling and baking industries; d) more diverse sources of germplasm could be utilized in the crossing program, including wheat landraces recently collected in Turkey [24] and winter synthetics with proven resistance to moisture stress (Morgounov, unpublished); e) utilization of single seed descent or doubled haploid technology to speed up the breeding process and contribute to more rapid genetic gains; f) the current modified bulk breeding methodology should be switched for another methodology, such as selected bulks, to enable semi-dwarf genotypes to demonstrate yield potential.

Acknowledgments

The International Winter Wheat Improvement Program is supported by CRP WHEAT and the Turkish Ministry of Food, Agriculture, and Livestock. Molecular markers were identified by Dr. Susanne Dreisigacker at CIMMYT, Mexico. The authors highly appreciate suggestions and technical editorial assistance from Emma Quilligan.

REFERENCES

[1] N. Alexandratos, J. Bruinsma, World agriculture towards 2030/2050: the 2012 revision, ESA Working Paper No.12-03, FAO, Rome, Italy, 2012.
[2] B. Skovmand, M.P. Reynolds, I.H. DeLacy, Searching genetic resources for physiological traits with potential for increasing yield, in: M.P. Reynolds, J.I. Ortiz-Monasterio, A. McNab (Eds.), Application of Physiology in Wheat Breeding, CIMMYT, Mexico, D.F., Mexico 2001, pp. 17–28.
[3] A.A. Abd El-Mohsen, M.A. Abd El-Shafi, E.M.S. Gheith, H.S. Suleiman, Using different statistical procedures for evaluating drought tolerance indices of bread wheat genotypes, Adv. Agric. Biol. 4 (2015) 19–30.
[4] T.G. Reeves, G. Thomas, G. Ramsay, Save and Grow in Practice: Maize, Rice, Wheat, FAO, Rome, Italy, 2016.
[5] FAOSTAT, http://faostat.fao.org.
[6] N. Gummadov, M. Keser, B. Akin, M. Cakmak, Z. Mert, S. Taner, I. Ozturk, A. Topal, S. Yazar, A. Morgounov, Genetic gains in wheat in Turkey: winter wheat for irrigated conditions, Crop J. 3 (2015) 507–516.
[7] http://www.tarim.gov.tr/BUGEM/TTSM.
[8] M. Joudi, A. Ahmadi, V. Mohammadi, A. Abbasi, H. Mohammadi, Genetic changes in agronomic and phenologic traits of Iranian wheat cultivars grown in different environmental conditions, Euphytica 196 (2014) 237–249.
[9] S.D. Battenfield, A.R. Klatt, W.R. Raun, Genetic yield potential improvement of semidwarf winter wheat in the Great Plains, Crop Sci. 53 (2013) 946–955.
[10] A. Cargnin, M.A. Souza, V. Fronza, C.M. Fogaça, Genetic and environmental contributions to increased wheat yield in Minas Gerais, Brazil, Sci. Agric. 66 (2009) 317–322.
[11] Y.Y. Sun, X.L. Wang, N. Wang, Y.L. Chen, S.Q. Zhang, Changes in the yield and associated photosynthetic traits of dry-land winter wheat (*Triticum aestivum* L.) from the 1940s to the 2010s in Shaanxi Province of China, Field Crops Res 167 (2014) 1–10.
[12] N. Afridi, I.H. Khalil, Genetic improvement in yield related traits of wheat under irrigated and rainfed environments, Sarhad J. Agric. 23 (2007) 965–972.
[13] A. Avcin, M. Avci, O. Donmez, Genetic gains in yields of bread wheat (*Triticum aestivum* L.) cultivars under Central Anatolian conditions, J. Field Crops Cent. Res. Inst. 6 (1) (1997) 1–13 (in Turkish).
[14] A. Avcin, M. Avci, O. Donmez, Genetic gains in yields of durum wheat (*Triticum durum* L.) cultivars under Central Anatolian conditions, J Field Crops Cent. Res. Inst. 6 (2) (1997) 1–12 (in Turkish).
[15] A. Kuşcu, Grain Yield Progress and Associated Physiological and Agronomical Traits in Spring Wheat (*Triticum aestivum* L.) in Cukurova during the Last Quarter of the 20th Century[PhD Dissertation] University of Çukurova, Adana, Turkey, 2006 [in Turkish].
[16] M. Çöl, Changing of Some Yield and Quality Components at Bread Wheat from Late to Now[Master's thesis] Selcuk University, Konya, Turkey, 2007.
[17] T.S. Cox, J.P. Shroyer, B.H. Liu, R.G. Sears, T.J. Martin, Genetic improvement in agronomic traits of hard red winter wheat cultivars from 1919 to 1987, Crop Sci. 28 (1988) 756–760.
[18] F.E. Yediay, E.E. Andeden, F.S. Baloch, A. Borner, B. Kilian, H. Ozkan, The allelic state at the major semi-dwarfing genes in a panel of Turkish bread wheat cultivars and landraces, Plant Genet Resour Charact Util 9 (2011) 423–429.
[19] F.E. Yediay, F.S. Baloch, B.H. Kilian, H. Ozkan, Testing of rye-specific markers located on 1RS chromosome and distribution of 1AL.RS and 1BL.RS translocations in Turkish wheat (*Triticum aestivum* L., *T. durum* Desf.) varieties and landraces, Genet. Resour. Crop Evol. 57 (2010) 119–129.
[20] R.M. Trethowan, R.P. Singh, J. Huerta-Espino, J. Crossa, M. van Ginkel, Coleoptile length of near-isogenic *Rht* lines of modern CIMMYT bread and durum wheats, Field Crops Res. 70 (2001) 167–176.
[21] G.J. Rebetzke, R.A. Richards, X.R.R. Sirault, A.D. Morrison, Genetic analysis of coleoptile length and diameter in wheat, Aust J Agric Res 55 (2004) 733–743.
[22] G.J. Rebetzke, R.A. Richards, N.A. Fettell, M. Long, A.G. Condon, R.I. Forrester, T.L. Botwright, Genotypic increases in coleoptile length improves stand establishment, vigour and grain yield of deep-sown wheat, Field Crops Res 100 (2007) 10–23.
[23] A. Morgounov, V. Zykin, I. Belan, L. Roseeva, Y. Zelenskiy, H.F. Gomez-Becerra, H. Budak, F. Bekes, Genetic gains for grain yield in high latitude spring wheat grown in Western Siberia in 1900–2008, Field Crop Res 117 (2010) 101–112.
[24] M. Kan, M. Kucukcongar, M. Keser, A. Morgounov, H. Muminjanov, F. Özdemir, C. Qualset, Wheat Landraces in Farmers' Fields in Turkey: National Survey, Collection and Conservation, 2009–2014, FAO, Ankara, Turkey, 2015.