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Status of Durum Wheat (*T. durum* Desf.) Genetic Resources in the Southeastern Anatolia from Past to Present

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ABSTRACT

Agriculture started to evolve in Anatolia about 10.000 years ago. Genetic diversity of crops plants with their wild relatives and center of domestication of durum wheat were always interested in by scientists. The connection between molecular markers such as AFLP (amplified fragment length polymorphism) and domestication geography showed that the Karacadağ mountain in the Southeast Anatolia was pointed out the origin of domesticated einkorn (*Triticum monococcum*) and emmer (*T. dicoccum*). Durum wheat spread out from the Fertile Crescent and through southern Europe, reaching North Africa around 7000 BC. More recently, 17 *Aegilops* and 11 *Triticum* species or sub species including *T. aestivum* and *T. durum* were defined under both geneses in Türkiye. Twenty-five of them were wild relatives. Wheat landraces are composed of traditional crop varieties developed by farmers through years of natural and human selection. There have been several collection missions for wheat landraces. Durum wheat landraces were mostly grown until 1960 in Türkiye. They used to be called as 'sarı buğday'. The acreage of the landraces grown in Türkiye is about 0.55 million ha. A survey held more recently proved the presence 162 names of wheat landraces in Türkiye. Many beneficial traits such as drought and cold tolerance and high grain quality were detected and tried to be exploited in modern breeding programs. Farmers have access to modern cultivars but keep their landraces. The main reason for maintaining landraces is satisfaction with the landraces' performance under poor input conditions. Tens of landraces are still grown in Türkiye. Unless additional measures are taken, landraces will disappear gradually.

Keywords: Historical evolution, wild relatives, landraces, present and future perspectives.

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Historical background

The information gathered from several excavations suggests that the agriculture started to evolve in Anatolia almost 10.000 years ago. Anatolia hosted many civilizations in the past and was the pathway between Asia and Europe in the history (Harlan 1995; Zeist et al., 1995; Karagöz et al., 2010). Recent excavations in Göbeklitepe of Sanliurfa province have a potential to shed light on the periods prior to known date of agriculture (Killian et al., 2010). For more than two decades, the use of molecular markers has been providing new information on genetic diversity of crop plants in relation to wild relatives, centers of domestication, time frame of the domestication process and specific alleles supporting domesticated traits. The connection between molecular markers and domestication geography took root in the paper by Heun et al., (1997) who found that based on AFLP (amplified fragment length polymorphism) markers, the closest wild relatives of domesticated

einkorn (*Triticum monococcum*, diploid) occur in a very restricted area within the Karacadag mountain range in south-eastern Türkiye (Fig.1). From that they concluded that this represents the site were humans first domesticated einkorn. Important contributions using different molecular markers for other species followed: einkorn (Killian et al., 2007); emmer (Ozkan et al., 2002; Ozkan et al., 2005; Mori et al., 2003; Luo et al., 2007).

Archaeological evidence verifies the occurrence of plant remains at different excavation sites, in different strati graphic layers that were analyzed, and radiocarbon dated (Hillman, 2000) from which a generally consistent picture emerges indicating that western agriculture originated in the Fertile Crescent after the last ice age, in aceramic Pre-Pottery Neolithic (PPN) from about 12,000 to 9,500 years ago (Zohary and Hopf 2000; Nesbitt 2002; Salamini et al., 2002). It is now widely held that Fertile Crescent agriculture originated in a "core area" in south-eastern Türkiye to northern Syria (Fig. 1), where the distribution of wild forms (Fig. 2).

Several issues concerning geography and domestication of wild emmer wheat were recently reviewed by (Ozkan, 2011). The authors considered published molecular and archaeological data and re-analyzed the data of (Ozkan et al., 2005). Wild emmer was probably domesticated in south-eastern Türkiye (Ozkan et al., 2002; Ozkan et al., 2005; Mori et al., 2003; Luo et al., 2007; Jaradat, 2013).

A reconsideration of the domestication geography of tetraploid wheats has been considered by (Ozkan et al., 2005) and (Luo et al., 2007). Phylogenetic analysis indicates that two different races of *T. dicoccoides* exist, the western one, colonizing Israel, Syria, Lebanon, and Jordan, and the central-eastern one, which has been frequently sampled in Türkiye and rarely in Iraq and Iran. It is the central-eastern race that has played the role of the progenitor of the domesticated germplasm. This is supported by the results from the collections of (Ozkan et al., 2002; Mori et al., 2003; Luo et al., 2007). A disagreement is nevertheless appearing at the local geographical scale: the chloroplast DNA data indicate the Kartal mountains at the western border of the "core area" (Abbo et al., 2006), while AFLP finger printing points to the Karacadag range as the putative site of tetraploid wheat domestication. From this area, emmer expanded across Asia, Europe, and Africa (Ozkan et al., 2005). South-western expansion of domesticated emmer generated sympatry with the southern populations of *T. dicoccoides* and the rise of a secondary diversity center (Luo et al., 2007).

Durum wheat (*T. turgidum* spp. *durum*) has been of great historical significance, because it provided a range of sub-species that were cultivated widely across the globe for thousands of years (Feuillet et al., 2007). Durum wheat spread out from the Fertile Crescent and through southern Europe, reaching North Africa around 7000 BC (Feldman, 2001). It came into cultivation originally in the Damascus basin in southern Syria about 9800 BC Zohary and Hopf (2000). A second route of migration occurred through North Africa during the Middle Ages (Moragues et al., 2006). Geographical expansion of durum wheat was intimately associated with human migrations. It is cultivated mainly in the marginal areas of Mediterranean region, Southern Europe, and North Africa, while more recently it has started to expand to Southern Asia (Baloch et al., 2017)

Wild relatives of wheat in Türkiye

Kimber and Feldman (1987) indicated the presence of 25 wide relative species in Türkiye. More recently, 17 *Aegilops* and 11 *Triticum* species or sub species including *T. aestivum* and *T. durum* were defined under both genera (Cabi 2010). Subspecies under *Aegilops* genus Waines and Barnhart (1992) are *Aegilops biuncialis* Vis., *Aegilops markgraffii* (Greuter) Hammer, *Aegilops columnaris* Zhuk, *Aegilops comosa* Sm. in Sibth. &Sm, *Aegilops crassa* Boiss., *Aegilops cylindrica* Host, *Aegilops geniculata* Roth, *Aegilop juvenalis* (Thell.) *Eig, Aegilops kotchyi* Boiss., *Aegilops neglecta* Req. Ex Bertol., *Aegilops peregrina* (Hack. in J. Fraser) Maire&Weiller., *Aegilops speltoides* Tausch., *Aegilops triuncialis* L., *Aegilops umbellulata* Zhuk., *Aegilops uniaristata* Vis., *Aegilops vavilovii* (Zhuk.) Chennav.

Subspecies under *Triticum* genus are; *T. boeticum* Boiss, *T. urartu* Thumanjan ex Gandilyan, *T. monococcum* L., *T. araraticum* Jakupz., *T. dicoccoides* Koern., *T. dicoccon* Schrank, *T. durum* Desf., *T. turgidum* L., *T. polonicum* L., *T. cartlicum* Nevski, *T. aestivum* L., *T. monococcum* in the north, west Anatolia and Marmara region, *T. dicoccon* in the north Anatolia, *T. urartu* and *T. dicoccoides* in the south east Anatolia, *T. boeticum* in the whole country is found extensively (Table 1 and 2).

Wheat landraces in Türkiye

Wheat landraces are composed of traditional crop varieties developed by farmers through years of natural and human selection and are adapted to local environmental conditions and management practices. As distinct plant populations, landraces are named and maintained by traditional farmers to meet their social, economic, cultural, and environmental needs. They are alternately called farmers' varieties or folk varieties to indicate the innovative role of farmer communities in their development and maintenance (Jaradat 2013). The first collection was completed at the first quarter of 20th

century by pioneering Turkish scientist Mirza Gökgöl who collected 2120 wheat landraces from all over Türkiye and evaluated them for basic characteristics. The name of the book is "Türkiye Buğdayları". Gökgöl identified about 18.000 types of wheat and among them he identified 256 new varieties (Gokgol, 1939). In the same period as Gökgöl, well known Russian scientist Zhukovsky conducted 3 collecting missions to Türkiye during 1925-1927. Zhukovsky was encouraged by Vavilov, and his missions were supported by The Botany Society of the Soviet Union. During three years in Türkiye, Zhukovsky collected around 10,000 samples of cereals, forages, and vegetables. The material was an enormous contribution to plant varieties of the Soviet Union (Zhuhovsky, 1951).

Another landrace collection was done by Harlan in 1948 to 1949 with contribution of Agronomy Department of the University of Ankara, the Toprak Ofisi of the Ministry of Trade, and the Plant Breeding Stations of the Office of the Director General of Agriculture. The collection includes in 2121 wheat accession (incl. *T. monococcum*), and 55 wild relatives of wheat. These populations were analyzed for botanical and agronomic composition, providing an unusual opportunity for studies on the behavior of botanical varieties in mixed populations under diverse climatic conditions. The wheat in Türkiye were represented by remarkable diversity and great varietal wealth (Harlan 1950).

Damania et al., (1996) evaluated the collection of 2420 accessions derived from single-spike population samples of durum wheat landraces collected in 1984 from 172 sites in 28 provinces in Türkiye. They found differentiation of these accessions for number of days to heading, maturity, grain filling period as well as for plant height, peduncle length, and number of spikelets per spike, spike length, awn length, and kernel weight. As result of the canonical analysis, significant correlation among province means temperatures, altitude, latitude, and length of growing season. Eight distinct groups of provinces were identified by cluster analysis. They concluded that accessions could be utilized in crop improvement programs targeted at either favorable or stressed environments. Several other regional or local collection missions were fulfilled (Karagoz 1996; Qualset et al.,1997; Tan, 2002; Karagoz and Zencirci, 2005; Akcura and Topal, 2006; Giuliani et al., 2009).

The last survey was carried out in 65 provinces of Türkiye between 2009-2014 (Giuliani et al., 2009; Kan et al., 2015; Morgounov et al., 2016). As a result of the survey, 162 different local wheat landraces' names were detected. The wheat landraces were ranked according from highest frequency to the lowest frequency. In Türkiye, the most common 10 wheat landraces according to the frequency were; 1. Ak Buğday (Durum/bread wheat), 2. Sarı Buğday (Durum/Bread wheat),3. Kırmızı Buğday (Bread Wheat),4. Karakılçık (Durum/ bread wheat), 5. Zerun (Bread wheat), 6. Kırik (Bread wheat), 7. Koca Buğday (Durum/ bread wheat),8. Siyez Buğdayı, 9. Topbaş (Durum/bread wheat), 10. Üveyik Buğdayı (Durum wheat).

Durum wheat landraces mostly grown until 1960 in Türkiye were given in Table 3. In early 20th century, bread and durum wheat landraces grown in Türkiye were so called 'Ak Buğdaylar' and 'Sarı Buğdaylar' respectively. Turkish farmers cultivated their landraces widely until the second half of 20th century. After the World War II, a program was started in Türkiye through an agreement with Rockefeller Foundation. Although it was a modest start in agriculture research, mechanization, use of fertilizers and chemicals, it resulted in unexpected consequences. Among several plant groups involved, wheat program had the greatest impact. It didn't take long for the new varieties to replace the landraces. The heritage begun to be demolished after so called high yielding "Mexican origin wheat varieties" were introduced to the country. The acreage of the landraces grown in Türkiye is about 0,55 mil ha (Karagoz 2014).

Breeding value of durum wheat durum landraces

Although the presence of regional differences, general breeding aims of durum wheat are high yielding, yellow semolina color, gluten quality, resistance to lodging, tolerance to cold, heat and drought, tolerance to rust diseases (Ozberk et al., 2010). In modern era of durum wheat breeding in Türkiye, variety development studies were initiated through the line selection from widely grown landraces. Therefore, Makarnalık Sarı Buğday 710 in 1931, Makarnalık 073/44 and 414/44 in 1944, Fata'S' 185/1 in 1961-63, Kunduru 1149 in 1967 were developed (Ozberk et al., 2016). Apart from molecular genetics studies many morphological, physiological, and quality characterization studies were carried out employing durum wheat landraces. Many beneficial traits were detected and tried to be exploited in modern breeding programs (Genc et al., 1993; Koc, 1993; Barutcular et al., 1993; Alp and Kun, 1999; Sonmez et al., 1999; Altınbas and Tosun, 2002; Ozberk et al., 2005; Alp, 2005; Alp and Akinci, 2005; Alp and Aktas, 2005; Kara and Akman, 2007; Serpen et al., 2008; Koksel et al., 2008; Kutuk et al., 2008; Ozturk et al., 2008; Gumus et al., 2008; Alp and Sagir, 2009; Koyuncu, 2009; Sayaslan et al., 2012; Akcura, 2009). Molecular genetic studies mainly based on characterizations employing some morphological,

physiological, and technological characteristics of landraces (Yıldırım et al., 2011; Baloch, 2017).

Domestic use of durum wheat landraces

Depending on the region, up to 80% of the farmers have tried modern cultivars and most of them kept growing them along with landraces. The proportion of area growing wheat landraces to total wheat area in farmers' fields varied from 45 to 55% in the central Black Sea region and up to 98% in the southern coastal region. Farmers have access to modern cultivars but keep their landraces. The main reason for maintaining landraces is satisfaction with the landraces' performance. While, on average, only 25 and 30% (bread wheat and durum wheat growers, respectively) of the farmers rated yield of the landraces as good; 83% of the respondents for bread wheat and 93% for durum wheat were happy with the grain quality and its suitability for homemade products (Fig. 4). The other highest ranked traits for bread wheat and durum wheat, respectively, were straw yield (74 and 80%) and straw quality (70 and 76%), cold tolerance (78 and 82%), and drought tolerance (71 and 84%). For most of these traits, durum wheat landraces were rated slightly higher than bread wheat landraces (Figure 4) (Morgounov et al., 2016).

Wheat grain in the rural areas is used for two main purposes: bread, including typical loaves and thin types, and bulgur or cracked wheat, which is cooked in water. Respectively, bread and durum wheat are normally used for these two products. Based on the survey of the farmers in the region's growing primarily bread wheat (Aegean, central Anatolia, northeastern Anatolia, and central eastern Anatolia), its grain is mainly used for bread (64.3 to 83% of farmers). Of the four regions dominated by durum wheat, grain in the southern coastal and eastern Mediterranean regions is mainly used for bulgur (55.5 and 87.1%, respectively). The durum grain in the central Black Sea and southeastern Anatolia regions is used for both bulgur and bread (61.1 and 83.3%, respectively). Generally, the farmers were quite flexible in dual use of their grain for bread, bulgur, and other homemade products). Most of the club or compact wheat is used for dual purposes. Hulled einkorn wheat is used for bulgur in Bolu and Kastamonu regions and for animal feed elsewhere. Emmer wheat is consumed by the farmers in Kars and Sinop provinces as well as in north Anatolian region villages in small quantities. It is also used as animal feed. Durum wheat farmers in the central Anatolia region were 100% satisfied with the grain, mostly using it for bulgur. In the southeastern Anatolia and central eastern Anatolia regions, the durum farmers also gave very high ratings to the quality of their landraces, using them for dual purposes (bread and bulgur) (Morgounov et al., 2016).

Conclusion

Some of wheat landraces have so far been conserved in low scale due to their suitability for local dishes. They are not able to compete with the modern cultivars in respect of grain yielding ability and profitability. Unless being profitable none of the landrace can be sustainable. On- farm landrace conservation requires the continuation of the farmer induced selection processes by on how these landraces have been developed and their genetic structure have been shaped. Farmers must keep on seed replacement and renewal. Participatory plant breeding (Fasoula, 2004; Galie, 2013) collaboration with the local self-sufficient farmers can proved farmers to access the improved landrace seed. Sharing of the indigenous knowledge from generation to generation is also vital for sustainable conservation of landraces. Climate change is expected to differentially affect components of complex biological interactions in modern and traditional wheat production systems. Wheat yield and quality will be affected by climate change directly or indirectly through diseases. Wheat landraces and their populations in and outside their centers of diversity might respond to climate change will determine their continued productivity, utility, and survival. Non-breeding approaches to create demand for landrace products to promote on-farm dynamic conservation and sustainable utilization of wheat landraces include; 1. Rising public awareness regarding current and future value of landraces, 2. Diversity fairs to allow for the exchange of landrace materials associated indigenous knowledge, 3. Visits among farmers in various localities to share the seed and experience, 4. Contests for choice of highest diversity holding farmer, 5. Recipe development and niche market creation for landrace products (Jaradat 2013), 6. Growing mixtures for similar phenotypes to meet more local dish demands 7. Amendments in seed certification system allowing landraces to have diversity within the pre-determined ranges, 8. Expand organic farming practices employing more landraces (Karagöz, 2014)

Coordination with the non-breeding approaches to create demand for landrace products to promote on-farm dynamic conservation and sustainable utilization of wheat landraces can be provided by activities generating additional value and profit.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

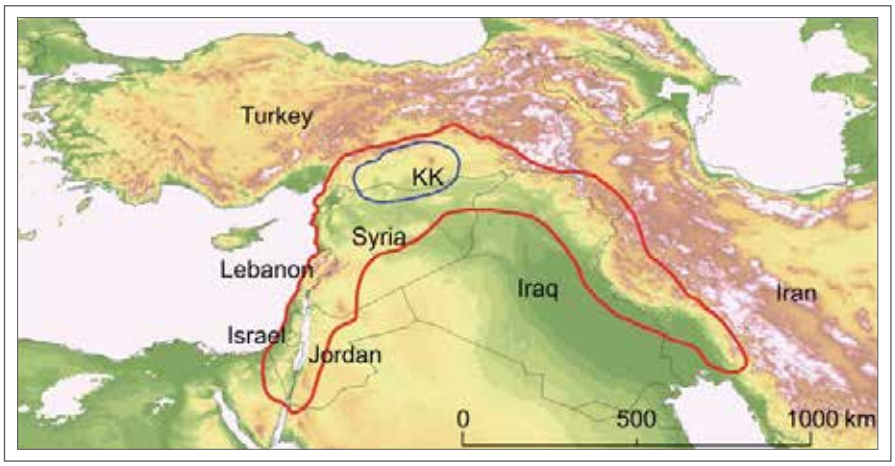

Figure 1. Fertile Crescent and "core area" of plant domestication within the Fertile Crescent. The Fertile Crescent is indicated with a red line and the "core area" is shown with a blue line. KK Karacadag mountain range in south-eastern Türkiye.

Figure 2. Wild einkorn, wild emmer and *Aegilops* species in their natural habitat in Karacadag mountain range. Picture taken by H. Ozkan in early July 2004.

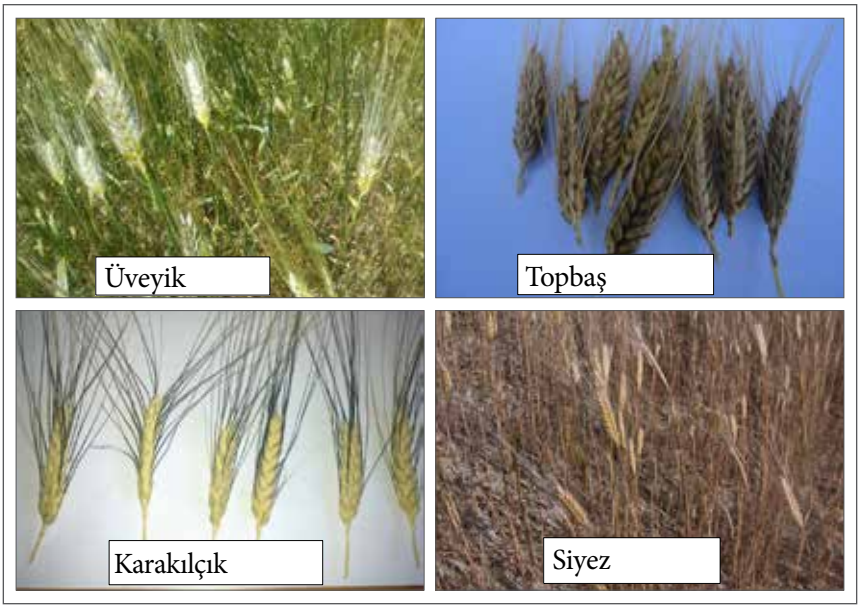

Figure 3. Some of durum wheat landraces still grown in Türkiye.

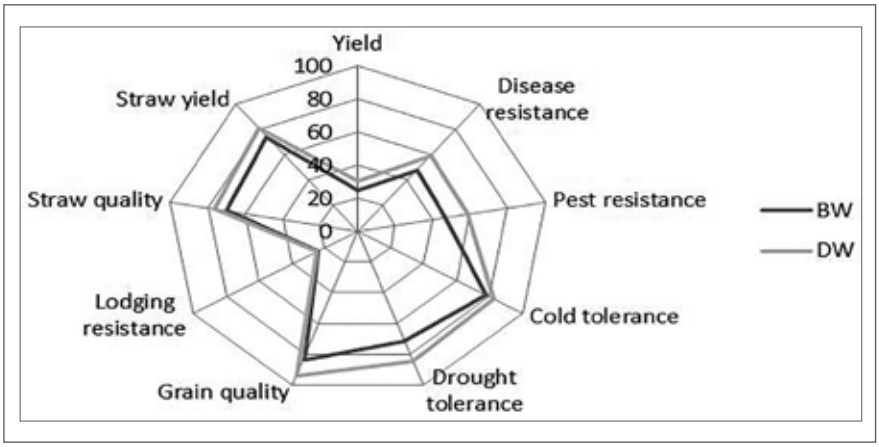

Figure 4. Percentage of farmers' ratings of different traits of bread wheat (BW) and durum wheat (DW) landraces as good based on a survey of 1026 households in Türkiye in 2009 to 2014.

Table 1. *Aegilops, Amblyopyrum* and *Dasypyrum* species, Turkish names, and genome formulas (Cabi and Doğan 2009; Waines and Barhart 1992).

Aegilops species	**Turkish name**	**Genome**
Ae. biuncialis Vis.	İki kılçık	UM
Ae. caudate L.,	Kara ot	C
Ae. columnaris Zhuk.	Kıl buğday	UM
Ae. comosa Sm. In Sibth. & Sm.	Uzun kılçık	M
Ae. crassa Boiss.	Kalın buğday	DM; DDM
Ae. cylindrica Host.	Kirpikli ot	DC
Ae. geniculata Roth.	Konbaş	MU
Ae. juvenalis (Thell.) Eig	Kaba buğday	DMU
Ae. kotchyi Boiss.	Asi buğday	SU
Ae. neglecta Req. Ex Bertol.	Tüylü buğday	UM; UMN
Ae. peregrina (Hack. in J. Fraser) Maire&Weiller	Kum buğdayı	SU
Ae. speltoides Tausch	Akbuğday anası	S
Ae. tauschii Coss.	Tespih buğdayı	D
Ae. triuncialis L.	Üç kılçık	UC; CU
Ae. umbellulata Zhuk.	Hanım buğdayı	U
Ae. uniaristata Vis.	Tek kılçık	N
Ae. vavilovii (Zhuk.) Chennav.	Zarif buğday	DMS
Amblyopyrum muticum (Boiss.) Eig	Narin Buğday	T
Dasypyrum villosum (L.) Candargy	Kızıl ev	V

Table 2. Wild *Triticum* species, Turkish name and genome formulas (Cabi and Doğan 2009).

Triticum species	Turkish name	Genome
T. boeoticum Boiss.	Yabani siyez	A^mA^m
T. dicoccoides (Körn. ex Aschers. et Graebn.) Schweinf	Yabani gernik	AABB
T. timopheevii (Zhuk.) Zhuk. v *araraticum* (Jakubz.) Yen	Deli Rus buğdayı	AAGG
T. urartu Thumanjan ex Gandilyan	Urartu buğdayı	AA
T. monococcum L.	Siyez	A^mA^m
T. turgidum L. ssp. *dicoccon*	Gernik=Çatal kaplıca= Çatal siyez	AABB
T. turgidum L. ssp. *durum*	Makarnalık	AABB
T. turgidum L. ssp. *durum commune*	Asıl makarnalık	AABB
T. turgidum L. ssp. *durum* ssp. *duro-compactum*	Makarnalık topbaş	AABB
T. turgidum L. ssp. *turgidum*	Kaba buğday	AABB
T. turgidum L. ssp. *polonicum*	Turna gagası buğday	AABB
T. turgidum L. ssp. *carthlicum*	Doğu buğdayı	AABB
T. turgidum L. ssp. *turanicum*	Turna dili buğday	AABB

Table 3. Wheat landraces grown in Türkiye before 1960.

Region	Provinces	Durum land races
Central-North Anatolia	Ankara, Çankırı, Uşak, Çorum, Kırşehir, Yozgat, Bolu, Bilecik, Eskişehir, Kütahya	Sarı Buğday, Karakılçık, Kunduru, Şahman, Sarı Bursa, Akbaşak, Üveyik
Central-East Anatolia	Amasya, Malatya, Sivas, Tokat, Tunceli, Elazığ	Üveyik, Menceki, Kunduru
Central-South Anatolia	Afyon, Kayseri, Niğde, Konya, Nevşehir	Bolvadin, Sarı Buğday, Karakılçık
North-Eastern Anatolia	Ağrı, Artvin, Kars, Erzincan, Erzurum	Karakılçık, Hazerik
South-Eastern Anatolia	Bingöl, Bitlis, Van, Hakkâri, Mardin, Muş, Siirt, Şanlıurfa	Bağacak, Sorgül, Sorik, Beyaziye, Menceki, Akbaş, İskenderi, Mısri, Havrani, Karakılçık, Akbaşak, Hamrik
Mediterranean	Antalya, Gaziantep, Hatay, İçel, Maraş, Adana	Akbuğday, Karakılçık, Tığrak Buğdayı, Sarı Buğday ve Kıbrıs Buğdayı
Aegean	İzmir, Aydın, Muğla, Denizli, Burdur, Isparta, Manisa, Balıkesir, Çanakkale	Fata, Gökala, Sarı başak, Kunduru, Menemen, Karakılçık, Sarı Çam, Akbaşak, Akpüsen, Çam Buğdayı, Sarı Buğday, Devedişi, Kırmızı Buğday
Marmara	Bursa, Kocaeli, Sakarya, İstanbul, Edirne, Tekirdağ, Kırklareli	Akbaşak, karakılçık, Tunus Buğdayı, Sarı Başak, Köse Buğday, Arnavut Buğdayı, Kunduz, Koca Buğday, Kokana
Black Sea	Rize, Trabzon, Giresun, Ordu, Samsun, Sinop, Kastamonu, Zonguldak, Gümüşhane	Rumeli (Yunan) Buğdayı, İlik Buğday, Sarı Buğday, Akbuğday, Sarıbaş, Karakılçık, Üveyik, Rumeli, Sarı Hamza, Koçarı, Diş Buğdayı

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