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Genetic Variation in Einkorn (*Triticum monococcum* L.) Wheat

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Abstract

The natural wealth of each country is an important genetic resource. Wild wheat families, in particular diploid plants, have useful characteristics in the improvement of wheat. The knowledge of genetically modified genotypes of einkorn wheat (*Triticum monococcum* L.) is the secret to ensuring food products which are healthy, sustainable, and adapted to different conditions. In addition to einkorn wheat, one of the first domesticated plants is *Triticum monococcum*. But it was discarded before the Bronze Age for agriculture and was rarely used in the breeding of wheat. Little is known about the genetic variation in adaptively important biological traits in *T. monococcum*. This study aims to investigate the genetic variation of einkorn wheat. The report will discuss the origin of einkorn wheat after its introduction and then a summary of the spread of einkorn wheat has been evaluated. Moreover, genetic variation in einkorn wheat will be discussed by evaluating a few previous studies that are related to the subject.

Keywords: Einkorn wheat, Genetic resources, Genetic variation, *Triticum monococcum* L.

1. Introduction

Einkorn wheat (*Triticum monococcum* L.) has been cultivated since the beginning of the 20th century thanks to its ability to grow and adapt to arid areas and to harsh climatic conditions. Einkorn wheat has hardly been reported until the late 1980s in the Caucasus, Turkey, Syria, Lebanon, Iraq, Iran, the Northwest, Albania, Bulgaria, Greece, and Italy. Today, however, einkorn wheat has been reported to be grown in Turkey, the Balkan Peninsula, and Central and Southwestern Europe, and in a limited area of Morocco (Zohary and Hopf, 2000). As in all living species, plant species also owe the continuity of their lineages to their adaptability under changing environmental conditions. Moreover, knowing the genetic variation of the plant species studied is essential for a sustainable agriculture, too. The genetic variation of wheat species is also used in today's wheat breeding studies for morphological, cytological, isoenzyme, and DNA markers / DNA sequences. The genetic variation in einkorn wheat is, on the other hand, of great importance for both diploid wheats and bread and durum wheat breeding programs (Zencirci and Karagöz, 2005). Today, the rate of genetic variation in genetic resources used in wheat breeding programs is gradually decreasing. As a result, wheat breeders give priority to using wild wheat species or their primitive forms, which are known to be resistant to especially biotic and abiotic factors. Therefore, phenotypic and genotypic characterization of einkorn wheat genotypes are very important due to the pre-stated reasons (Vuorinen et al., 2018).

Einkorn wheat produces more B_1, B_2, and B_5 than modern wheat species, such as durum and bread wheat. Meanwhile, the amount of total vitamin E in wheat of einkorn is higher than that of emmer, durum, and bread wheat. Among wheat species, E vitamin isomers were higher in bread wheat grains, except for α-TT. The ancient einkorn is in nutrition rich and more valuable than durum and bread wheat. The maximum quantification of vitamin B_1 was produced from bread wheat (1.108 µg/g dw) and einkorn grain (1.118 µg/g dw). In single grain (4.442 µg/g dw) and emmer (4.478 µg/g dw), the highest amount of B_2 existed on wheat leaves (Karakas et al., 2021).

Drought and salinity are the most dramatic environmental stress factors which seriously worsen crop yield and quality. The genotypes of bread and einkorn behave differently for the characteristics under dry stress. The results of field and *in vivo* cold and drought stress studies are considered to contribute to the development of credible proposals (Aslan et al., 2017; Zencirci et al., 2019). However, plant safety mechanisms may overcome these stresses. One of the most conserved mechanisms is the post-transcriptional shift in gene expression by microRNAs (miRNAs). They have been involved in the control of salt and drought stress in plant species, including wheat genomes (Ünlü et al., 2018). Moreover, germination rate, germination power, and root- shoot length ratio in einkorn wheat populations were suggested that these populations performed better under drought stress, and similar results were reported by Zencirci et al. (2019).

Genetic linkage maps base on wheat and other plant species DNA. Using these genetic linkage maps, some qualitative / quantitative trait regions were determined in different plant groups, including wheat. Some genetic maps were obtained using various molecular DNA marker techniques (RFLP, AFLP, SSR, etc.) in einkorn wheat, but the studies to determine the quantitative feature regions using these genetic linkage maps, limited (Yu et al., 2017). In recent years, SNP markers have been developed in many plants using the new generation sequencing technique, and high-resolution link maps have been obtained.

The unweighted pair-group method with arithmetic (UPGMA) means approach separates all genotypes according to their genetic structure and position. Of the three wheat species of UPGMA related clusters, hard wheat was clearly distinguished from wild and cultivated emmer wheat. Principle coordinate analysis (PCoA) and model structure algorithm support the results. iPBS-retroposons power in the investigation of diversity and phylogenetic relationships show that this marker system can be used effectively to investigate the phylogenetic and taxonomic relationships of any crop because of its universal existence (Nadeem et al., 2019).

As a result of mapping studies using high-resolution link maps, quantitative property regions (QTLs) related to some yields and yield elements were determined, and it was started to be used according to with Marker Assisted Selections (MAS) in wheat breeding. Since einkorn wheat has a diploid structure and its genome is small compared to bread and durum wheat, fewer genomic studies are performed on it (Xie et al., 2010; Karakas et al., 2021; Dalby, 2003).

2.The Origin and History of Einkorn Wheat

The first cultivated plant in the Fertile Crescent region is einkorn wheat. McCorriston and Hole (1991) did not adopt this view and argued that einkorn wheat was first cultivated in the Jordan Valley. This hypothesis has been supported by Jones et al. (1998). But especially wheat grains found in archaeological sites, the beginning of einkorn wheat 12,000 years ago, based on the wild form is replaced gradually with larger cultural forms of small seeds, and later made DNA analysis of einkorn wheat for the first time in Turkey's Southeast. It has been shown that it was domesticated from *T. monococcum* ssp. *boeoticum*, which is its wild ancestor in the regions around Karacadağ in the South Eastern Anatolian region (Kilian et al., 2007).

At the same time, the oldest archaeological sites in settlements near Karacadağ (Diyarbakır - Şanlıurfa) einkorn wheat residues, e.g., the presence of Çayönü (in Southeastern Turkey) mound and proved the validity of the hypothesis. Cultivated einkorn wheat later spread to the Middle East, Balkans, and Europe (Zaharieva and Monneveux, 2014). Kilian et al. (2007) investigated the haplotype variation among more than 12 million nucleotides sequenced at 18 loci in 321 wild and 92 cultivated einkorn. They reported that *aegilopoides* had been subjected to a natural genetic differentiation process before being cultured, resulting in the emergence of wild einkorn with three different genetic structures defined as α, β and γ, and that only the β group was cultured by humans. The same researchers reported that the genetic variation of the studied cultured einkorn genotypes was higher in the wild einkorn group. The researchers hypothesized that the cultivation of einkorn wheat does not reduce its genetic variation and that multiple independent cultivation events occur. Regarding the evolution of einkorn wheat, the settled Natufian society first collected the β group T. monococcum ssp. aegilopoides from nature and then started to cultivate it.

In the next stage of agricultural development, it was thought that the β group may have moved elsewhere, probably at the beginning of the new culture process, by farmer migration or exchange of seeds for goods (Willcox, 2005).

This hypothesis is also consistent with plant remains found in archaeological excavations. In the Fertile Crescent region, seed grinding tools belonging to previous years and thought to be used actively were found in the cultivated einkorn wheat residues. This supports the view that people in the region collect and consume wild seeds from nature before the culture of einkorn wheat (Weiss et al., 2006; Kilian et al., 2007). Some summer forms have been developed by farmers by selection from wild einkorn wheat forms, which are mostly winter types (Golovnina et al., 2010). Fragile spikelet forms were transformed into non-fragile or unbreakable form and allowed the whole grain to be harvested (Hillman and Davies, 1990). The grain size has been increased (Zohary and Hopf, 2000), and forms that can be blended relatively easily have developed (Nesbitt and Samuel, 1996).

3.The Spread of Einkorn Wheat

The spread of einkorn wheat from the region where it was first cultivated can be determined chronologically thanks to the remains found in archaeological excavations. Einkorn wheat has spread to the BC 8 and 7, 000 years down the north of the Southeast of Turkey and Syria, Mesopotamia (Nesbitt and Samuel, 1996). It started to be seen in Greece, Cyprus, and the Balkans at the beginning of 6 millennium BC. It reached the Carpathian Mountains and the middle Danube basin in 5,500 BC, and Turkmenistan and the Caucasus between 5,500 and 5,000 BC. It spread to Moldavia and Central Europe, Italy, Southern France, and Spain in the fifth millennium BC (Hovsepyan and Willcox, 2008).

In the fourth millennium BC, einkorn spread from Moldavia to Ukraine, from Central Europe to Switzerland, and Germany. It has been reported that einkorn wheat was found in Belgium and Holland around 300 - 400 BC. Finally, it reached Scandinavia in 3,000 years BC. It has been reported that since 2,800 BC, it has been cultivated in the Jutland region of Denmark (Robinson, 2007). Unlike emmer wheat, einkorn wheat is not thought to be grown in Egypt. Although emmer wheat is widely cultivated in Ethiopia and the Arabian Peninsula, no archaeological indication has been found regarding the cultivation of einkorn. Although it is reported that einkorn wheat was grown in the Mehargarh region (Baluchistan / Pakistan) in the fifth millennium BC, some researchers have reported that no scientific data regarding the existence of einkorn in India has been revealed to date. Einkorn wheat had a similar process with emmer and spread more rapidly to Southern Europe and the Caucasus (Dalby, 2003). Thanks to its resistance to biotic and abiotic environmental factors, einkorn wheat was able to survive in the Fertile Crescent region, in the mountainous regions of the Caucasus, Europe, and North Africa with harsh climates until the beginning of the 20th century. Until 1980, Turkey, Syria, Lebanon, Iraq, northwestern Iran, Albania, Bulgaria, Greece, and continued farming in Italy, but today, only Turkey, the Balkan Peninsula, Central and to be grown in limited areas in countries such as Southwest Europe and Morocco continues. Russian investigators on detailed fieldwork carried out, result with wheat in the 1925-1927 year, it was reported that Turkey constitutes one – two % of the wheat farming. Kastamonu in Turkey, Bolu, Sinop, Balıkesir, Bilecik, and the agricultural fields of small farmers in Çankırı province is still ongoing. Its agriculture continues in the northern regions of Italy (South Tyrol and Valtellina). Its agriculture in Iran continued until the 1970s and 1980s, and it has been reported that it is still grown in a very limited area in the northwest of Iran (Salimi et al., 2005; Alsaleh et al., 2016).

Today, einkorn wheat production has attracted the attention of farmers engaged in organic farming. Three varieties of einkorn ('Tifi', 'Terzino', and 'Svenskaja') have been developed in Germany and suggested to farmers engaged in organic agriculture. In Italy, where cultivation started to gain importance, the first einkorn wheat variety was registered with the name "Monlis" (Akhalkatsi, 2012; Yaman et al., 2019).

4.Diversity in Einkorn Wheat (*Triticum monococcum* L.)

Knowing the genetic variation of the plant species studied is essential for sustainable agriculture. The genetic variation of wheat species is also used in today's wheat breeding studies. The genetic variation in einkorn wheat is of great importance for both diploid wheats and bread and durum wheat breeding programs (Alsaleh et al., 2016). Although this genetic material is very scarce, only a few of these accessories have been phenotypically and molecularly analyzed (Brandolini et al., 2016; Knüpffer, 2009). Guzy et al. (1989) reported that einkorn wheat has a wide variation for the number of spikelets per spike and the number of grains per spike. Sharma et al. (1981) compared 93 genotypes of einkorn with "Modoc" durum wheat and "Anza" bread wheat varieties, the plant height, grain weight, protein ratio in flour and lysine content, spike weight, and earliness characteristics. They reported that they had a wide genetic variation and had earlier and shorter genotypes than bread and durum wheat varieties. In the study where Castagna et al. (1995) investigated the yield and yield characteristics of einkorn genotypes, they found that there were important genetic variations in einkorn wheat genotypes for characteristics such as heading date, plant height, grain yield, and loading, except for the total biomass and the number of ears per m^2.

Empilli et al. (2000) reported that they examined 1039 wheat genotypes (*T. monococcum* ssp. *monococcum* ssp. *aegilopoides*). They reported that there was a wide variation in size; 13 genotypes had a thousand kernel weight over 40 g; many genotypes examined had low SDS sedimentation values, and eight einkorn genotypes had very high SDS sedimentation values. Butnaru et al. (2003) have characterized 37 local einkorn wheat genotypes collected in Romania and Hungary for 11 agro-morphological characteristics (six morphological characteristics and five agronomic characteristics). They reported that there was a wide variation.

Brandolini et al. (2013) examined a collection of 169 einkorn wheat genotypes for agro-morphological and quality characteristics, for a heading time of different origin einkorn wheat genotypes, spikelet number, grain size, protein content and SDS sedimentation volume. Seifolahpour et al. (2017) examined the populations of 252 wild einkorn which were collected from Zagros Mountains for morphological, agricultural and phenological characteristics during the 2013-2014 growing season. They reported that there is a wide variation in plant height and weight of a thousand grain.

In a study by Karagöz et al. (2007) 64 einkorn wheat genotypes obtained from different origins to determine the agro-morphological variation for two years under Çukurova conditions, plant height, upper internode length, spike length, spike weight, number of spikelets per spike, they reported that a wide variation among the genotypes studied for ear number and ear yield.

5. Conclusion

The *Triticum* genus is the largest one in the *Triticeae* tribe and has been the subject to several biological studies. The genomic constitution of all *Triticum* species comprises four essential genomes: A, B, D, and G. Around three million years ago, the ancestral diploid species resulted in A, B, and D differed from a shared ancestor. In the northern and easterly parts of the fertile highlands, the primary habitats of the wheat age precedents were created, and the modern wheat farmers were mainly distributed in this region from their predecessors. The earliest species of cultivated wheat to be domesticated by the wild progenitor *Triticum boeoticum* Boiss is einkorn (*Triticum monococcum* L.) (2n = 2x = 14, nuclear genome constitution of AA).

Wheat terraces provide an important source of genetic variation, which can be exploited by adding new alleles or combinations of genes to enhance commercial varieties. Besides, wild bread wheat relatives are considered major sources of traits for the genetic enhancement of wheat. There are rich gene pools in wild relatives of crop plants which give the best hope for crop improvement in future breeding programs. *Triticum* L. species of wild and progenitor. *Aegilops* L. and so forth. Provide a valuable source of new genetic variation accessible for the improvement of wheat, including stress on biotic (drought, cold, heat, salinity, and herbicides, etc.) and abiotic (pathogens, etc.). The domestication has resulted in the reduction of genetic crop diversity that could pose great challenges for plant producers and farmers along with climate change and endanger world food protection.

They, therefore, recommend that wild crop families be collected, conserved, and evaluated for useful and essential characteristics and that the findings are widely available for the future of agriculture. The wild wheat progenitors come from semi-arid western and central Asian areas. Consequently, they are well suited to numerous stresses frequently present in all regions with climate variations annually. They can also be used for stress resistance, plant production, yield stability, and adaptation to the rich indigenous genetic variation of wild wheat diploid progenitors.

6. Conflict of Interest

There is no conflict of interest.

7. Declaration of Author Contribution

Authors are equally contributed to the article.

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