
Wheat landraces in Türkiye: Genetic diversity, agroecological adaptation, and breeding potential

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Abstract Turkish wheat landraces are heterogeneous populations that have been maintained by farmers under contrasting local conditions. Evidence from morphological, physiological, and molecular research indicates substantial allelic variation and population structure associated with geography and environment. This diversity has been linked with yield stability, adaptation to marginal areas, tolerance to drought and heat, and variation in grain quality and micronutrient concentration. Nevertheless, landrace cultivation has declined considerably as modern high-yielding cultivars have expanded, resulting in continuing genetic erosion. The material that remains in farmers' fields and genebank collections is therefore important for crop improvement. In this review, we evaluate current knowledge of the diversity, agroecological adaptation, and functional traits of wheat landraces from Türkiye, with particular attention to their possible contribution to climate-resilient breeding. We also discuss how genomic tools, detailed phenotyping, participatory breeding, and complementary in situ and ex situ conservation can support their effective use in sustainable wheat production.

Keywords: Climate resilience, Crop domestication, Germplasm conservation, Traditional wheat varieties, Yield stability

Introduction

Wheat (*Triticum* spp.) is a major cereal crop and an important source of dietary energy and plant protein. During recent decades, genetic improvement, irrigation, mineral fertilisation, and more intensive crop management have substantially increased wheat production. These gains were accompanied by greater reliance on a relatively small number of elite cultivars, which narrowed the genetic base used in production (Khoury *et al.*, 2014; FAO, 2019). Such uniformity may restrict the capacity of the crop to respond to diseases and environmental variation. This limitation is increasingly relevant as wheat production is exposed to land degradation and more frequent drought and heat events (Reynolds *et al.*, 2015).

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A landrace is not automatically a better crop. Its breeding value lies in the variation that may be present within it. Zeven (1998) and Camacho Villa *et al.* (2005) describe such populations as products of local conditions and repeated farmer selection. That history can preserve an uncommon quality trait or stress response, but it can also leave a population uneven and relatively low yielding in favourable fields. Evaluation must therefore be tied to a named trait and a relevant modern check. Only then is there a basis for retaining the population or using it as a donor (Jarvis *et al.*, 2008; Dempewolf *et al.*, 2014; Reynolds *et al.*, 2015).

Anatolia deserves particular attention because wheat was brought into cultivation there very early and across sharply contrasting environments (Vavilov, 1992; Salamini *et al.*, 2002; Zohary *et al.*, 2012). Harlan (1971) emphasised the continuing effects of seed exchange and local selection on Anatolian wheats. Molecular surveys later identified marked diversity in Near Eastern and south-eastern Anatolian material (Özkan *et al.*, 2002; Balfourier *et al.*, 2019). Gökgöl's pre-breeding-era surveys (1935, 1939) provide a useful historical reference, although their morphological categories cannot be treated as genetic groups without further evidence.

Despite this growing body of work, the evidence is dispersed among historical, genetic, ecological, and agronomic studies. The present review brings these fields together to examine the origins and diversity of Turkish wheat landraces, their morphological and physiological characteristics, their place in agroecological production, and their potential use in breeding. This combined assessment also identifies areas where evidence remains limited and where further research could improve conservation and use of wheat genetic resources in Türkiye. Figure 1 summarises the progression from wild wheats to Anatolian landraces and modern cultivars.

Local wheat landraces: Concept and terminology

The word landrace is used loosely, usually for locally adapted crop populations that grew up inside traditional farming. Its sense shifts from one field to the next, though — a plant breeder, a conservation biologist, and an agroecologist will not always mean the same thing by it. So it helps to pin the term down and set it apart from neighbours like local variety, traditional cultivar, and modern cultivar, which differ in how uniform they are, how they were bred, and how they are managed (Zeven, 1998; Camacho Villa *et al.*, 2005).

A local name, by itself, does not establish that a seed lot is a landrace. Evidence is also needed for a history of cultivation, farmer management, and variation among plants. Some village materials are old cultivars, mixtures, or

selections from improved seed. Zeven (1998) and Negri *et al.* (2009) warn that these categories matter: a mistaken label distorts diversity estimates and conservation priorities. Where wheat names overlap, collection records should describe seed history and population variation explicitly.

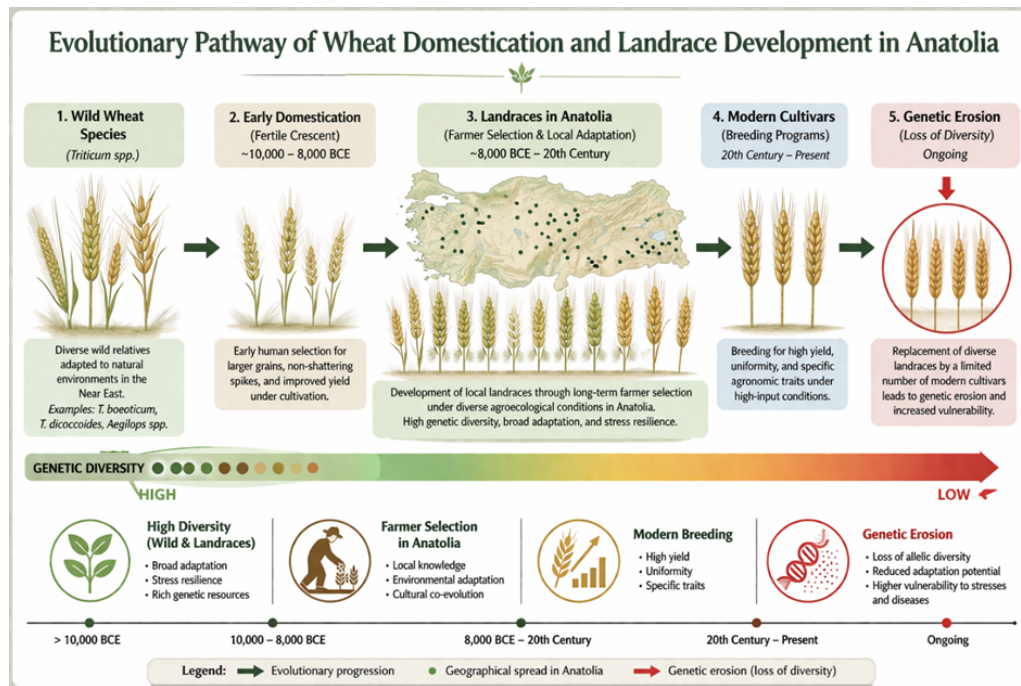


Figure 1. Evolutionary pathway of wheat domestication and the emergence of wheat landraces in Anatolia, from wild wheat species to modern cultivars and the process of genetic erosion

Farmer selection also means that a landrace is not genetically fixed. Seed retained for reliable harvests, food quality, straw, or easy threshing is exposed at the same time to soil and climate. Frequencies within the population may consequently shift while the local name remains unchanged (Brush, 2000; Jarvis *et al.*, 2008). The result may be a good fit to one farming system, not adaptation everywhere.

For breeders, characterisation is the first test of usefulness. A screened population may contribute resistance, a stress-response trait, or alleles absent from a narrow elite pool. Until such a contribution is demonstrated, its position between wild relatives and uniform cultivars is descriptive rather than evidence of breeding merit (FAO, 2014; Dempewolf *et al.*, 2014).

In this review, local wheat landrace refers only to a farmer-maintained population with a substantial history in its production area and appreciable variation among plants. The narrower definition excludes locality alone as proof of landrace status.

Historical development of local wheat diversity in Türkiye

The history of wheat diversity in Türkiye cannot be separated from the farming history of Anatolia, one of the first places wheat was ever grown. Archaeobotany and genetics agree that the Fertile Crescent, south-eastern Anatolia included, was among the earliest homes of wheat domestication, from which the crop later travelled outward (Vavilov, 1992; Salamini *et al.*, 2002; Zohary *et al.*, 2012). Einkorn (*Triticum monococcum*) seems to have been brought under cultivation on Karacadağ, in the south-east, roughly ten thousand years ago — one of the opening chapters of agriculture itself (Nesbitt and Samuel, 1996; Zohary *et al.*, 2012).

For much of Anatolian agricultural history, farmers produced and exchanged seed locally. Harlan (1971) argued that this decentralised system allowed wheat populations to diverge gradually. Selection concerned the whole farm: stable grain production, food quality, threshing, and straw could all influence which seed was kept. The result was not one Anatolian wheat type but many named populations associated with different environments and uses.

Gökgöl's surveys (1935, 1939) remain the clearest early record of Anatolian wheat forms, but appearance has limits. Altuner *et al.* (2025) found differences among Turkish materials that looked similar, while regional studies reported variation in grain and agronomic characters (Karagöz, 1996; Zencirci *et al.*, 2003). Names and morphology are therefore useful for sampling; neither is a genetic diagnosis.

Marker data offer an independent line of evidence. AFLP, SNP, and genome-wide studies found rich allelic variation and geographic structure in Near Eastern collections (Özkan *et al.*, 2002; Cavanagh *et al.*, 2013; Balfourier *et al.*, 2019). They confirm that diversity remains, but they do not identify the agronomic value of an accession. That requires reliable origin records and phenotyping in comparable trials.

Genetic diversity and molecular evidence

Türkiye is widely recognised as an important centre of wheat diversity. Wheat has been cultivated across its contrasting agroecological regions for a long

period, and Turkish landraces include diploid, tetraploid, and hexaploid *Triticum* species (Salamini *et al.*, 2002; Zohary *et al.*, 2012).

The species that dominate among Turkish landraces are bread wheat (*Triticum aestivum* L.), durum wheat (*Triticum durum* Desf.), emmer (*Triticum dicoccum* Schrank), and einkorn (*Triticum monococcum* L.). Each marks a different stage in wheat's domestication and evolution, above all in the polyploidy that built up its genome and its capacity to adapt. Bread wheat is hexaploid (AABBDD); durum and emmer are tetraploid (AABB); einkorn is diploid (AA) and one of the oldest domesticated wheats of all (Feldman and Levy, 2012; Dubcovsky and Dvorak, 2007). Table 1 lists representative landraces from around Türkiye with their taxonomic placing.

Table 1. Representative wheat landraces cultivated in different regions of Türkiye and their taxonomic classification

Local wheat landrace	Species	Wheat group	Hull type	Main production regions	References
Siyez	<i>Triticum monococcum</i>	Einkorn wheat	Hulled	Kastamonu, Western Black Sea	Kan <i>et al.</i> , 2015
Kavılca	<i>Triticum dicoccum</i>	Emmer wheat	Hulled	Kars, Ardahan	Kan <i>et al.</i> , 2015
Karakılçık	<i>Triticum durum</i>	Durum wheat	Free-threshing	Aegean, Mediterranean regions	Morgounov <i>et al.</i> , 2016
Sorgül	<i>Triticum durum</i>	Durum wheat	Free-threshing	Southeastern Anatolia	Morgounov <i>et al.</i> , 2016
Zerun	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Eastern Anatolia	Kan <i>et al.</i> , 2015
Kırık	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Eastern Anatolia	Kan <i>et al.</i> , 2015
Ak Buğday	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Central Anatolia	Kan <i>et al.</i> , 2015
Kırmızı Buğday	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Central Anatolia	Kan <i>et al.</i> , 2015
Koca Buğday	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Central Anatolia	Kan <i>et al.</i> , 2015
Topbaş	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Eastern Anatolia	Kan <i>et al.</i> , 2015
Sarı Buğday	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Central Anatolia	Kan <i>et al.</i> , 2015
Şahman	<i>Triticum aestivum</i>	Bread wheat	Free-threshing	Eastern Anatolia	Kan <i>et al.</i> , 2015

Of these, the hulled wheats — einkorn and emmer — carry the most evolutionary weight. Einkorn was first domesticated on Karacadağ in south-

eastern Türkiye about ten thousand years ago, which puts Anatolia among the earliest centres of wheat domestication (Nesbitt and Samuel, 1996; Zohary *et al.*, 2012). Free-threshing wheats have largely pushed the hulled species out of intensive farming, but einkorn and emmer are still sown in parts of the country, mostly on marginal land and in traditional systems.

The simultaneous cultivation of several wheat species in traditional farming systems contributed to the genetic breadth of Turkish material. This taxonomic diversity gives breeders access to distinct sources of stress tolerance, yield stability, and grain-quality traits.

Molecular studies on wheat landrace diversity

Molecular markers allowed differences hidden by local names or spike form to be measured directly. In an early example, Özkan *et al.* (2002) found substantial AFLP, RAPD, and microsatellite variation among Near Eastern and Anatolian samples. The result supported the region's status as a diversity centre, while also showing why morphology alone is an incomplete guide.

More recent genome-wide analyses have strengthened that conclusion. High-throughput SNP genotyping and genome sequencing generally reveal a broader allelic range in landraces than in modern cultivars, reflecting their different histories of selection and adaptation (Cavanagh *et al.*, 2013; Balfourier *et al.*, 2019). Some of this variation may be useful for improving response to drought, high temperature, and nutrient-poor soils.

The value of genebank collections shows up clearly at large scale. Genome-wide analyses of tens of thousands of accessions reveal strong geographic structuring and put Near Eastern landraces near the centre of cultivated wheat's evolution (Sansaloni *et al.*, 2020; Balfourier *et al.*, 2019), which means populations from places like Türkiye keep genetic signatures that modern breeding germplasm largely lacks. Molecular data have also laid bare how tangled wheat's evolution really is — hybridisation, polyploidy, gene flow back and forth between wild and cultivated forms — the very processes that built the diverse genome of today's crop (Dubcovsky and Dvorak, 2007; Feldman and Levy, 2012). Landraces, then, are raw material for widening the breeding base.

The weight of molecular evidence puts wheat landraces from Türkiye and the Near East at the heart of global wheat diversity, with a lot to offer for resilience and for sustainability. Making use of it means marrying genomics to the older business of scoring plants in the field, so that adaptive traits can be found and moved into breeding. Progress notwithstanding, the history, the genetics, and the function of these populations have rarely been brought under one analytical roof. Studies tend to describe — domestication, morphology,

regional patterns — and to leave the genomic and phenotypic data to one side. How far past selection actually shaped traits that matter for today's and tomorrow's climates is still largely unknown. Answering that will take genuine cross-talk between archaeobotany, molecular genetics, and field phenotyping, and it is the only way to turn what we know into working strategies for improvement, conservation, and a more climate-proof agriculture.

Current status of wheat landrace cultivation

As modern cultivars took over through the twentieth century, the ground given to traditional landraces shrank hard. On recent figures they now cover under one per cent of Türkiye's wheat area (Kan *et al.*, 2015).

Even so, landraces are still grown in particular places, above all in:

- Eastern Anatolia
- mountainous areas of the Black Sea region
- marginal agricultural environments in South-eastern Anatolia

In these places the landraces are suited to low inputs and to rough conditions, and their diversity and hardiness keep them useful for breeding aimed at climate change and abiotic stress (Dempewolf *et al.*, 2014; Reynolds *et al.*, 2015).

Conservation of Turkish Wheat genetic resources in genebanks

Holding on to wheat landraces is what keeps their diversity — and the useful traits inside it — available for future breeding. With traditional varieties swept aside so fast in the last century, storing them *ex situ*, in genebanks, has become the main line of defence (Dempewolf *et al.*, 2014). Figure 2 lays out the main routes, *in situ* and *ex situ* both, by which Turkish landraces are conserved.

Türkiye runs two big national genebanks for plant genetic resources, wheat landraces among them: the Turkish Seed Gene Bank in Ankara and the National Gene Bank at the Aegean Agricultural Research Institute (AARI) in İzmir. Between them they carry the country's *ex situ* conservation.

The Turkish Seed Gene Bank in Ankara was established by the Ministry of Agriculture and Forestry and has capacity for approximately 120,000 accessions. Its collection covers many crop species and includes wheat landraces sampled from different parts of Türkiye.

The National Gene Bank managed by AARI in İzmir holds approximately 60,000 accessions, including landraces and wild relatives of wheat, barley, and several legumes (Tan and Tan, 2010).

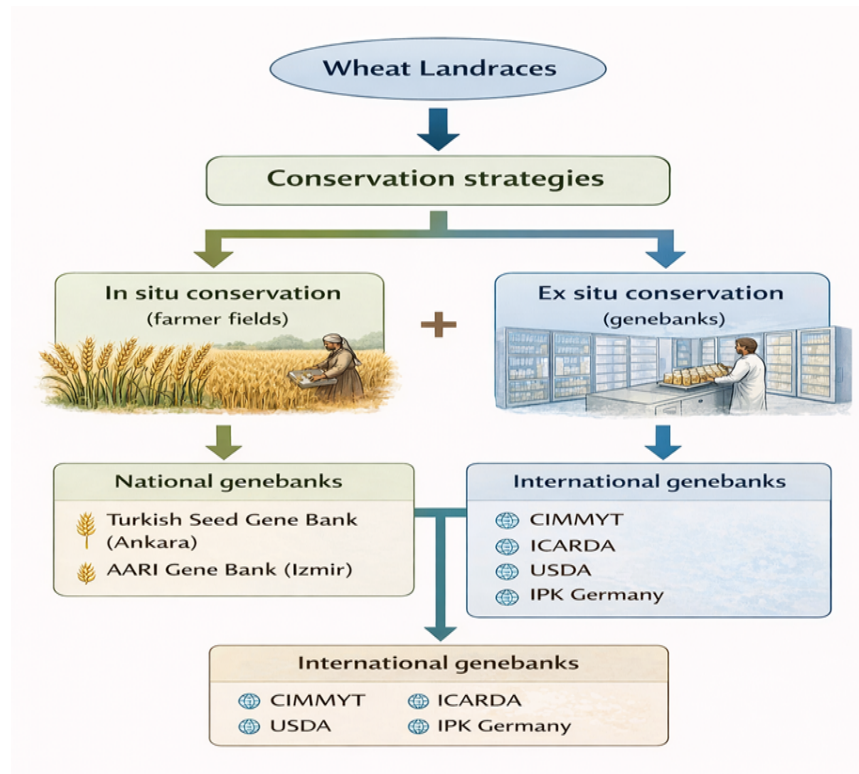


Figure 2. Conservation strategies for wheat landraces through in situ (on-farm) and ex situ (genebank) approaches, including major national and international genebanks maintaining Turkish wheat genetic resources

Accessions originating from Türkiye are also maintained outside the country. Important collections are held by CIMMYT in Mexico, ICARDA, the USDA National Small Grains Collection, and the IPK institute in Germany. Together, these repositories conserve thousands of Turkish wheat accessions and provide an additional safeguard for national collections (FAO, 2010; Morgounov *et al.*, 2016).

Held in national and international banks alike, these collections guard against genetic erosion and keep useful material on hand for research and breeding — including the search for climate-resilient wheat.

Morphological and phenological traits

Of all the ways genetic diversity shows itself in wheat landraces, morphology and phenology are the most visible and among the most consequential. Modern cultivars are largely uniform and cut for one kind of field;

landraces vary — in architecture, in growth habit, in when they reach each stage. That variation is the joint work of genes, a patchy environment, and farmer selection, and it is a large part of why landrace populations are so resilient (Zeven, 1998; Jaradat, 2013).

Early Turkish classifications relied on spike, grain, height, and growth-habit descriptors (Gökgöl, 1939). These characters remain useful for organising collections, but their expression is affected by environment. They should be treated as measurements to be repeated under standard conditions, not as fixed properties of a local name.

Karagöz and Zencirci (2005) reported geographic and elevational patterns in height, spike length, awns, kernel size, and tillering. Such patterns are compatible with local selection, but shared ancestry or sampling can produce the same result. Common-environment trials are needed to separate these explanations.

Heading and maturity often have a more immediate effect on performance because they determine exposure to terminal drought, heat, or frost (Akcura and Kaya, 2008). Genotype rankings change among environments: some genotypes yield less at favourable sites but fluctuate less at stressful ones (Kaya *et al.*, 2006). Such stability should not be attributed to within-population diversity until differences in maturity and plant architecture have been accounted for. Canopy form may alter resource capture or disease development, but resistance still requires direct testing (Jaradat, 2013).

Genetic erosion of Wheat Landraces in Türkiye

Genetic erosion is the draining-away of diversity within a crop as traditional landraces give way to modern high-yielding cultivars and as the whole system of production changes (FAO, 2010). Across the last century, intensification and the spread of improved varieties thinned the diversity in farmers' fields the world over. Cereals felt it most: in wheat, breeding has long favoured the uniform cultivar built for high inputs (Brush, 2004).

Turkish wheat once rested on locally adapted landraces kept alive by farmers' own seed. Cycle after cycle of selection, exchange, and adaptation spread a wide range of genetically diverse populations across the country's agroecological zones (Karagöz, 1996). The Green Revolution changed that in the century's second half. Where conditions were good and inputs available, high-yielding cultivars steadily displaced the old landraces (Karagöz, 2014).

The decline is on record. A national survey run from 2009 to 2014 across 65 provinces found landraces reduced to scattered pockets, under one per cent of the wheat area (Kan *et al.*, 2015). It logged more than 160 landrace names and

gathered over 1,500 samples from farmers — and still showed how tightly the old populations had contracted onto a few regions.

Today landraces are mostly a matter of the remote and marginal — Eastern Anatolia, the Black Sea highlands, parts of the south-east. Often, they are grown for the household or for traditional foods rather than the market (Morgounov *et al.*, 2016), bound up with subsistence farming and the older ways of working the land.

Several forces drove the erosion. Chief among them: the spread of high-yielding cultivars, mechanisation, the reach of commercial seed, and a market that wants uniform grain. Add to that rural migration and the fading of the farmer seed systems that had carried landrace diversity in the first place (Brush, 2004).

The on-farm decline is not the whole story. Much of what was collected in earlier decades now sits in national and international genebanks, a hedge against outright loss and a source of germplasm for breeding toward stress tolerance and resilience under a shifting climate (Dempewolf *et al.*, 2014).

Erosion has cut deep into landrace cultivation in Türkiye, then — but what farmers still grow and what the banks still hold remain a real store of diversity. Protecting it, and folding it into modern breeding, is what will keep wheat production resilient over the long run.

Stress adaptation and ecological resilience: physiological foundations

Survival in a marginal field is often taken as evidence of stress tolerance, although the inference is weak unless both the stress and the population are defined. Variable management may instead select for early development, plasticity, or a mixture of plant types (Blum, 2011; Reynolds *et al.*, 2015). Claims of tolerance therefore need comparisons with suitable cultivars under the intended stress environment.

The strongest evidence concerns drought. Certain landraces retain green leaf area or yield as water becomes limiting; conservative water use and slower senescence are among the proposed explanations (Blum, 2011). Timing complicates interpretation. Early flowering can escape terminal drought without conferring tissue tolerance. The same caution applies to heat and salinity: the collection site is context, not a physiological measurement (Nevo and Chen, 2010; Passioura, 2012).

Roots are a conspicuous gap in the Turkish literature. Studies in other wheat material link deeper or redistributed roots with access to stored water (Manschadi *et al.*, 2006), but comparable measurements are scarce for Turkish landraces. It is not yet clear whether their populations differ in soil exploration or whether observed shoot responses merely reflect drought escape.

A useful test would measure phenology, root distribution, canopy response, and yield on the same accessions in more than one environment. Genomic associations could then be made with measured characters rather than a general label of resilience. Such a design would also separate genetic effects from the management history of traditional fields (Araus and Cairns, 2014; Richards *et al.*, 2010).

Why farmers still keep landraces

A farmer-maintained population continues to change through seed choice and exchange. In Türkiye, seed saved at home or obtained from neighbours and local markets still circulates outside formal supply channels (Brush, 2000; Jarvis *et al.*, 2008). This circulation can maintain variation, but it can also mix populations. Collection records should therefore include where the seed came from and how it has moved.

Farmers keep or discard a landrace for several linked reasons. Surveys describe reliable performance under low inputs, familiarity, seed access, bread or bulgur quality, and straw value (Kan *et al.*, 2015; Morgounov *et al.*, 2016; Özberk *et al.*, 2023). A household may accept lower grain yield when the crop performs several functions. Conversely, mechanisation, certified seed, weak demand, and younger farmers' preferences favour modern cultivars. These economic and cultural factors are as important to on-farm conservation as biological adaptation.

On-farm cultivation and genebank storage conserve different things. A genebank secures a sampled population; continued cultivation allows selection and seed exchange to continue (Jarvis *et al.*, 2008; Dempewolf *et al.*, 2014). Programmes that connect farmers with documented collections and participatory breeding can therefore preserve material while also testing its value.

Yield performance, quality traits, and nutritional value

Modern cultivars usually lead in favourable, well-managed trials. A landrace may still be preferred when a household values dependable output in poor seasons, useful straw, or grain for a particular food. Turkish experiments report lower yield potential in many populations and, in some cases, less variation among environments (Karagöz and Zencirci, 2004; Akcura and Kaya, 2008). Table 2 presents tendencies reported across studies; it is not a profile of every landrace.

Table 2. Key agronomic and adaptive traits of wheat landraces compared with modern cultivars

Trait	Wheat landraces	Modern cultivars	Importance
Genetic diversity	High	Low	Broad adaptation
Yield potential	Moderate	High	Productivity
Yield stability	High	Moderate	Risk reduction
Drought tolerance	Often high	Variable	Climate adaptation
Nutrient use efficiency	Often high	Moderate	Low-input systems
Grain quality diversity	High	Moderate	Traditional foods
Adaptation to marginal environments	Strong	Limited	Sustainable agriculture

Grain quality must likewise be judged against its intended use. Protein level or gluten behaviour that is inconvenient for standard milling may suit a traditional product (Karagöz and Zencirci, 2004). High iron or zinc has been reported in some accessions (Cakmak *et al.*, 2010; Piergiovanni, 2013), but concentration changes with environment and yield. Nutritional claims therefore need confirmation across sites and seasons (Shewry and Hey, 2015).

Heterogeneous height, lodging, and grain size can prevent direct large-scale use. Breeding offers a more practical route: identify the favourable character, establish that it is inherited, and transfer it without the undesirable background. Most landraces are therefore better regarded as possible donors or specialised crops than as replacements for modern cultivars.

What regional comparisons do—and do not—show

A regional label supplies environmental context, yet it can hide variation among villages and seed lots. Central Anatolia, for example, combines irregular rain with widespread calcareous soils. Early maturity, short stature, and relatively stable rainfed performance have been reported in some material from the region (Karagöz, 1996; Zencirci *et al.*, 2003). Those traits should be attributed to regional adaptation only after populations are compared at shared sites.

Eastern Anatolia imposes cold winters, high elevation, and a short growing season. Near Lake Van, flowering date and winter survival are therefore obvious traits to test, and Özbek *et al.* (2001) reported substantial variation in regional material. Wheat from the milder Aegean and Marmara areas is often later, taller, and higher in biomass (Karagöz, 1996). Even so, local soil, microclimate, and seed history can be more informative than the broad regional contrast.



Figure 3. Geographic origin of representative Turkish wheat landraces and adaptive features commonly associated with four production regions

Genotype rankings change across locations (Kaya *et al.*, 2006), so landraces should be tested both near their source and in common trials. Areas where farmer seed management remains active are priorities for collection and on-farm conservation (Kan *et al.*, 2015). Together, source information and multi-site data are more informative than region or landrace name alone.

The role of local Wheat Landraces in breeding, conservation, and sustainable agriculture

Worries about genetic erosion, about the climate, and about whether modern farming can last have all turned attention back to landraces. In wheat they are reservoirs of the diversity modern breeding lacks — carriers of adaptive traits thinly represented, or missing, in elite cultivars (Dempewolf *et al.*, 2014; Reynolds *et al.*, 2015). Figure 4 gathers their several roles across breeding, resilience, and sustainable farming.

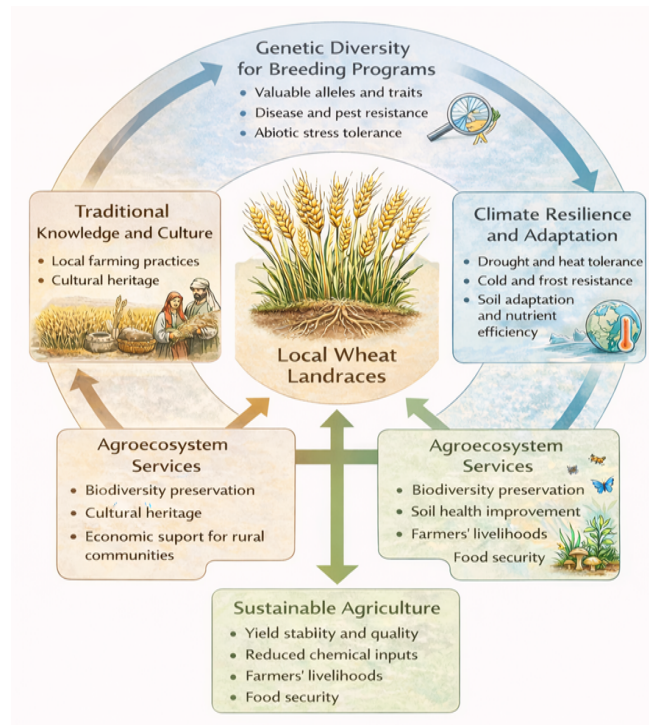


Figure 4. Conceptual framework illustrating the multiple roles of wheat landraces in breeding programs, climate resilience, agroecosystem services, and sustainable agriculture

Their first gift to breeding is width. Modern wheat has climbed in yield, but leaning on the same few parents narrowed its base; landraces, grown up under every kind of condition, hold allelic variation the elites never sampled — genes for drought, heat, poor soils, some diseases (Reynolds *et al.*, 2015).

Participatory and decentralised breeding has proved a good way to bring that variation in. Farmers and researchers choose locally adapted material together, in real fields, and the approach earns its keep on marginal land, where conventional programmes struggle to make anything that performs reliably under mixed stress (Ceccarelli and Grando, 2007; Ceccarelli *et al.*, 2007). Landraces do more than feed breeding, though — they help conserve agricultural biodiversity. Genebanks are essential but frozen; they cannot reproduce the evolution that goes on in a farmer's field. In situ and on-farm conservation lets a population keep changing under local conditions and local selection, and so keeps its adaptive edge (FAO, 2010; Dempewolf *et al.*, 2014).

Agroecological and climate-resilient breeding provide possible uses for this diversity, but the problem must be defined first. Material maintained under

low inputs may contain useful differences in nutrient acquisition or stress response (Altieri *et al.*, 2015). It may also perform poorly or vary too much for a target market. Evaluation against modern checks is therefore essential.

Future environments will combine heat, irregular rainfall, and soil constraints that are not well represented in every elite pool (Reynolds *et al.*, 2015). Landraces may carry useful alleles, but agronomic heterogeneity, poor documentation, and demand for uniform grain slow their use. The productive question is not whether landraces are generally valuable, but whether a documented accession solves a defined breeding problem.

Conclusion: priorities for evidence and use

Turkish wheat landraces differ too much in history and composition to support a single judgement about their value. Studies report variation in stress response, stability, and grain quality, but the strength of evidence varies by trait. A population becomes useful to breeding when its identity is documented and its claimed advantage survives an appropriate comparison.

Anatolia's long cultivation history and environmental contrasts helped produce many local populations. Their displacement by improved cultivars reduced cultivation sharply, especially in productive areas. Genebanks protect collected samples from loss; farms maintain continued use, selection, and exchange. These functions are complementary rather than interchangeable.

The immediate research need is to test genomic and field evidence together. The same accessions should be evaluated repeatedly for phenology, roots, resource use, yield, and a clearly imposed stress. An association observed at one site should be verified elsewhere before the allele or accession is recommended to breeders.

Farmers can add seed origin, exchange, food use, and local performance—details often missing from passport records. Linking this knowledge with documented collections and participatory selection would improve conservation and evaluation, while distinguishing breeding material from populations kept mainly for food, culture, or history.

Conflicts of interest

The authors declare no conflict of interest.

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