Chapter 3

Genetic Resources of *Triticum*

Karl Hammer and Helmut Knüpfper

Abstract The political framework and the development of molecular biology and electronic data management caused a general paradigm shift in plant genetic resources (PGR), exemplified here for wheat. (1) *In situ* versus *ex situ* maintenance of PGR. *Ex situ* maintenance lost predominance. Wild wheats are effectively maintained in the wild; landraces do well on farm. New methods did not lead to the expected progress. (2) Inclusion of neglected and underutilized crop species. Some species are probably extinct in traditional cultivation areas, whereas landraces were recently found for others. Wild relatives have gained importance in wheat breeding: besides wild *Triticum* species, also *Aegilops*, *Secale*, *Hordeum* and other genera are used. $\times$ *Triticosecale* reached world importance; $\times$ *Tritordeum* will follow soon. (3) Methods of analysing diversity within and between taxa. New technology yields new insights in the structure and evolution of populations. (4) Genetic erosion is a problem, also inside genebanks. (5) Landraces show complex morphological diversity. Intraspecific classification systems are useful for their characterization and handling, but less recognised by breeders. (6) Methods of evaluation. Molecular markers identify genetic differences on a fairly simple level without reference to ecological adaptation. (7) Genebanks should expand classical evaluation programmes. Pre-breeding will gain importance. (8) Storage and reproduction in genebanks is done effectively and cost-efficiently under long-term conditions, but strategic concepts for reproduction are needed. Traditional methods are often neglected, and modern possibilities over-emphasized. Maintenance of landraces in genebanks and on farm poses challenges. PGR work is conservative. Landraces can be studied by traditional methods; molecular methods can resolve specific questions.

Keywords Crop wild relatives • Diversity • *Ex situ* • Evaluation • *In situ* • Landraces • Neglected crops • Paradigm shift • Wheat

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K. Hammer • H. Knüpfper (✉)

Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) Gatersleben,
Corrensstr. 3, D-06466 Stadt Seeland OT Gatersleben, Germany
e-mail: knuepfer@ipk-gatersleben.de

Introduction

The importance of wheat as a world crop is reflected by the large amount of wheat accessions in the world's genebanks. The FAO (2010) estimated that wheat has the largest number of accessions (856,000), followed by rice (774,000) and barley (467,000). An earlier count (Knüpfper 2009) yielded 732,000 wheat accessions. Large collections have been brought together, especially during the period of the Plant Genetic Resources Movement, described by Pistorius (1997) for ca. 1960–1990. A prominent figure in this Movement has been Erna Bennett (Hanelt et al. 2012) who organised the First Technical Conference on Plant Genetic Resources (Bennett 1967), along with Sir Otto Frankel, Jack Harlan, and Jack Hawkes.

In the beginning of the 1990s, a general paradigm shift (Hammer 2003) was observed in the discipline of plant genetic resources (PGR). The “Convention on Biological Diversity” (CBD 1992) substituted and partly replaced an earlier (1983) instrument, the “International Undertaking on Plant Genetic Resources for Food and Agriculture” of the FAO. A harmonization process between both agreements resulted in the “International Treaty on Plant Genetic Resources” (FAO 2001), still in a state of needing improvements (Moore and Tymowski 2005). Different constituents of plant biodiversity were named differently and, accordingly, treated differently.

Apart from this political framework, a second challenge for PGR arose from the rapid development of molecular biology and of electronic data documentation, management and exchange.

The political and scientific processes together led to a general paradigm shift in PGR, which is here exemplified for wheat.

Paradigm Shifts

In Situ as Opposed to Ex Situ Maintenance of PGR

The *ex situ* maintenance in genebanks lost its predominance (Brush 2000). For wild wheats, the *in situ* approach has definite advantages. But also for landraces, on-farm maintenance is increasingly being proposed, particularly in their areas of high diversity (Vavilovian gene centres). Since such areas sometimes are suffering from political instability, a loss of genetic resources of wheat is possible. A complementary consideration of the different levels of diversity (intraspecific, species, and ecosystem diversity) is necessary. Wild wheats can be most effectively maintained and protected in the wild, whereas landraces do well on farm, but only if farmers are interested and have the possibilities to take care of them. Here, the methods are still developing but did not lead to the expected progress.

Another shift took place from emphasis on collecting and rescuing landraces and crop wild relatives (CWR), to emphasis on their preservation, evaluation and utilization. Some genebanks still continue collecting, because of the threats of genetic erosion and the expected loss of valuable material for future breeding and utilization. Genetic erosion was an important argument for the Plant Genetic Resources Movement.

Inclusion of Neglected and Underutilized Cultivated Plants

Their importance has been highlighted by Padulosi et al. (2012). Apart from *Triticum aestivum* L., *T. compactum* Host, *T. durum* Desf., and *T. turgidum* L., all other domesticated wheat species can be considered rare, perhaps with the exception of *T. turanicum* Jakubz. (“Kamut”) and *T. polonicum* L. with a slightly increasing area of cultivation because of their larger grains for improved and new bakery products. Some wheat species are probably extinct in their traditional cultivation areas, such as *T. ispahanicum* Heslot first described by Heslot (1958), also reported by Kihara’s expedition (Kihara et al. 1965) and Kuckuck’s FAO missions in 1952–54 (Kuckuck and Schiemann 1957), but later not found again in Iran despite intensive searches (Damania et al. 1993; Khoshbakht and Hammer 2010); *T. jakubzineri* (Udachin et Shakhm.) Udachin et Shakhm., *T. karamyshevii* Nevski, *T. macha* Dekapr. et Menabde, *T. parvicoccum* Kislev, *T. timopheevii* (Zhuk.) Zhuk., and *T. zhukovskyi* Menabde et Ericzjan. Most of them are, however, maintained in genebanks (Table 3.1). Landraces were recently found (re-discovered) for *T. sphaerococcum* Percival in India (Mori et al. 2013), *T. aethiopicum* Jakubz. in Yemen, Oman, and Egypt, *T. dicoccon* Schrank, and *T. monococcum* L.

We want to provide two examples. In Italy from 1980 on, PGR have been collected every year in a collaborative programme between the genebanks of Gatersleben and Bari. In Basilicata province, P. Perrino and K. Hammer found relics

Table 3.1 Total number of accessions of some rare cultivated *Triticum* species in genebanks, and the number of genebanks preserving them

Taxon	Accessions	Genebanks
<i>Triticum aethiopicum</i>	909	17
<i>T. dicoccon</i>	4,775	52
<i>T. ispahanicum</i>	53	16
<i>T. jakubzineri</i>	5	5
<i>T. karamyshevii</i>	71	25
<i>T. macha</i>	232	28
<i>T. monococcum</i>	5,367	54
<i>T. timopheevii</i>	590	37
<i>T. zhukovskyi</i>	64	22

After Knüpfper 2009; Table 5

of emmer and einkorn cultivation (Perrino et al. 1981), which had been considered extinct in Italy. This encouraged other Italian researchers to successfully look for these species, as well as *T. spelta* L., in other parts of Italy (e.g. Laghetti et al. 2009). Discoveries of relic cultivation of hulled wheat species in other European countries and beyond led to a workshop on “Hulled Wheats” in Italy (Padulosi et al. 1996). Since that time, the scientific interest in traditional hulled wheats is unbroken. Their cultivation is gradually increasing.

In the 1930s, *T. aethiopicum* was described as a new species from Ethiopia and Yemen by Vavilov and co-workers. This wheat is recognized as a good species in Flora Ethiopica (Phillips 1995), contrary to other treatments proposing infraspecific recognition at the best. *Triticum aethiopicum* is not yet fully understood, being related with *T. durum* and *T. turgidum*. A large proportion of the wheats grown in Ethiopia still belong to this species (Teklu and Hammer 2006). It was also found in cultivation in Oman (Hammer et al. 2009) and in Egypt, concluding from herbarium sheets in the Vavilov Institute (St. Petersburg) that were re-classified as *T. aethiopicum* (Gowayed 2009). The variable landraces still present in Oman (often mixtures of *T. aethiopicum*, *T. compactum*, *T. aestivum*, *T. durum*, and *T. turgidum*) and in Ethiopia deserve our special consideration.

Crop wild relatives, i.e. *T. urartu* Thumanjan ex Gandilyan, *T. boeoticum* Boiss., *T. dicoccoides* (Körn. ex Asch. et Graebn.) Körn. ex Schweinf., and *T. araraticum* Jakubz., have gained importance. This is in agreement with increasing priority attributed to CWR (cf. Maxted et al. 2008). – *Aegilops* (Kilian et al. 2011), *Secale*, *Hordeum* and many other genera of the Hordeae (formerly Triticeae) are increasingly being used for improving yield, adaptation and quality characters in wheat. The diagram (Fig. 3.1) by Bothmer et al. (1992) today needs revision and amplification. ×*Triticosecale* Wittm. (triticale) has already reached world importance (Hammer et al. 2011). ×*Tritordeum* Asch. et Graebn. (Martín et al. 1999) will follow soon. Other grass genera have been included in crossing experiments.

Methods of Analysing Diversity Within and Between Taxa

New technologies are rapidly developing and increasingly provide results towards the status and evolution of populations. Heterogeneity and heterozygosity have characteristic functions inside the genetic structure of populations. Genetic erosion is a specific problem, also inside genebanks: collected samples may be lost during maintenance in genebanks, and the allelic composition of populations may change. In the last 20 years, landraces have gained new interest as sources for extended variation (Zeven 1998). They are usually characterized by complex morphological diversity. For such variation, diagnostic infraspecific classifications have been used (e.g. Percival 1921; Mansfeld 1951; Dorofeev et al. 1979), and they proved useful for characterizing and handling landraces. For example, Dorofeev et al. (1979) (Table 3.2) recognises 27 species with 17 subspecies, 32 convarieties and 1,055 botanical varieties (Knüpfper et al. 2013). If infraspecific forms are not named and

Fig. 3.1 Genepools in Hordeae (formerly Triticeae) (After Bothmer et al. 1992)

described systematically, their diversity is at risk of being lost. Modern cultivars usually show only few morphologically discernible variants, since breeders selected only a fragment from the previously existing diversity, and, therefore, they do not see the need for traditional classification systems using botanical varieties. Scholz (2008), for example, observed that in *T. aestivum* only a single botanical variety, var. *lutescens* (Alef.) Mansf., is still present in modern cultivars, with very few exceptions.

Methods of Evaluation

Molecular markers in the form of DNA segments, even if they do not always represent functional genes, are used to identify genetic differences on a fairly simple level without reference to ecological adaptation. Traditionally many other evaluations are carried out in the breeding process. Genebanks should increase or newly

Table 3.2 Classification of *Triticum* according to Dorofeev et al. (1979), with minor changes. Authors of scientific names omitted

Subgenus	Section	Species group	Species	2n	Genome	Different genomes
<i>Triticum</i>	<i>Urtutu</i>	Small spelts	<i>T. urartu</i>	14	A ^u	1
	<i>Dicoccoidea</i>	Emmer wheats	<i>T. dicoccoides</i>	28	A ^u B	2
			<i>T. dicoccon</i>	28		2
			<i>T. karamyshevii</i>	28		2
			<i>T. ispahanicum</i>	28		2
		Naked tetraploids	<i>T. turgidum</i>	28	A ^u B	2
			<i>T. jakubzineri</i>	28		2
			<i>T. durum</i>	28		2
			<i>T. turanicum</i>	28		2
			<i>T. polonicum</i>	28		2
			<i>T. aethiopicum</i>	28		2
			<i>T. carthlicum</i>	28		2
		<i>Triticum</i>	<i>T. macha</i>	42	A ^u BD	3
			<i>T. spelta</i>	42		3
			<i>T. vavilovii</i>	42		3
		Naked hexaploids	<i>T. compactum</i>	42		3
			<i>T. aestivum</i>	42		3
			<i>T. sphaerococcum</i>	42		3
			<i>T. petropavlovskiyi</i>	42		3
<i>Boeoticum</i>	<i>Monococcon</i>	Small spelts	<i>T. boeoticum</i>	14	A ^b	1
			<i>T. monococcon</i>	14		1
		Naked diploid	<i>T. sinskajae</i>	14	A ^b	1
	<i>Timopheevii</i>	Emmer wheats	<i>T. araraticum</i>	28	A ^b G	2
			<i>T. timopheevii</i>	28		2
			<i>T. zhukovskiyi</i>	42	A ^b A ^b G	2
		Naked tetraploid	<i>T. militinae</i>	28	A ^b G	2
	<i>Kiharae</i>	Spelt wheat	<i>T. kiharae</i>	42	A ^b GD	3

establish the classical evaluation programmes. Screenings for disease resistance or reaction to abiotic stresses have been carried out in Gatersleben for long time (e.g. Nover 1962 and other publications listed by Hammer et al. 1994; Börner et al. 2006). Pre-breeding (also called germplasm enhancement) will gain importance. It is necessary to bridge the gap between geneticists (aiming at excellent research and high-ranking publications), breeders (aiming at developing new cultivars), and genebanks (aiming at conserving the existing diversity). None of them has the capacity to do pre-breeding alone. Only a combination of efforts developed by all three players can help overcoming this situation.

Storage and Reproduction in Genebanks

Plant genetic resources are usually preserved in genebanks effectively and cost-efficiently under long-term conditions, although the mutation rate may increase during storage, leading to genetic changes (Stubbe 1937). However, strategic concepts are needed for reproduction. This seemingly simple procedure is full of problems and needs higher scientific and technical inputs. For example, genebanks as a rule cannot provide sufficient seed for immediate use of accessions in experiments on larger plots. Perhaps this problem is closely related to pre-breeding.

Outlook

As is the case with all major methodological and technological changes, it is dangerous to neglect the repertoire of methods formerly used and to over-emphasize modern technologies. Landraces of crops are a challenge for maintaining in genebanks and on farm (Maxted et al. 2008). In genebanks, initially diverse landraces may lose rare alleles, due to reproduction and storage conditions, but hundreds and thousands of landraces cannot be efficiently maintained alone on-farm in their regions of origin; costs and logistics requirements are prohibitively high. The historical background and evolutionary history of landraces can be investigated in a first step by using traditional methods. Landraces show the structures for which the traditional methods have been developed. The work with PGR is conservative because we have the task to conserve them. The subsequent examination with the help of molecular methods can resolve specific questions in a satisfactory and meaningful fashion.

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