# Reaching into the past to tackle new challenges:

## Improving wheat by conserving wild 'goat grass'

**GENEBANK IMPACTS BRIEF** No. 2 | December 2019

### Seeking a rugged resilience

Genebanks ensure that plant breeders and agricultural researchers have ready access to the diverse genetic resources needed to improve crops as global environmental conditions and our dietary needs change. Crop wild relatives (CWR) are an especially important component of genebank collections because they are valuable sources of resistance to pests and diseases and tolerance to abiotic stresses in addition to yield-related traits. Compared with the cosseted products of modern plant breeding, crop wild relatives retain a rugged resilience that we can draw upon to cope with some of today's emerging challenges.

**HIGHLIGHTS**

- The availability of synthetic hexaploid wheat (SHW) widens the genetic base for bread wheat improvement.
- ICARDA and CIMMYT hold 1,570 accessions of goat grass (*Aegilops tauschii*). More than 600 accessions were used to develop 1,577 SHW since 1986.
- Over 10,000 samples of SHW were distributed to 110 institutions in 39 countries since 2000, representing 21% of the total germplasm distributed externally by CIMMYT genebank.
- Survey findings indicate that wheat varieties derived from SHW are currently grown on 10% and 34% of the wheat area in India and southwest China, respectively.

Goat grass (*Aegilops tauschii*) is the wild progenitor of bread wheat and a source of numerous useful traits in wheat, including several genes that confer resistance to stem rust, karnal bunt, tan spot and hessian fly. In the process of evolution, goat grass crossed naturally *in situ* with an ancestor of durum wheat (emmer). The result was hexaploid wheat, which we know today as bread wheat. Scientists succeeded in replicating this cross and named it synthetic hexaploid wheat (SHW). SHW serves as a bridge to transfer desirable traits from both goat grass and durum wheat into elite lines. Researchers consider it to be the ideal germplasm for raising both yield potential and diversity of several traits simultaneously. The fact that lines derived from SHW have exhibited traits that are not expressed in either of the parents confirms that this germplasm can create novel genetic variation.

While there is mounting research interest in using crop wild relatives as a source of important traits for adaptation to environmental and social change, there is scant information regarding their contribution to varieties that have been introduced to farmers. This study addresses that gap by

**BOX 1** The CIMMYT and ICARDA genebanks

Together, CIMMYT and ICARDA genebanks hold 50% of the wheat collection reported in Genesys. Conserving more than 150,000 wheat accessions, CIMMYT is the largest genebank for a single crop. The ICARDA genebank has high proportions of landraces and wild relatives, where they represent 56% and 13% of the wheat collection, respectively. These two genebanks are complementary; the CIMMYT collection is rich in breeding lines and pre-bred germplasm whereas ICARDA holds rare landraces and CWR. The germplasm conserved at CIMMYT and ICARDA is available for distribution through the multilateral system under the terms of the International Treaty on Plant Genetic Resources for Food and Agriculture.

The genebanks play a vital role in crop improvement because they conserve, maintain and make available both raw and pre-bred germplasm for the development of wheat varieties containing


economically valuable traits that are needed to confront emerging challenges such as climate variability and micronutrient deficiency.

tracing the use of goat grass accessions conserved in the genebank through the stages of wheat improvement to varieties grown in the fields of farmers. Temporal patterns in the distribution of SHW by the CIMMYT genebank were also analysed as an indication of the demand for this intermediate germplasm.

## Synopsis of methods

We searched the available evidence in order to trace goat grass (*Aegilops tauschii*) from accessions conserved in the genebank through the components of the wheat improvement process to farmers' fields.

We began by analysing the pedigree of primary SHW to identify parents. Once the goat grass accessions were identified in the genebank, passport data enabled us to assess their origins as well as the frequency of their use in SHW development. Promising pre-bred germplasm is incorporated into breeding lines for further selection and evaluation. The elite lines derived from SHW are then included in the international nurseries where nearly finished varieties are assembled for evaluation and selection under different environmental conditions by wheat breeders around the world. We examined the incorporation of SHW-derived lines into seven nurseries over time between 1996 and 2018 using records provided by CIMMYT.

Next, we identified the list of varieties released with SHW parentage from online databases (http://www.wheat-pedigree.net/, http://wheatatlas.org/), literature review and wheat survey data collected by CIMMYT. In the last stage, we explored the potential for impact on farm production by conducting a survey of users and breeders. The countries included in our survey were China, India, Argentina, Pakistan, Turkey, Kazakhstan and Bolivia. Respondents generated estimates of the share of wheat area planted to varieties with SHW parentage and reported the economically important traits associated with their use.

## Main findings

The development of primary synthetics mobilized more than 600 *Aegilops tauschii* accessions from genebanks in numerous countries around the world, leading to the creation of some 1577 SHW (Figure 1).

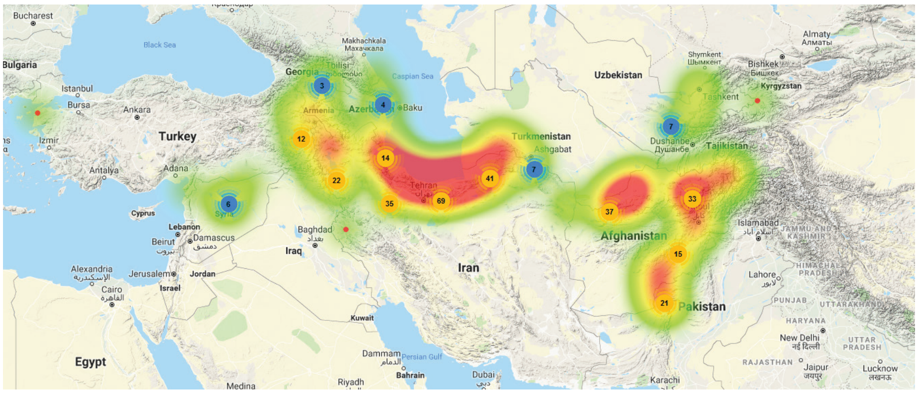


**Figure 1.** Geographic distribution of geolocalised *Aegilops tauschii* accessions used for the development of SHW by CIMMYT (Authors).

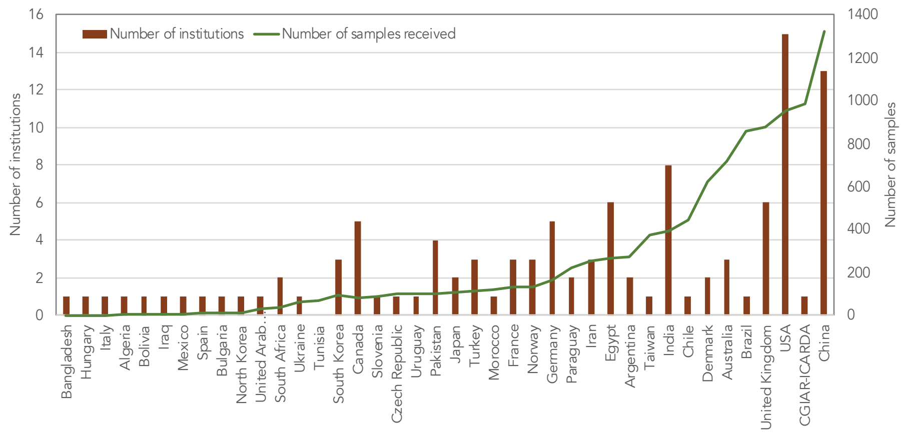


**Figure 2.** Countries receiving SHW germplasm from CIMMYT genebank since 2000

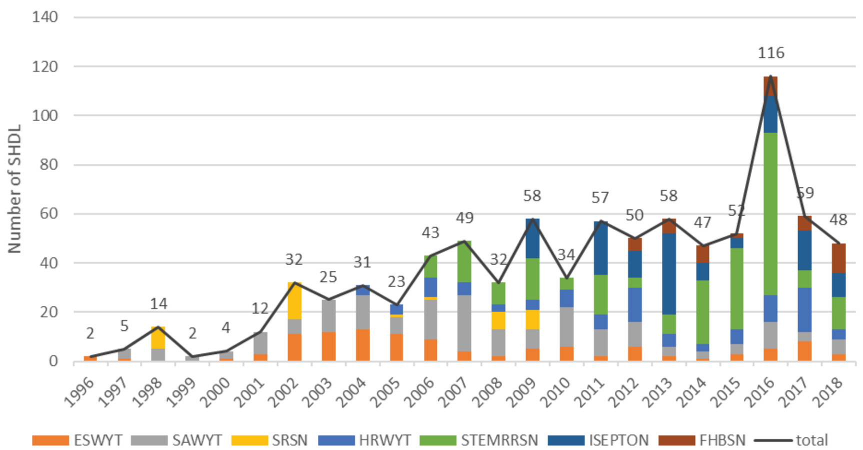


**Figure 3.** Evolution number of SHDL in seven spring wheat international nurseries since 1996 (ESWYT: Elite spring wheat yield trials, SAWYT: Semi-Arid wheat yield trials, SRSN: Scab resistance screening nursery, HRWYT: High rainfall wheat yield trial, STEMRRSN: Stem rust resistance screening nursery, ISEPTON: International Septoria Observation nursery) (Authors). *FHBSN replaced SRSN since 2011.

The accessions used represent the range of diversity in the goat grass conserved in CGIAR genebanks. In terms of origins, Iran and Afghanistan provided more than 54% of the wild germplasm used in 231 and 111 accessions respectively. Every year, on average, 42 *Aegilops* accessions were used to produce around 62 SHW. Since 2008, the number of tetraploid parents used in the crosses has increased simultaneously with the incorporation of additional goat grass accessions.

These primary synthetics represented an accessible reservoir of genetic diversity that could be explored by plant breeders in their continual search for economically important traits. We observe this in a high demand for SHW germplasm. Around 10,167 samples of SHW were distributed to 110 institutions in 39 countries since the year 2000 (Figure 2).

## BOX 2 The Genebank Impacts Fellowship

Throughout the Genebank Impacts Fellowship, I had a unique chance to visit several genebanks and learned about different ways in managing germplasm collections. In addition to the scientific knowledge gained, I could see the strength of working in a multidisciplinary team. Our impact study involved genebank managers, pre-breeders, breeders, agricultural economists, and scientists from other disciplines. These different backgrounds allowed me to analyze many aspects of genebank management from conservation to evaluation in the farmers' field.

This experience expanded my perspective on genetic resources conservation. I could see how the focus is now shifting towards the use with different strategies in each institution. In CIMMYT, for example, pre-breeding is a key activity linked to the incorporation of traits from CWR in adapted background. Having this pre-bred germplasm in the genebank allow for its characterization, evaluation and therefore make it easier for the users. ICARDA is exploiting germplasm passport data, especially for landraces, to develop algorithms allowing to make trait by origin association. This approach is called FIGS (Focused Identification for Germplasm Strategy) and it is successful in finding several traits in landraces.

*Hafid in the ICARDA Morocco active genebank.*

The Wheat Genetic Resources Center at Kansas State University is using the genotypic data to reduce the physical number of wild seed accessions for use, but at the same time increasing the use of wheat diversity in pre-breeding.

Turning to use in breeding, we found that the incorporation of SHW in elite germplasm had its impact on the composition of the international nurseries. Since 1996, 853 lines derived from crosses with *Aegilops tauschii* were evaluated in the seven nurseries included in this study (Figure 3). Synthetic hexaploids were extensively screened for resistance to Septoria, stem rust, and fusarium head blight. The number of SHW-derived lines included in these nurseries over the years reflects their significance. In the last nine years, 30% of SHW-derived lines were screened for Septoria resistance.

These findings corroborate the results of an analysis showing that genetic diversity conferred though parentage (Coefficient of Parentage) rose as more SHW-derived parents were included in pedigrees of CIMMYT germplasm distributed in nurseries. This finding is made more meaningful when we consider that nurseries are a gateway for wheat germplasm selection by national agricultural research services (NARS)—representing a lower bound on the genetic diversity available for introduction to farmers.

Eighty-five wheat varieties with SHW in their genetic background have been released to farmers in 21 countries. Our survey revealed that 57% of these varieties reached NARS through the international nurseries. Most of them are released in China (18), India (10) and Pakistan (9). Survey respondents estimated that SHW-derived cultivars are currently grown on over 2 million hectares in southwest China (34% of total wheat area) and on 10% of the wheat area in India. Reported yield potential of these varieties ranges from 2.7 to 9 tonnes/ha depending on the environment and growing conditions. The variety Chuanmai 42 reached a record yield of 10.7 t/ha in 2010 – 30% higher than the previous provincial record for a wheat variety (Li, Wan, and Yang 2014).

The traits most frequently cited by survey respondents in the varieties currently grown by farmers were disease and pest resistance, yield potential, and yield stability. Drought and heat tolerance were reported in 30% of the varieties described by respondents and are important traits associated with yield stability. In addition to agronomic performance, SHW contributed to zinc-enriched, biofortified varieties that have now been introduced to farmers—such as Zinc Sakhti in India and INIAF Yesera in Bolivia. Introduction of both of these involved a participatory approach with farmers. Regarding traits of utility in germplasm development to address micronutrient deficiencies, tests of the performance of synthetic hexaploid lines in different growing environments have demonstrated high content of iron, magnesium, and zinc (Calderini and Ortiz-Monasterio 2003).

## Conclusion and future considerations

Pre-breeding links the conservation of crop wild relatives to the incorporation by plant breeders of economically valuable traits that are needed to confront emerging challenges, such as climate variability and micronutrient deficiency. The genebank plays a vital role in crop improvement because it conserves, maintains, and makes readily available both raw and pre-bred germplasm. The story of goat grass (*Aegilops tauschii*) and synthetic hexaploid wheat illustrates this process. Goat grass, one of the wild ancestors of modern bread wheat, has been re-incorporated into new varieties via intermediate germplasm. These new varieties supply crucial traits, including tolerance to drought and heat and pest resistance, that are much needed by farmers around the world. They are especially important to farmers in developing countries who often have little means other than the seed they plant to protect their crop.

We found that the complexity of the overall crop improvement process including pre-breeding makes it difficult to trace back to the origin of advanced lines and released cultivars. A more integrated data management system is needed to better accomplish this aim in future studies. For example, DOIs could enhance our ability to directly link genetic resources conserved in genebanks with the germplasm devel-


**Picture 1.** Seeds of the biofortified variety INIAF Yesera released in Bolivia Source (INIAF).

**Picture 2.** Participative Evaluation for the selection of the variety INIAF Yesera Source (INIAF).

oped by plant breeders and the varieties eventually introduced to farmers.

The full economic value of any germplasm is directly related to its uniqueness and rarity. Enriching genebank collections with unique germplasm requires a thorough analysis of the global collection to reduce duplication and fill gaps. Next generation sequencing has shown its potential to reveal the redundancies and rationalize the management of collections. The vulnerability of crop wild relatives in natural habitats should also be taken into account when prioritizing the collecting. Moreover, the value of using crop wild relatives in crop improvement will rise as pre-breeding programs expand and as more crossing barriers are overcome.

## Further reading

Calderini, Daniel F., and Ivan Ortiz-Monasterio. 2003. "Are Synthetic Hexaploids a Means of Increasing Grain Element Concentrations in Wheat?" *Euphytica* 134 (2): 169–78. https://doi.org/10.1023/B:EUPH.0000003849.10595.ac.

Dempewolf, Hannes, Gregory Baute, Justin Anderson, Benjamin Kilian, Chelsea Smith, and Luigi Guarino. 2017. "Past and Future Use of Wild Relatives in Crop Breeding." *Crop Science* 57 (3): 1070. https://doi.org/10.2135/cropsci2016.10.0885.

Dreisigacker, S., M. Kishii, J. Lage, and M. Warburton. 2008. "Use of Synthetic Hexaploid Wheat to Increase Diversity for CIMMYT Bread Wheat Improvement." *Australian Journal of Agricultural Research* 59 (5): 413. https://doi.org/10.1071/AR07225.

Gollin, D., M. Smale, and B. Skovmand. 2000. "Searching and Ex Situ Collection of Wheat Genetic Resources." *American Journal of Agricultural Economics* 82 (4): 812-827.

Hajjar, Reem, and Toby Hodgkin. 2007. "The Use of Wild Relatives in Crop Improvement: A Survey of Developments over the Last 20 Years." *Euphytica* 156 (1–2): 1–13. https://doi.org/10.1007/s10681-007-9363-0.

Lage, J., and R. M. Trethowan. 2008. "CIMMYT's Use of Synthetic Hexaploid Wheat in Breeding for Adaptation to Rainfed Environments Globally." *Australian Journal of Agricultural Research* 59 (5): 461. https://doi.org/10.1071/AR07223.

Li, Jun, Hong-Shen Wan, and Wu-Yun Yang. 2014. "Synthetic Hexaploid Wheat Enhances Variation and Adaptive Evolution of Bread Wheat in Breeding Processes: Synthetic Hexaploid Wheat Enhances Evolution." *Journal of Systematics and Evolution* 52 (6): 735–42. https://doi.org/10.1111/jse.12110.

## Suggested citation

Hafid Aberkane, Thomas Payne, Masahiro Kishi, Melinda Smale, Ahmed Amri and Nelissa Jamora. 2019. Reaching into the past to meet today's challenges: Improving wheat by conserving wild 'goat grass'. Genebank Impacts Brief No. 2. In *Genebank Impacts: Working Papers Series.* 2019. Edited by Nelissa Jamora, Melinda Smale and Michael Major. CGIAR Genebank Platform and the Crop Trust.

## Acknowledgement

Funding for this research was provided by the CGIAR Genebank Platform, CIMMYT, ICARDA and the Crop Trust through the 2018 Genebank Impacts Fellowship.

---

*Additional details can be found in the paper on which this brief is based: Hafid Aberkane, Thomas Payne, Masahiro Kishi, Melinda Smale, Ahmed Amri and Nelissa Jamora. 2019. Transferring diversity of goat grass to farmers' fields through the development of synthetic hexaploid wheat. Genebank Impacts Working Paper No. 2. CGIAR Genebank Platform, CIMMYT, ICARDA, and the Crop Trust.*

## AUTHORS

**Hafid Aberkane**
International Center for Agricultural Research in the Dry Areas (ICARDA)
h.aberkane@cgiar.org

**Thomas Payne**
International Maize and Wheat Improvement Center (CIMMYT)

**Masahiro Kishi**
International Maize and Wheat Improvement Center (CIMMYT)

**Melinda Smale**
Michigan State University

**Ahmed Amri**
International Center for Agricultural Research in the Dry Areas (ICARDA)

**Nelissa Jamora**
Global Crop Diversity Trust

CGIAR Genebank Platform

CROP TRUST

ICARDA
Science for resilient livelihoods in dry areas

CIMMYT
International Maize and Wheat Improvement Center