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SUSTAINABLE AGRICULTURE AND RURAL DEVELOPMENT

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INSTITUTE OF AGRICULTURAL ECONOMICS BELGRADE

Volgina Street no. 15, 11060 Belgrade, Serbia
Phone/Fax: +381 (0) 11 69 72 858
Phone: +381 (0) 11 69 72 848

E-mail:
office@iep.bg.ac.rs

Internet address:
www.iep.bg.ac.rs

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CONSERVATION, SUSTAINABLE USE AND INSTITUTIONAL CAPACITIES OF GENETIC RESOURCES OF CEREALS

Svetlana Roljević Nikolić[1]

Abstract

Plant genetic resources which are important for food and agriculture represent only a small part of total biodiversity, but their sustainable management is crucial for maintaining the most expressive genotypes of cultivated crops made by nature itself. In accordance with the requirements of species and possibilities of countries, plant genetic material for food and agriculture is mainly conserved in two ways: in situ or in natural habitats and on farms, as well as ex situ or in gene banks. Taking into account that cereals represent the basis of the world food security, the paper examined the genetic resources of these crops i.e., their state in ex situ preservation conditions. Desk research methodology was used to collect data on the number of samples in the largest collections of cereal germplasm worldwide, with the focus on the genetic resources of wheat and maize. It is estimated that there are more than 1,750 gene banks holding approximately 7.4 million samples of different gene material of plants significant for food and agriculture worldwide. Collections of the two main cereal crops - wheat and maize - make up as much as 15% of the global ex situ conserved germplasm.

Key words: *genetic resources, cereals, gene banks, collections, samples.*

Introduction

Biological diversity, or variability of living organisms, represents a significant resource for human existence. Within the total diversity, a separate group includes plant genetic resources for food and agriculture. This group of the total diversity involves *varieties* (obsolete varieties, varieties represented in production and new varieties), *local populations, relatives* (cultivated or wild plant species) and *different selection materials* (line, pure line, inbred line or hybrid) of all species important for agriculture (Prodanović i Šurlan Momirović, 2006). Genetic variability provides the basic elements for improving the productivity, hardiness and nutritive content of cultivated plants, and represents the foundation for human existence and food security.

1 Svetlana Roljević Nikolić, Ph.D., Research Associate, Institute of Agricultural Economics, Volgina Street no. 15, 11060 Belgrade, Serbia, Phone: +381 11 69 72 842, E-mail: svetlana_r@iep.bg.ac.rs

However, the modernization of production and altered nutrition in modern times have resulted in the concentration of global agriculture on only several crops, which has led to the erosion of biodiversity. Today, only 150 plant species provide food for the largest part of global population. Not more than 12 crops provide 80% of calories obtained from plants, while only four plant species (wheat, maize, rice and potato) contribute 60% of calories of plant origin (European Communities, 2007).

The value and significance of plant genetic resources (PGRs) for the future of humanity were recognized as early as in the beginning of the twentieth century. Namely, Russian scientist N.I. Vavilov organized numerous collecting expeditions worldwide in the 1920s in order to find, conserve and use PGRs for research and breeding programmes (Loskutov, 1999). The material collected during these expeditions provided the basis for creating the first germplasm collection in the Bureau of Applied Botany (today N.I. Vavilov Research Institute of Plant Industry).

Nowadays PGRs are conserved in accordance with the species requirements and possibilities of countries in two ways: (1) *in situ* or (2) *ex situ*. *In situ* conservation is the natural and most desirable method, but cannot be applied for all species for various reasons. This method is mostly used for the conservation of wild species, wild relatives and some fruit species, while the *ex situ* method is used for the conservation of cultivated species and species reproduced by means of seeds and micro-propagation. The main forms of *ex situ* conservation are banks of plant genes which apply scientifically based technology and strictly controlled conditions for long-term (over 50 years) and medium-term (up to 20 years) conservation of samples.

It has been estimated that there are more than 1,750 banks worldwide with approximately 7.4 million samples of different genetic material of plants for food and agriculture (Crop Trust, 2016). National genebanks store around 6.6 million samples, 45% of which are held in only seven countries.

Approximately 50% of the germplasm conserved in *ex situ* conditions includes only 10 plant species, while the three largest collections (wheat, rice and barley) account for as much as 28% of the global germplasm. Approximately half of the samples in the collections are selection materials; a third is made of local populations and obsolete varieties, while the smallest percentage is represented by relatives and wild plant species. Although the least represented, the collections of relatives and wild species are the most significant since they represent the basis for increasing the germplasm divergence and breeding in the future (Roljević et al., 2011).

Centres and organizations for conservation of cereal genetic resources

Cereals have a very significant role in ensuring food security of the growing global population, as well as great trade importance. The total area of 718,123,243 ha is covered by cereals worldwide, which represents 45% of arable agricultural land. The global trade in these crops was estimated to be 413 million tonnes in 2019/20 (FAO database, 2018).

Use of the available genetic resources of these crops with the aim of breeding and productivity improvement is also significant in order to alleviate negative impacts of agriculture and food production on the environment (Pimentel et al., 1995).

Owing to their significance, cereals are the species with the largest germplasm collections conserved in genebanks worldwide. There are regional centres and national genebanks in the world conserving the germplasm of only several cereal species, as well as the genebanks focused on only one or two species. Thus, the Chinese Crop Germplasm Information System stores the genetic material of almost all main cereal species, while the Institute for Cereal Crops Improvement and John Innes conserve only the germplasm of three cereal species (barley, oat and wheat).

Table 1. Centres and organizations that store the germplasm of several cereal species

Name centres and organizations	Cereal species maintained
Chinese Crop Germplasm Information System	Barley, maize, millet, oats, rice, rye, sorghum and wheat
Institute for Cereal Crops Improvement	Barley, oats, wheat
John Innes Centre - BBSRC Cereals Collections	Barley, oats, wheat
National Institute of Agrobiological Science GenBank (Tsukuba, Japan)	Rice, barley, wheat, sorghum, millet
National Small Grains Collection (GRIN; Aberdeen, Idaho)	Oats, rice, rye, triticale and wheat

Source: Sachs, 2009

In genebanks, samples are organized into collections. Depending on their purpose, they can be:

- *Base collections* – they contain samples of germplasm under long-term conservation (over 50 years) in order to maintain its genetic identity. Seeds are conserved in cryogenic conditions, at temperatures close to freezing (up to -20 °C) and low humidity in order to ensure their longevity.

- *Active collections* – they represent the part of base collections which is operated with and regularly multiplied in the field and which is available for use, exchange and evaluation. In these collections, the samples are maintained under medium-term storage (up to 20 years) at temperatures from 0 to 10°C and relative air humidity of 20-30%.
- *Core collections* – they contain the representatives of different sample groups with similar characteristics.
- *Gene collections* – they include genotypes with specific characteristics significant for research and development.

State of wheat genetic resources

Wheat is cultivated on 214 million hectares in the world where more than 700 million tonnes of grains are produced, while the global trade in this crop was estimated to be 173.5 million tonnes in 2019/20 (FAO database, 2018). The largest areas cultivating wheat are in Asia (45.3%), Europe (28.4%) and America (16.6%). The main role of wheat as food arises from its proteins which are unique among agricultural crops. Wheat products, primarily bread, represent basic elements of human nutrition. Although wheat is an important factor in ensuring food security, recent years have witnessed the loss of wheat biodiversity due to the world population increase and creation of high-yield and intensive varieties and the accompanying economic and environmental changes (Roljević et al., 2011).

Global wheat production is almost completely based on two species: hexaploid common soft wheat or bread wheat (*Triticum aestivum* subsp. *vulgare)* accounting for more than 95% of global production and tetraploid hard wheat (*T. turgidum* subsp. *durum*).

Genebanks preserve over 800,000 samples in around 80 collections (11% of the total number of *ex situ* samples). These collections vary in size, the largest ones having more than 100,000 samples, and the smallest ones consisting of several hundred samples (Table 2). Germplasm collections contain a large number of duplicates and their number should be determined in future research.

According to the FAO data, the largest number of wheat samples can be found in the international genebank the International Maize and Wheat (CIMMYT) storing 13% of germplasm samples of this crop at the global level. The second largest genebank collection is NSGC in America, conserving 7% of wheat germplasm, followed by genebanks in China (ICGR-CAAS), India (NBPGR), and Syria

(ICARDA) (Table 2). Since there are a large number of genebanks preserving wheat germplasm, Table 3 provides only those whose collections contain more than twenty thousand samples.

Table 2. Genebanks with the largest number of wheat germplasm samples

Gene bank		Samples	
Name	Acronym	Number of samples	%
Centro Internacional de Mejoramiento de Maíz y Trigo	CIMMYT	110.281	13
National Small Grains Germplasm Research Facility, States Department of Agriculture, Agricultural Research Services	NSGC	57.348	7
Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences	ICGR-CAAS	43.039	5
National Bureau of Plant Genetic Resources (India)	NBPGR	35.889	4
International Centre for Agricultural Research in the Dry Areas	ICARDA	34.951	4
National Institute of Agrobiological Sciences (Japan)	NIAS	34.951	4
N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry (Russian Federation)	VIR	34.253	4
Istituto di Genetica Vegetale, Consiglio Nazionale delle Richerche (Italy)	IGV	32.751	4
Genebank, Leibniz Institute of Plant Genetics and Crop Plant Researsh (Germany)	IPK	26.842	3
Australian Winter Cereals Collection, Agricultural Research Centre	TAMAW C	23.811	3
Others (219)		422.052	about 50
Total (229)		856.168	100

Source: FAO, 2010.

The wheat genetic pool includes modern and obsolete varieties and breeding lines, local populations, relatives, genetic and cytogenetic stocks. *The primary gene pool* includes genes of all forms which freely recombine with the cultivated species providing fertile hybrids. *The secondary gene pool* consists of genes of related species which express a certain degree of hybridization barriers (most commonly the species *Triticum* and *Aegilops*). *The tertiary gene pool* contains related species between which the gene transfer is extremely difficult because they do not cross with the cultivated wheat species (FAO, 2010). However, the boundaries between these groups are unclear and can be altered by technological changes (Ortiz et al., 2008).

State of maize genetic resources

Maize originates from the American continent, more specifically the southern and south-western parts of Mexico, where wild species related to maize (*Teosinte* and *Gamma grass*) can still be found. Crossed with maize, they provide hybrids (Goodman and Suketoshi, 2007). While maize is domesticated over wide geographical areas, the distribution of teosinte is significantly lower. It can be mainly found in the area of central and south-western Mexico, Guatemala and Nicaragua. As opposed to most cultivated crops, the ancestor of maize is not exactly known (Jevtić, 1996).

Economic significance of maize originates from the features of the plant itself, variety of its use and production volume. The primary use of maize is for animal food (around 78% of the total global production), but it is also used in human nutrition, primarily in developing countries, and in processing industries (for the production of semolina, flour, sugar substitutes, corn oil, starch, alcohol and whiskey) (Anđelković et al., 2017).

Today maize is cultivated on 194 million ha, which is by 83% more than in 1961, the year from which the FAO data for this crop originate. The largest area under maize is in America (37%), Asia (34%) and Europe (9%). In the previous decades, selection and breeding processes tripled the yield – from 1.9 t/ha in 1961 to 5.9 t/ha in 2018. Nowadays the total global maize production amounts to more than 1.1 billion tonnes (FAO database, 2018).

Maize germplasm conservation represents the main source of desirable genes which can increase the volume and quantity of maize production and consequently the food for people and animals. The dominant strategy for maize conservation is preserving the seed samples in genebanks. The germplasm in the collections consists of local populations (traditionally cultivated), varieties, lines, hybrids, and wild relatives.

The primary genetic pool includes the species of maize (*Zea mays*) and teosinte, with which maize can easily cross and create fertile hybrids. *The secondary genetic pool* consists of *Tripsicum* species (around 16 species). The variability between the local maize populations (around 300 identified species) is significantly higher than for any other crop, and it is related to the plant height, vegetation period, number of grains per ear, yield per hectare and the altitude favourable for its growth (FAO, 2010)

Maize collections are stored in 280 genebanks worldwide, while the total number of samples is estimated at over 300,000. The four largest global collections are held in CIMMYT in Mexico, BPGV-DRAEDM in Portugal, NC7 in the USA, and ICGR-CAAS in China, storing almost one third of maize germplasm. On the other hand, national collections are smaller but still vital for research and development (Table 3). In general, collections in America are significantly greater than those in the rest of the world.

Since there is a large number of genebanks preserving maize germplasm, Table 3 provides only those with more than ten thousand samples.

Table 3. Gene banks with the largest number of maize germplasm samples

Gene bank		**Samples**	
Name	Acronym	Number of samples	%
Centro Internacional de Mejoramiento de Maíz y Trigo	CIMMYT	26.596	8
Portuguese Bank of Plant Germplasm	BPGV-DRAEDM	24.529	7
North Central Regional Plant Introduction Station, United States Department of Agriculture, Agricultural Research Services	NC7	19.988	6
Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences	ICGR-CAAS	19.088	6
Programa Nacional de la Papa, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (Meksico)	INIFAP	14.067	4
N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry (Russian Federation)	VIR	10.483	3
Others (275)		213.181	about 65
Total (281)		327.932	100

Source: FAO, 2010.

Out of the total number of 137,727 samples with the known germplasm type, wild relatives and local populations amount to 34%, while lines and modern varieties amount to 25%. This indicates that the interactions with the local environment have an important impact on creating germplasm variations within one species.

Security of stored material

A considerable number of PGRs is not stored under optimal conditions, which negatively affects the collection sustainability. The key limitations for the sustainability of the existing collections, recognized by the SoWPGR-2 (2010), are duplication and lack of regeneration of collections. It is estimated that out of the total sample number of 7.4 million, only a quarter represents distinct samples. Namely, the current system containing data and information on samples frequently makes it impossible to identify the same sample in different genebanks. Therefore, the existence and number of unnecessary duplicates cannot be determined. Similarly to other crops, numerous collections of wheat and maize germplasm are partly or completely duplicated. However, the greatest problem is the fact that the significant number of duplicates is not intended for a specific purpose, particularly regarding main crops, while the collections of other crops are inadequately duplicated.

Ageing of samples stored in genebanks occurs even under the optimal *ex situ* conditions. Therefore, monitoring the sustainability and timely regeneration of genetic material in the collections represents the crucial part of *ex situ* conservation. In this respect, key limiting factors are financial, infrastructural and human resources (FAO, 2010). Therefore, stronger efforts should be made at the national, regional and international levels in order to build adequate infrastructural capacities required for the sustainable *ex situ* conservation and management of PGRs for food and agriculture. Namely, a large number of countries do not possess suitable infrastructural and human capacities necessary for collection, maintenance, regeneration, characterization, documentation and distribution of PGRs according to the prescribed standards. Consequently, numerous collections are endangered since their storing and conservation are not conducted in the optimal manner.

Conclusion

Climate change and human activities have resulted in the impoverishment of biodiversity. It is estimated that ¾ of agro-biodiversity was lost only in the twentieth century and that the erosion is still ongoing. Thus, efforts are being made at the national and global level to preserve PGRs for food and agriculture for future generations and further research and development. Today, genetic resources are preserved in *in situ* and *ex situ* conditions, while the *ex situ* conservation is a dominant strategy for preservation of genetic materials.

There are more than 1,750 banks worldwide with approximately 7.4 million samples of genetic material of plant species significant for food and agriculture. According to the sample number, collections of cereals are the largest. Wheat, maize, rice, barley and oat comprise 35% of the germplasm stored in genebanks. However, it is estimated that only a quarter of the total sample number are distinct samples. Therefore, the most significant challenges in the future sustainable management of PGRs are the decrease of the number of duplicates and appropriate maintenance of collections. In order to improve the management system of PGR collections and encourage a wider use of germplasm, it is requisite to make more substantial investment in building the infrastructure and strengthening human resources. This will result in the global standardization and availability of data and information on PGR collections.

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