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Status and prospects of plant genetic resource conservation in Yemen

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Abstract: This study provides a comprehensive examination of the conservation status of plant genetic resources in Yemen, with a particular focus on the national genebank, natural sites and field genebanks. Employing a historical and descriptive approach, the study sheds light on the inception of field inventories and collection surveys, the roles and contributions of various projects and institutions since the late 1980s, and the quantities of seed samples collected from different crop varieties and species. Additionally, the study highlights the challenges faced, especially during the last decade following the eruption of war in early 2015. Specifically, it emphasizes the detrimental impact of the war and sanctions, resulting in the loss of conserved seed samples, and the damage and sabotage of field genebanks. In contrast, there is a need to ensure the enhancement of functioning seed systems and agriculture production even during times of conflict to reduce the impact of food insecurity. To conclude, the study puts forth several proposals, with a strong emphasis on expanding conservation efforts beyond natural sites, enhancing the capabilities for seed conservation in genebanks, and building genetic resources capacity.

Keywords: Agricultural research, Conservation, Genebank, Field genebanks, Natural sites, Yemen

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Introduction

For thousands of years, farmers in Yemen have inherited and managed their local seeds. In particular, the sorghum crop shows a remarkable level of diversity, serving as a clear testament to their commitment. They have cultivated, conserved, exchanged and managed the seeds of agricultural crops since the early stages of history when dams, irrigation canals and highland terraces were developed across different regions during the eras of ancient Yemeni kingdoms and states dating back to between the tenth and fifth centuries BCE (Alafif Cultural Foundation, 2003). However, the systematic conservation, characterization and use of plant genetic resources in a modern scientific manner can be traced to the establishment of agricultural research work in Yemen during the mid- to late-1940s.

The first agricultural research station was established in the El-Kod district of Abyan governorate, which later evolved into the fully-fledged El-Kod Agricultural Research Center (EARC) in 1955. The first systematic activities related to the conservation and use of plant genetic resources in Yemen took place in this centre in the early 1970s. Since then, various Yemeni government bodies, including the Ministry of Agriculture and Irrigation (MAI), the Ministry of Water and Environment (MWE), as well as institutions like the Agricultural Research and Extension Authority (AREA) and the Environment Protection Authority (EPA), have made diverse contributions to the conservation and sustainable use of genetic resources. These bodies have been actively involved in supporting the implementation of numerous national programmes, projects and activities in collaboration with local, regional and international organizations.

In recent decades, there has been an increasing interest in plant genetic resources due to their recognition as a national asset and a sovereign resource for any country worldwide. These resources play a vital role in achieving food security, sustainable development, resilience, better livelihoods and higher income. Yemen,

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characterized by diverse climates and a rich and distinct plant diversity, unfortunately, has not made optimal use of its traditional plant genetic resources. On the contrary, these resources have been diminishing and lost due to various factors, including human interventions such as urban expansion, road construction at the expense of agricultural lands, and the expansion of qat (*Catha edulis*) cultivation, an important cash crop in Yemeni social life but with negative effects on human nutrition and health, as well as the introduction of new crops.

The deterioration and loss of plant genetic resources can in addition be attributed to factors such as the absence of legislation, weak institutional frameworks, limited national programmes and inadequate material and human capacities to leverage modern technologies for conservation and sustainable use.

Since 2015, the ongoing war and conflict have also significantly impacted Yemen's plant genetic resources, resulting in severe economic and social consequences. The collapse of state institutions, the paralysis of public service agencies and facilities, the internal and external displacement of millions of citizens, currency devaluation, limited availability of goods and services, rising prices, declining investment and the loss of income sources for many Yemeni families all exert immense pressure on natural resources, including the country's biodiversity in all its forms.

In recent years, amid worsening conditions and the effects of the war and recurring food crises, official authorities and decision-makers, prompted by cases of tampering with plant genetic resources, have called for more attention to be given to the country's biodiversity. The need for implementing relevant research and raising awareness about these issues has become increasingly urgent. The present study was undertaken in response to these calls. The request made by international bodies and organizations such as the Commission on Genetic Resources for Food and Agriculture (CGRFA) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), among others, for member states to contribute to monitoring and assessing the state of plant genetic resources, served as further justification for conducting this study.

Materials and methods

To assess the status of plant genetic resource conservation in Yemen, the authors employed a historical descriptive approach. This involved gathering and reviewing national and international documents, reports, studies and surveys related to plant genetic resources. The authors also utilized the available electronic and paper information systems, including databases and records, of the Genebank of the National Genetic Resources Center (NGRC) within the Agricultural Research and Extension Authority (AREA) in Dhamar, Yemen. Furthermore, various institutions contacted during the study provided additional information that was incorporated into the research.

Additionally, the authors relied on their personal knowledge as co-witnesses, drawing from their extensive experience in research and agricultural technologies, as well as their involvement in various activities related to plant genetic resources. They also considered events and developments they have witnessed or been exposed to up until the time of preparing this study.

It is worth noting that the authors followed the methodology established by the Commission on Genetic Resources for Food and Agriculture of the Food and Agriculture Organization of the UN (FAO), as well as the approved indicators, to guide the monitoring of the implementation of the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (Second GPA). A total of 55 indicators from this guide were used in the study to assess the state of conservation of plant genetic resources in Yemen from 2012 to 2022 (FAO, 2019). The assessment was conducted based on the themes and activities outlined in the Second GPA, as well as the medium-term plan of AREA and the NGRC's plan.

The execution of this study encountered numerous difficulties and obstacles, with the most significant ones being:

- Limited availability of data: The study faced challenges due to the scarcity of available data. The existing information was dispersed across multiple sources and exhibited a diversity of forms and formats, making it challenging to gather comprehensive and standardized data.
- Low response rate from contacted agencies: Despite efforts to collect relevant and available data, the study encountered a low response rate from most of the local agencies contacted. This lack of cooperation hindered the acquisition of crucial information necessary for the research.
- Impact of war: The study was conducted amidst the ongoing war, which created adverse conditions and posed additional challenges. Coordinating and communicating with relevant entities and individuals became difficult due to the disrupted infrastructure and limited resources. Obtaining the requested information became a daunting task in such a context.

These difficulties and obstacles significantly influenced the implementation of the study, impacting the comprehensiveness and accuracy of the collected data. Nonetheless, the authors made their best efforts to overcome these challenges and ensure the reliability of the findings within the existing constraints.

Table 1. Studies surveying natural vegetation in the different Yemeni regions and numbers of species identified.

Study Title	No. of species	Source
Survey and classification of medicinal and aromatic plants in Sana'a and Dhamar governorates	858	NGRC (2022)
Survey and classification of the forest-pastoral vegetation cover in the Al-Jawf governorates	93	RNRRC (2022)
Inventory of the natural plant species in important areas in the Arabian Peninsula: Bani Omar, Taiz governorate, Yemen	135	Al-Khulaidi *et al* (2000)
Survey of the natural flora of some districts in Ibb, Taiz, Al-Mahweet and Sana'a governorates	1,603	AREA (2015)
Studying the existing natural resources and the climate change dimension in Taiz governorate using remote sensing and geographic information systems techniques (second phase)	389	AREA (2014)
Surveying, collecting and classifying the vegetation cover in Bura'a	240	AREA (2014)
Survey of the natural plants in Al-Makha district	167	NGRC (2013)
Survey of the natural plants in Ibb governorate	316	Al-Khulaidi (2013)
Surveying and collecting plant germplasm of pasture and forest, medicinal and aromatic plants, and the unexploited plants in the highlands region of Ba'adan and Al-Sher'ar districts, Ibb governorate	219	NGRC (2011)
Survey and evaluation of the deterioration of the vegetative cover in the upper stream area of Wadi Rasyan	332	Mufarreh *et al* (2011)
Surveying and collecting unexploited plant germplasm of pastures, forests, and medicinal and aromatic plants in the highland region of Sana'a, Al-Mahweet Amran Hajjah governorates	1,329	AREA (2013)
Surveying and collecting unexploited plant germplasm of pastures, forests, and medicinal and aromatic plants in Mareb governorate	294	NGRC (2009)
Surveying and collecting unexploited plant germplasm of pastures, forests, and medicinal and aromatic plants in 14 districts of the coastal plain of Hadramout and Al-Mahrah governorates	172	NGRC (2008)
Inventory and evaluation of the pastural genetic resources in Al-Kusumah district of Raymah governorate	289	Mufarreh (2004)
Inventory and evaluation of the pastural genetic resources in Belad Al-Ta'am district of Raymah governorate	311	Mufarreh (2003)
Survey of the natural vegetative cover of Madinat Al-Sharq – Wadi Rama'a	78	Al-Khulaidi (1994)

Results and discussion

State of *in situ* conservation and on-farm management

Surveys and inventories of plant genetic resources

Understanding crop diversity, including its distribution and changes over time, is a crucial prerequisite for the development and implementation of effective and efficient conservation strategies. Various studies have been conducted to survey and inventory plant diversity across different regions in Yemen by agencies such as the Agricultural Research and Extension Authority (AREA), colleges of agriculture and sciences in Yemeni universities, and institutions like the Social Fund for Development (SFD).

Al-Khulaidi (2013) reported the identification of 2,838 plant species, as part of the Yemeni flora, of which 2,602 are native, 129 are cultivated and 107 are introduced. Among these species, 608 were found to be endemic or semi-endemic (457 are endemic, among which 307 on Socotra Island alone), confined to Yemen or the Arabian Peninsula. The diverse topography of Yemen's plains, mountains, plateaus, valleys and deserts, with varying altitudes, has contributed to the emergence of this unique plant diversity in the country.

The uniqueness of such diversity extends to the varied crops grown in the country, which includes both tropical and temperate crops. Additionally, there is a diversity within species, with multiple crop varieties adapted to different environments or agroecological zones in the country. For instance, sorghum is characterized by a great diversity of types that mature over a range of durations (after three, four, five or even six months).

Table 1 presents the results of some recent studies and surveys, which involved counting and classifying plant species, compiling lists with their scientific and local names, providing photographs, and mapping their distribution in specific areas. These studies also identified the uses of the plant species, such as food, fodder, medicine and other purposes. Additionally, they focused on identifying threatened, rare, endemic and semi-endemic plants, some of which are introduced plants.

On-farm management and improvement of plant genetic resources for food and agriculture

Plant diversity plays a vital role in food security and adaptation to climate change. Therefore, it is crucial to focus on on-farm management and improvement of local crop varieties, including neglected and underutilized crops. By doing so, the resilience and adaptability of the cropping systems can be enhanced, enabling better withstanding of biotic and abiotic stresses and eventually better production and food security for the farmers' households.

NGRC has undertaken various activities to support the management and improvement of genetic resources on farm through multiple projects (Table 2). These initiatives primarily involved the characterization, evaluation and dissemination of local varieties suitable for different agroclimatic zones. The germplasm collected by various projects has been safety duplicated at the national genebank. The aim was to increase genetic diversity and broaden the range of options available to farmers for selecting varieties that are well-adapted and tolerant to biotic and abiotic stresses prevalent in their specific local conditions.

Providing seeds to farmers and researchers in case of disasters to restore cropping systems

NGRC is ideally positioned to play an important role in preserving plant genetic resources, especially in the face of natural disasters (such as droughts and floods) and man-made disasters (like conflicts and wars). NGRC's mandate includes providing high-quality seeds adapted to farmers' environmental conditions in disaster-affected areas, in coordination with relevant National authorities and organizations like regional agricultural research stations, the General Improved Seed Multiplication Corporation (GISMC), the Public Corporation for Grain Development and Production (PCGDP), and provincial MAI offices. However, due to limited material and human resources, NGRC's efforts are constrained, particularly in the current challenging conditions within the country.

In 2016, the regional station for agricultural research in the western coastal plain (Al-Kadan, Sardoud, Tihama region) was severely damaged by airstrikes. The seed stores in the station were significantly affected, leading to spoilage and loss of different varieties that had been collected and preserved by the station's researchers over many years (Figure 1).

Nonetheless, NGRC has managed to provide services to farmers and researchers in conflict and war-prone zones in some instances. This has been achieved through quality testing of locally distributed seeds and by providing seeds of important local strains to research stations in the respective agricultural regions.

For example, NGRC collaborated with other organizations and international agencies operating in Yemen to provide seeds of cereal, legumes and vegetable crops to affected farmers as part of humanitarian relief activities. Organizations such as FAO, the Red Cross, Acted and others have contributed to seed distribution efforts. However, the distribution mechanism faced drawbacks, including poor coordination with official agencies, poor seed quality and sometimes unsuitable seeds for the targeted agricultural climatic zones. These issues created a negative impression among farmers and decision-makers regarding the effectiveness and safety of the distribution mechanism.

In response, measures were established to mitigate these negative effects. These measures included conducting seed quality tests in laboratories, seed screening and purification by GISMC, and ensuring direct coordination with government authorities and institutions in the targeted areas.

Table 2. Projects implemented by the National Genetic Resources Center (NGRC) that have contributed to enhancing the on-farm conservation of genetic resources in Yemen. AREA, Agricultural Research and Extension Authority; BSF, the Benefit-Sharing Fund; FAO, Food and Agriculture Organization of the UN; GEF, Global Environment Facility; ICARDA, International Center for Agricultural Research in the Dry Areas; IFAD, International Fund for Agricultural Development; MAI, Ministry of Agriculture and Irrigation; WB, World Bank.

Project name	Funding agency	Implementing agencies	Implementation period	Implementation site	Activity
Participation of the rural community in raising crops (barley and lentils) in the mountain terraces (Ceccarelli, 2002)	ICARDA	AREA/Farmers' groups in the selected sites, Agriculture office	1998–2010	Kuhlan Affar, Hajjah governorate	Evaluation of strains of barley and lentil on farmers' fields. An economic and social study for the farmers of the selected villages; study and analysis of gender (the role of the farm household, male and females).
The rainfed agriculture and livestock Project (YRALP, 2005)	WB	AREA/GRC-Sana'a University, GCISM	2006–2013	Sana'a, Al-Mahweet, Hajjah, Al-Hodeidah and Lahj governorates	Farmer-based seeds improvement and management system. Evaluation of several local genotypes of sorghum, millet and cowpea
The participatory rural development of the Raimah governorate (IFAD, 2010)	IFAD	AREA and Dhamar MAI office	2001–2007	Raimah governorate	Evaluation and dissemination of adapted cereal and legume cultivars
Irrigation improvement project (IIP, 2009)	WB	AREA, Agricultural Services Corporation, Tehama Development Authority and Nasser's Faculty of Agriculture Sciences (Lahj)	2005–2007	Al-Hodeidah, Lahj, and Abyan governorates	Evaluation and dissemination of adapted cultivars of cereals, cotton and sesame
The participatory rural development of Al-Mahrah governorate (IFAD, 2011)	IFAD	AREA, MAI office	2002–2006	Al-Mahrah governorate	Evaluation and dissemination of adapted maize and sesame cultivars
The participatory rural development of Dhamar governorate (IFAD, 2012)	IFAD	AREA, MAI office	2006–2010	Dhamar governorate	Evaluation and dissemination of adapted cereal and legume cultivars
Improvement of the medicinal, and aromatic plants and underutilized crops (Gotor and Cherfas, 2012)	FAO	NGRC, MAI offices	2009	Sana'a, Dhamar and Lahj governorates	Cultivation of neglected and underutilized crops on farmers' fields

Continued on next page

Table 2 continued

Project name	Funding agency	Implementing agencies	Implementation period	Implementation site	Activity
Enhancing food security in the Arab countries (Yemen) (Communication Team ICARDA, 2018)	ICARDA	AREA and Dhamar MAI office	2012–2019	Dhamar	Dissemination of wheat, lentils and peas varieties on farmers' fields
Agricultural biodiversity and adaptation to climatic changes (YACCAP, 2010)	GEF	AREA, Sana'a College of Agriculture, and the GCISM	2014	Sana'a, Taiz, Ibb and Al-Mahweet governorates	Evaluation of local sorghum strains on farmers' fields
Participatory conservation and sustainable use of landraces to improve farmer's livelihood and their resilience in adapting to climate changes in Yemen (FAO, 2023)	BSF	AREA and MAI offices	2019–2023	Dhamar and Hadramout governorates	Evaluation and characterization of local strains of sorghum, wheat, barley, lentils and peas on farmers' fields

Unfortunately, there have been instances where poor-quality seeds have been distributed. In April 2021, MAI destroyed a large quantity of rotten seeds that were provided by FAO for distribution to farmers in Al-Hodeidah governorate. The spoiled quantity was estimated to be more than 240 tonnes. These seeds, intended as donated assistance to Yemeni farmers, were infected with fungi and deemed unsuitable for cultivation.

This incident highlights the importance of strict quality control measures and coordination among relevant authorities and organizations to ensure the effective and safe distribution of seeds in Yemen in line with the recommendation of the International Plant Protection Convention (IPPC) on "ensuring safe provision of seed during humanitarian assistance disbursement" (IPPC, 2021).

Changes and trends in on-farm genetic resources conservation

Yemen is known as one of the main countries that are growing qat. Qat or khat or khata (*Catha edulis*) is a mild stimulant plant consumed by most Yemenis in a daily afternoon session by chewing its fresh leaves (Zahran *et al*, 2019). The expansion of qat cultivation at the expense of the main cereals and legumes (sorghum, millet, wheat, barley, lentil and pea) poses a significant threat to crop diversity in Yemen. The yearly agricultural statistics book indicates a decline in the cultivated area of cereal crops over the years, while qat cultivation has increased (GDSID/MAI, 2022). However, the actual increase in qat cultivation may be even greater than what is reflected in the official figures (Figure 2). Due to the war and resulting consequences, including the institutional divide and ineffectiveness, no agricultural census has been conducted for the past two decades.

The urban population expansion on agricultural lands is another factor threatening crop diversity. Figure 3 shows the trend in population growth over the past 70 years.

A study conducted by the Renewable Natural Resources Research Center (RNRRC) in 2021 on the urban expansion in Dhamar governorate revealed a dramatic increase over the past 50 years.

Reports from field surveys conducted by NGRC and RNRRC highlight the expansion of urban centres and population at the expense of agricultural lands (Figure 4). This phenomenon is considered one of the most critical factors endangering agricultural biodiversity.

The disappearance of certain plant species and fruit varieties (quince, walnuts, pear, peach, apricot, fig and grapes) from areas like Sana'a governorate, which used to be known for cultivating them, further emphasizes the negative impact of urban expansion on agricultural biodiversity. Parks and orchards (for example of walnuts, peach and grapes) have been replaced by commercial and residential areas, resulting in a significant decrease in green coverage.

On the other hand, there has been an expansion in the cultivation of some vegetable crops (tomato, onion, potato, pepper, carrot, cucumber, zucchini, cabbage), including varieties introduced from abroad. Although the cultivated area of vegetable crops fluctuates, the number of greenhouses in different regions of Yemen has increased. Strawberry cultivation has also grown in response to high demand from fresh juice shops in major cities.

The cultivation of fruit crops, particularly almonds, has expanded due to relatively low water requirements and the profitability of production. The almond cultivation area has increased between 2011 and 2020, with significant expansion in Sana'a governorate, particularly in the districts of Al-Haima and Bani Matar.

Coffee cultivation has also expanded due to increasing demand for Yemeni coffee locally and internationally. The cultivation area has increased over the past few years much more than the estimated figures made in the agricultural census book for 2020, which indicated an increase of 2,000 hectares in the coffee area between 2016 (33,900ha) and 2020 (35,900ha). Also, there has been a focus on improving agricultural processes and post-harvest operations to meet desired quality standards. High government authorities and MAI have shown increased interest in the coffee sector, establishing the National Center for Coffee Research and supporting farmers' associations. A decree was issued in 2022 banning the import of both processed and unprocessed coffee from abroad to encourage domestic cultivation and increase the income of coffee farmers.

Overall, while there is an expansion in certain crops, the threats to crop diversity posed by the expansion of qat cultivation, urbanization and population activities remain significant challenges in Yemen.

Status of *ex situ* conservation of plant genetic resources (genebanks)

The NGRC in Yemen operates under the umbrella of AREA and has its headquarters outside Dhamar city, about 100km from the Yemeni capital Sana'a. In addition, there are two other genetic resource centres working under the faculties of agriculture sciences of Sana'a and Aden universities and some field genebanks as detailed in Table 5.

Supporting the targeted collection of plant genetic resources

The primary drivers for implementing targeted collecting of genetic resources were the risk of loss of on-farm diversity, opportunities for use, and the need to address deficiencies in *ex situ* conservation. Bawazir (2004) conducted a study on cereal diversity in southern Yemen and emphasized the importance of surveying and collecting genetic resources of cereal crops and their wild relatives across different agroclimatic zones in Yemen. The study aimed to document these resources and utilize them in breeding and genetic improvement programmes.

The study's findings revealed that sorghum varieties in these areas exhibited genetic variation within each environmental zone, as evidenced by differences in

Figure 1. Examples of the effects of the air raids of the war coalition against Yemen on the buildings, equipment and seed stores of the Tehama regional agricultural research station in the western coastal plain, Al-Kadan, Sardoud, Tihama zone, Al-Hodeidah governorate (A and C), including damage to the preserved seed samples of various crops (B).

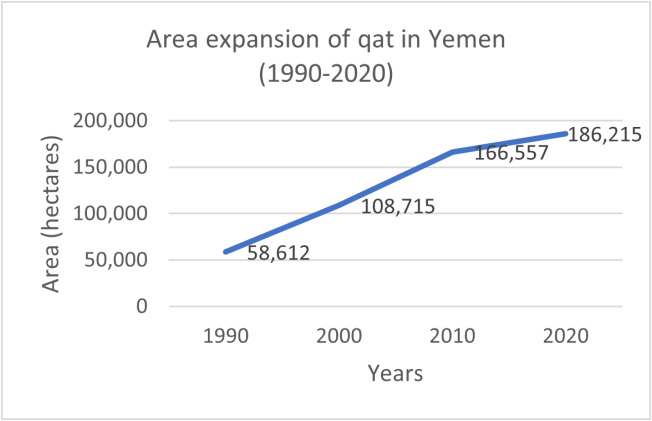

Figure 2. Expansion of qat cultivated area from 1990 to 2020. Source: CSO (2020)

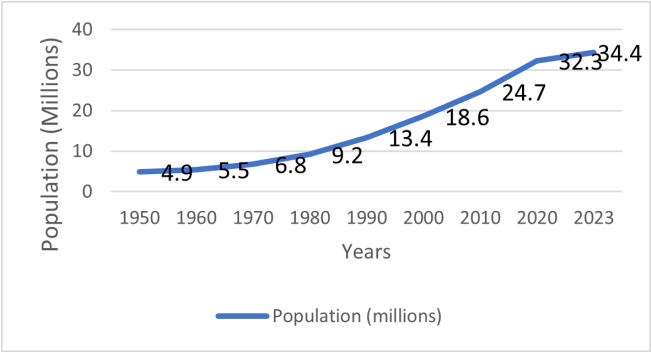

Figure 3. Trend of population growth in Yemen over the past 70 years. Source: Macrotrends (2023)

phenotypic characteristics, anatomical features and resistance to environmental stress conditions. The researcher pointed out that the varieties of sorghum grown in coastal areas showed early maturity (100–120 days), while the varieties grown in the highland areas matured late (160–180 days). According to the study, sorghum varieties in the highland areas were tallest (300cm) while in the coastal areas plant height ranged from 250–300cm.

The study also demonstrated that local wheat varieties possessed drought tolerance. This may be accounted for by their morphological and anatomical traits, such as the smaller number of seminal roots and the small size of seminal root vessels. Most of the local varieties of wheat grown in the southern, medium-altitude regions of Yemen belong to *Triticum aestivum*. In some areas, there may be a mixture of *T. aestivum* and *T. durum*.

The local varieties of millet grown in the southern Yemeni regions belong to *Pennisetum glaucum* (pearl

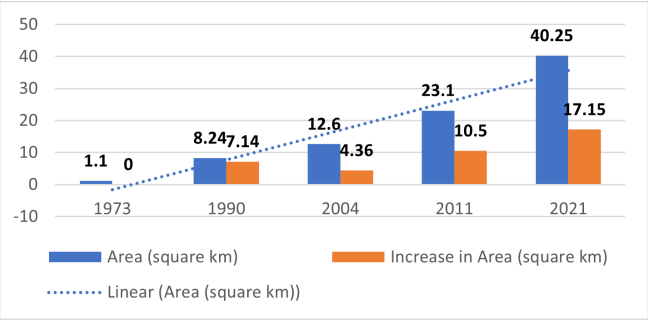

Figure 4. Urban sprawl on fertile agricultural lands in Dhamar City (km^2) (1973–2021)

millet), *Pennisetum setaceum*, *Pennisetum rigidum* (little millet) and *Eleusine coracana* (finger millet). Misibli is the local name for pearl millet throughout Yemen, Kanab is the local name for finger millet, and Heba is the local name for small (short) millet (and an early-maturing type) on Socotra Island.

The efforts made in collecting and conserving plant genetic resources in Yemen can be divided into three phases:

1) First phase (1970s and 1980s): During this period, international organizations collaborated with researchers from the El-Kod Research Station in Abyan governorate and the Southern Highlands Regional Agricultural Research Station (SHRAR) in Osaiferah, Taiz governorate to collect hundreds of samples. Notable collecting missions during this period in the different Yemeni regions are presented in Table 3.

Unfortunately, all the samples collected during this period were lost due to inadequate storage conditions, except for those preserved outside Yemen by supporting organizations, such as FAO, the International Plant Genetic Resources Insitute (IPGRI), the United States Agency for International Development (USAID), the International Maize and Wheat Improvement Center (CIMMYT) and others (Al-Mua'alem *et al*, 1993).

2) Second phase (1990s): During this period, a specialized unit for plant genetic resources was established under RNRRC of AREA in Dhamar. Over 2,000 plant samples were collected during this phase. Notably, a joint team from AREA and the International Center for Crop Research in the Semi-Arid and Arid Tropical Areas (ICRISAT) conducted significant collecting trips. They collected 685 seed samples, mostly of sorghum and millets, from Al-Dhalea, Radfan, Yafe'a, Abyan, Lahj and Tehama. Details on this collection trip and other trips are presented in Table 3.

Despite having a refrigeration room for cold storage (-18°C), frequent power shortages and blackouts led to the loss of many collected samples, despite their data being recorded in NGRC's records.

3) Third phase (2000s to present): This stage witnessed the establishment of NGRC in 2002, an increase in specialized staff and the establishment of various departments within the centre. FAO stated that NGRC in Dhamar held 3,281 samples in its genebank (FAO, 2009). The number of samples collected from different regions of the country has increased to over 6,500 accessions at present. Notable collecting operations, covering most Yemeni governorates, conducted by NGRC during this phase are displayed in Table 3.

The collecting trips conducted by NGRC between 1989 and 2013 to collect seeds from natural and cultivated plants, targeting all geographical regions in Yemen are shown in Figure 5.

Most of the collection activities previously reviewed were carried out with support and funding within bilateral or multilateral cooperation or joint work projects between Yemen and several partners over the previous decades, and copies of samples of genetic resources that were collected found their way abroad and have been preserved by institutions outside Yemen. Early reports indicate that over 8,000 samples were deposited in various genebanks abroad (Al-Ghouri *et al*, 1996). The Second National Report on the State of Plant Genetic Resources for Food and Agriculture stated that international organizations held 8,619 samples from Yemen (FAO, 2009). Currently, data on the Genesys platform show 8,958 samples from Yemen conserved in 19 genebanks, covering 44 plant species, with a focus on grain crops (Genesys, 2021). Data from FAO WIEWS and the Svalbard platform also align closely with these figures (Table 4).

Expanding diversity in genebanks

It is crucial to expand *ex situ* conservation efforts for neglected crops, crop wild relatives and forages to facilitate research and crop improvement. The genebank of NGRC currently conserves seeds from 45 different crops. These crops encompass cereals such as sorghum, maize, millet, wheat and barley; legumes including lentils, beans, kidney beans, cowpeas, peas and fenugreek; vegetables like onions, tomatoes, chilli peppers, cucumbers, zucchini, mallow, radishes, eggplant and okra; oil-producing crops like sesame and peanuts; less commonly utilized crops, such as black seed (*Nigella sativa*), henna (*Lawsonia inermis*), coriander (*Coriandrum sativum*), caladium, arugula (*Eruca sativa*) and mustard (*Brassica juncea* L.).

Additionally, field genebanks situated in various regions hold a diverse range of crops, including date palms, mangoes, citrus fruits, almonds, grapes, bananas and papayas, along with forage and forest crops. There are eight field genebanks in various regions – the northern, central and southern highlands, the Tihama coastal plains region, the southern coast region (Al-Kud, Abyan) and the Eastern Plateau region (Marib and Sayun). More details are provided in Table 5.

It is important to note that the acquisition of new species and samples to expand the genetic resources reserve at NGRC was temporarily halted between 2014 and 2018 due to the prevailing conditions of the war and the resultant socioeconomic deterioration and institutional ineffectiveness in the country.

Table 3. Details of the main phases of plant genetic resource collection and conservation in Yemen

Main Genus/Species	No. of accessions	Location(s)	Year	Project/programme	Reference
Phase 1: 1970s–1980s					
Sorghum, millet and Sudan grass	4,500	Northern Yemeni Governorates	1975–1977	The American Sorghum Improvement Assistance Project	Hakimi and Ya'ni (2008); Jaradat (1997)
Wheat, barley and some legumes	490		1978–1979	The German Technical Cooperation Agency (GTZ)	
Field crops (Sorghum, millet, wheat, barley and some legumes)	783		1980–1981	The International Board for Plant Genetic Resources (IBPGR)	
30 crops of human and animal food	351	Southern and Eastern Yemeni Governorates	1969–1989	IBPGR	Hakimi and Ya'ni (2008); Guarino (1989)
Phase 2: 1990s					
70 plant species	617	Tehama, central and south highlands, and east regions	1990–1999	AREA programme	Jaradat (1997)
Sorghum and millets	685	Al-Dhalea, Radfan, Yafe'a, Abyan, Lahj, and Tehama.	1992	Sorghum and Millet Improvement Project	
Sorghum and millet	294	Saada, Taiz, Sana'a, Al-Dhalea, Ibb and Socotra	1992	Sorghum and Millet Improvement Project	Amer and Al-Dahmashi (1997)

Continued on next page

Table 3 continued

Main Genus/Species	No. of accessions	Location(s)	Year	Project/programme	Reference
Phase 3: 2000–present time					
Sorghum bicolor, *Pennisetum americanum*, *Zea mays*, *Vigna* spp., *Cajanus cajan*, *Phaseolus vulgaris*, *Trigonella foenum-graecum*, *Sesamum indicum*, *Raphanus* spp. *Corchorus olitorius*, *Abelmoschus esculentus*, *Eruca sativa*, *Cyamopsis tetragonoloba*, *Cucumis* spp, *Nicotiana* spp., *Capsicum annuum*, *Gossypium* spp.	629	Sana'a, Hajjah, Al-Mahweet, Al-Hudiedah and Lahj	2007	The Rainfed Agricultural Project	NGRC (2008)
36 species of human and animal food	390	Western and Eastern Coastal Plain	2008	AREA research programme	NGRC (2009)
Sorghum bicolor, *Zea mays*, *Pennisetum americanum*, *Triticum aestivum*, *Hordeum vulgare*, *Lens culinaris*, *Trigonella foenum-graecum*, *Vicia faba*, *Pisum sativum*, *Vigna* spp., *Lablab vulgaris*, *Phaseolus vulgaris*, *Trifolium* spp., *Abelmoschus esculentus*, *Corchorus olitorius*, *Capsicum annuum, Sesamum indicum*, *Brassica napus*, *Linum usitatissimum*, *Coffea arabica*	330	Sana'a, Amran, Ibb, Dhamar, Hajjah, Al-Mahweet and Al-Hodeidah	2009	AREA research programme	NGRC (2010)
Fruit crops (*Vitis vinifera*, *Prunus amygdalus*, *Prunus persica*, *Cydonia oblonga*, *Ficus carica*, *Malus sylvestris*, *Morus alba*, *Pyrus* spp., *Olea* spp., *Ceratonia siliqua*, *Mangifera indica*, *Citrus* spp., *Manilkara achras* (Mill), *Musa* spp., *Psidium guajava* L., *Carica papaya* L., *Passiflora edulis* Sims, *Annona* spp., *Opuntia ficus-indica*, *Phoenix dactylifera*)	150	Sana'a, Amran, Al-Mahweet and Hajjah	2009	AREA research programme	NGRC (2010)
Honeydew pumpkin (*Cucurbita* spp.)	70	Belad Alrous District, Sana'a governorate	2010	AREA research programme	NGRC (2011)
Sorghum bicolor (30), *Pennisetum americanum* (2) *Zea mays* (14), *Triticum durum* (1), *Hordeum vulgare* (2), Faba bean (1), *Vigna* spp. (14), *Sesamum indicum* (1), T*rigonella foenum-graecum* (1), *Phaseolus* spp. (1), *Cajanus cajan* (5)	72	Al-Salafiya Directorate and Bilad Al-Ta'am in Raymah governorate	2012	AREA research programme	NGRC (2013)

Continued on next page

Table 3 continued

Main Genus/Species	No. of accessions	Location(s)	Year	Project/programme	Reference
Sorghum bicolor (33), *Zea mays* (7), *Triticum durum* (26), *Hordeum vulgare* (16), *Lens culenaris* (11), *Vigna* spp. (11), *Pisum sativum* (6), *Trigonella foenum-graecum* (9), *Brassica* spp. (1), *Linum usitatissimum* (3), *Allium* spp. (1), *Cucumis sativum* (1), *Phaseolus* spp. (1)	126	Sabah district in Al-Bayda governorate	2012	AREA research programme	NGRC (2013)
Sorghum bicolor (33), *Zea mays* (7), *Triticum durum* (32), *Hordeum vulgare* (20), *Lens culenaris* (4), *Vigna* spp. (3), *Pisum sativum* (8), *Trigonella toeniccum* (1)	108	Ans, Jahran and Al-Hada'a in Dhamar governorate	2012	AREA research programme	NGRC (2013)
Cereals, vegetables and fruits	282	Sana'a, Al Mahwit, Ibb and Taiz governorates	2014	The Agricultural Biodiversity and Climate Adaptation Project	NGRC (2013)
The project team collected a total of 368 landraces (228 from Dhamar and 140 from Hadramout and Almahrah governorates) and more than 20 species: sorghum, maize, wheat, barley, millet, cowpea, pea, bean, fava bean, lentils, fenugreek (*Trigonella*, spp.), sesame, *Lablab purpureus*, mustard (*Brassica* spp.), flax (*Linum* spp.), pepper (*Capsicum annum*), *Eleusine* spp., *Pennisetum* spp., Roselle (*Hibiscus sabdariffa*), *Plectranthus* spp., black caraway (*Nigella sativa* L.), fennel (*Foeniculum vulgare*)	383	Several districts in the governorates of Dhamar, Hadramout and Al-Mahra governorates	2019	The conservation and sustainable use of local landraces project - BSF	NGRC (2022)

Efforts have also been made to conserve genetic resources of threatened and endemic species *ex situ* in various research stations located in different agricultural regions. Notably, a specialized team from the El-Kod research station in Abyan governorate collected the Socotra wild pomegranate (*Punica protopunica* Balf. f.) in 1989 and 1990. This threatened species, which is endemic to the Island, has been confirmed by international organizations such as the International Union for Conservation of Nature (IUCN) to be one of the species at risk of overexploitation without natural regeneration. The collected seeds were grown, and the trees were nurtured at the El-Kod research farm (Bazara'a, 2000).

Regeneration and multiplication of genebank seed samples

Even under optimal storage conditions, it is necessary to periodically regenerate and multiply seed accessions due to the decline in viability over time and the limited quantity of preserved seeds resulting from their distribution to users such as researchers and farmers.

Hence, NGRC carries out annual processes to regenerate seed accessions that are at risk of viability loss and to multiply accessions with limited quantities. The most recent regeneration and multiplication initiative was conducted by NGRC in 2014. Due to the prevailing war conditions, regeneration operations were suspended from the beginning of 2015 until 2020, resulting in no activity in this regard during that period. Subsequently, with the initiation of the 'Participatory Conservation and Sustainable Use of Local Varieties' project, funded by the Benefit Sharing Fund (BSF) of the ITPGRFA, approximately 200 plant accessions (mainly cereal crops) were regenerated in the governorates of Dhamar and Hadramout (Seiyun) (FAO, 2023).

Table 6 shows the numbers of seed samples that have been regenerated until 2014 and those still requiring regeneration, as reported by NGRC in Dhamar.

Conservation changes and trends in genebanks

The study period witnessed several notable positive changes and trends in the field of genebank conservation, including:

- Increase and expansion of plant samples: The number of seed accessions in the NGRC genebank increased from 3,281 in 2006 to approximately 6,500 accessions in 2021. Similar growth was observed in the Genetic Resources Center (GRC) of Sana'a University, with the number of accessions rising from 1,528 to over 3,000 (Table 5).
- Improved energy security: Noteworthy progress was made in securing electrical energy for cold storage in the NGRC genebank in Dhamar. Solar energy systems were introduced in 2016, funded by the Agricultural and Fisheries Production Encouragement Fund (AFPEF). Additionally, the Public Corporation for Grain Development and Production (PCGDP) provided a solar energy system for the GRC at the Faculty of Agriculture, Sana'a University, in 2019.
- In 2022, with support from the Crop Trust and the ITPGRFA, the NGRC genebank in Dhamar was provided with several solar energy batteries to improve the electricity supply for cooling the long-term seed storage.
- Safety duplication: Copies of seed accessions from cereal and leguminous crops were sent to ICARDA in 2013 and subsequently stored in the Svalbard Seed Vault (Table 4).

However, there were also negative changes and trends observed in germplasm conservation in genebanks.

Negative impact on field genebanks: The conservation of plant genetic resources in field genebanks managed by research stations across the various regions was significantly affected by the war and its associated socioeconomic and institutional consequences. The lack of operational budgets hindered essential agricultural activities such as ploughing, levelling, weeding, pruning, grafting, fertilizing and irrigation. Fuel shortage and high prices further exacerbated the challenges faced by research stations in adequately maintaining the field genebanks. In certain field genebanks in the northern (Al-Errah) and central highlands (Dhamar), some fruit trees were cut down by residents for firewood during periods of gas shortage and high prices resulting from the war and siege (Figure 6). Complete destruction of field genebanks occurred in the Southern Highlands Agricultural Research Station (Osaiferah, Taiz) for mango, guava and coffee varieties, as well as in the Southern Coast Agricultural Research Station in El-Kod, Abyan governorate. Similarly, the field genebank for pomegranate at the College of Agriculture and Veterinary Medicine, University of Dhamar, experienced the same fate, with all preserved trees being cut down due to war and siege conditions.

Limited implementation of biotechnologies: The use of biotechnologies, such as tissue culture, for the conservation of plant genetic resources has not been possible due to a lack of resources, including electrical energy sources, laboratory materials and equipment. Thus, no duplicates of the accessions maintained in field genebanks had been maintained in tissue cultures and thus, as safety duplicates.

Limited multiplication and regeneration of seed samples: Except for a limited number of seed accessions regenerated and multiplied through funded projects such as the 'Participatory Conservation and Sustainable Use of Landraces' (2019–2023) (NGRC, 2022) and activities supported by the General Corporation for Grain Production and Development, the war's economic effects halted vital regeneration programmes and seed multiplication activities. Improper storage conditions, insufficient seed quantities and difficulties in providing seeds to farmers and researchers have led to a decline in seed viability. Hundreds of samples are currently at risk of spoilage and loss, requiring regeneration and multiplication.

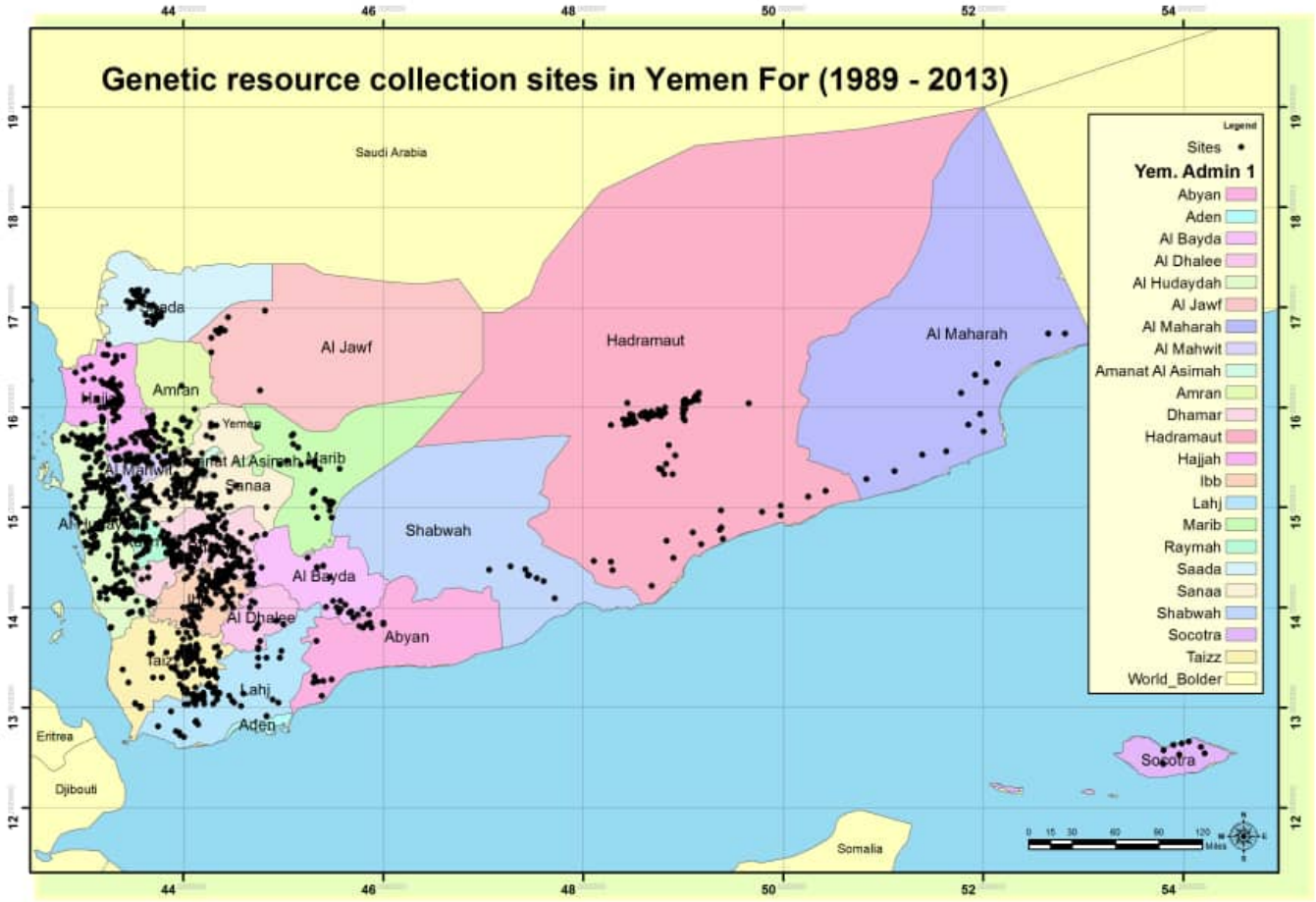

Figure 5. Areas of plant genetic resources collection in various parts of Yemen (1989–2019). Source: NGRC (2021), NGRC database (2021) and FAO (2023)

Table 4. Number of accessions of some types of Yemeni plant genetic resources preserved outside Yemen (SGSV, 2023). ICRISAT, The International Crops Research Institute for the Semi-Arid Tropics; CIMMYT, The International Maize and Wheat Improvement Center; ICARDA, The International Center for Agricultural Research in the Dry Areas; IITA, International Institute of Tropical Agriculture; US NPGS, United States National Plant Germplasm System. *, includes the following genera: *Capsicum, Nigella, Citrullus, Linum, Coriandrum, Medicago, Teramnus* and *Ricinus*.

Crop	ICRISAT	ICARDA	IITA	CIMMYT	US NPGS	Others	Svalbard
Sorghum	2,144				3,376	45	5,565
Maize				2		1	3
Wheat		13		33	12	115	173
Barley		66			25	55	146
Millet	289					49	338
Cowpea			25			12	37
Lentil		38				48	86
Bean		3					3
Peas						50	50
others*	2	7			33	88	130
Total	**2,435**	**127**	**25**	**35**	**3,446**	**463**	**6,531**

Table 5. Changes in the number of species and accessions of genetic material in seed and field genebanks in Yemen (2006–2020). Source: FAO (2009) and AREA (2021).

Centre/Reserve	Institution	Site	No. of species		No. of accessions	
			2006	2020	2006	2020
National Genetic Resource Center (NGRC)	Agricultural Research and Extension Authority	Dhamar	56	47	3,281	6,300
Genetic Resource Center	College of Agriculture, Sana'a University	Sana'a	38	54	1,528	> 3,000
Genebank	Nasser's College of Agricultural Sciences, University of Aden	Lahj	9	0	136	0
Field genebank of date palm and lemon	The Valley and the Desert Agricultural Research Station, Seiyun	Seiyun	1	1	67	48
Field genebank of coffee, guava and mango	The Southern Highlands Agricultural Research Station	Osaifr, Taiz	16	0	36	0
Field genebank of pomegranate	The College of Agriculture and Veterinary Sciences, Dhamar University	Dhamar	1	0	22	0
Field genebank of mango and date palm	Tihama Plateau Agricultural Research Station	Al-Kadan, Surdud, Al-Hudeidah	5	2	64	47
Field genebank of apricot, grapes, almond, pomegranate, fig and olive	The Northern Highlands Agricultural Research Station	Al-Errah, Sana'a	11	6	218	78
Field genebank of apple, olive and almond.	The Central Highlands Agricultural Research Station	Dhamar	–	65	55	144
Field genebank of banana, papaya, mango and date palm	The Southern Coast Agricultural Research Station	Al Kod-Abyan	65	67	230	> 400
Field genebank date palm, coconut and Jasminum sambac	The Eastern Coast Agricultural Research Station	Mukalla, Hadramout	15	24	68	> 200
Total			**217**	**266**	**5,705**	**10,217**

Figure 6. Remains of the field genebank of mango, coffee and guava crops in the field genebank of the Osaifera experimental farm, Taiz

Table 6. Number of seed accessions in NGRC in Dhamar that have been regenerated until 2014 and those that need regeneration. Source: Data were collected during the genetic resources inventory of NGRC in 2014 (NGRC, 2022).

Crop	Scientific name	No. of accessions	No. of regenerated accessions	No. of accessions needing regeneration
Cereals				
Sorghum	*Sorghum bicolor*	2,436	679	1,757
Millet	*Pennisetum glaucum*	589	225	364
Maize	*Zea mays*	505	108	397
Barley	*Hordeum vulgare*	362	164	198
Wheat	*Triticum aestivum*	351	229	122
Finger millet	*Eleusine coracana*	36	0	36
Al-Tahf	*Eragrostis* spp.	11	0	11
Legumes				
Cowpea	*Vigna unguiculata*	451	88	363
Lentils	*Lens culinaris*	180	78	102
Fenugreek	*Trigonella foenum-graecum*	141	141	0
Beans	*Vicia faba*	100	40	60
Kidney beans	*Phaseolus vulgaris*	90	90	0
Peas	*Pisum sativum*	80	80	0
Lablab	*Lablab purpureus*	45	0	45
Vegetables				
Okra	*Abelmoschus esculentus*	95	0	95
Radish	*Raphanus sativus*	47	33	14
Eggplant	*Solanum melongena*	42	0	42
Tomatoes	*Solanum lycopersicum*	41	0	41
Carrot	*Daucus carota*	19	0	19
Cumin	*Cuminum cyminum*	20	0	20
Arugula	*Eruca sativa*	10	7	3
Onion	*Allium cepa*	10	0	10
Leek	*Allium porrum*	3	0	3
Chilli	*Capsicum* spp.	40	0	40
Cucumber	*Cucumis sativus*	8	0	8
Pumpkin	*Cucurbita* spp.	6	0	6
Melon	*Cucumis melo*	60	0	60
Watermelon	*Citrullus lanatus*	10	0	10
Calabash/Squash	*Cucurbita maxima*	53	0	53
Mallow	*Corchorus olitorius*	37	0	37
Oil and cash crops				
Sesame	*Sesamum indicum*	88	71	17
Peanut	*Arachis hypogaea*	9	0	9
Underutilized crops				
Coriander	*Coriandrum sativum*	50	24	26
Black seed	*Nigella sativa*	49	23	26

Gaps and challenges facing the conservation of genetic resources in Yemen

This list of gaps and challenges in the conservation of plant genetic resources in Yemen, in addition to the recommendations and conclusions, is based on government documents, including the first, second and third country reports prepared as contributions to the FAO Reports on the State of the World's Plant Genetic Resources for Food and Agriculture. AREA, as a national public agricultural research institution in Yemen, has asked the national focal point of the ITPGRFA and CGRFA to prepare a working paper to be presented at the planned National Conference on Genetic Resources but postponed it to an undefined future time after preparatory efforts of more than a year. Such a paper was prepared and reviewed by the steering committee and included a set of gaps, conclusions and recommendations. Moreover, the recently prepared documents on a road map of the agricultural research programmes and projects (AREA, 2022), prepared

by a specialist team, discussed thoroughly with the AREA management, and endorsed by higher agricultural authorities, are compatible with what is stated in this article. However, the content of this paper and other developments will serve as a background primary paper for any national symposium or conference when the time comes after the resumption of peace in the country.

Based on the above-reported situation, the most significant points can be summarized as follows.

***In situ* conservation gaps and challenges**

- Limited knowledge about rich areas/regions of plant genetic diversity and regions at risk of extinction and loss of diversity
- Inadequate methodologies for monitoring and evaluating genetic diversity, including geographical and plant species gaps
- Lack of a policy for restoring cropping systems after disasters and wars
- Absence of targeted collecting, propagation and reintroduction of rare and threatened species to their natural habitats
- Insufficient sustainable use of economically promising plant species
- Absence of *in situ* conservation and management of crop wild relatives and wild food plants
- Weak technical capabilities, including a shortage of specialized staff in farm systems management, biodiversity, environmental systems management, plant taxonomy, remote sensing, control and monitoring, and evaluation systems. Additionally, laboratories in agricultural research, environmental protection and university science colleges lack certain devices and equipment.
- Lack of support and funding for managing natural sites, and inadequate funding for scientific research activities
- Lack of coordination between relevant authorities, particularly between AREA and EPA, which serve as the national focal points for the ITPGRFA and CBD, respectively.

***Ex situ* conservation gaps and challenges**

- Weak integration between on-farm/*in situ* and *ex situ* conservation
- Absence of a plan for regeneration and multiplication under normal and emergency circumstances.
- Lack of a specialized supportive unit for communication, publication and coordination of genetic resources
- Genetic collection operations are not comprehensive and do not cover most geographical areas, genera or plant species
- Weak human, technical and institutional capabilities in NGRC
- Weakness in the basic infrastructure for managing plant genetic information
- Weak participation of local partners and government institutions in collecting, preserving and using plant genetic resources
- Lack of annual budgets to cover the expenses of collecting and preserving plant genetic resources
- Weak cooperation and participation in regional and international initiatives in the field of conservation and use.

Conclusion and recommendations

Based on the preceding results and discussion, the plant genetic resources system in Yemen faces numerous problems and gaps, which have been exacerbated by the ongoing war since 2015. However, it is possible to identify a set of needs to develop conservation processes for both *in situ* and *ex situ* plant genetic resources in the country. In this regard, the most important recommendations can be summarized as follows:

On farm/*in situ*

- Assess the impact of threats and pressures on crop diversity based on scientific foundations
- Identify areas of diversity and threats and develop an action plan for their conservation
- Conduct targeted collecting of threatened and rare species
- Reintroduce threatened or rare species and varieties into Yemen through a coordinated effort
- Conduct inventory and survey operations for crop wild relatives, in coordination with *ex situ* activities
- Promote *in situ* conservation and management of crop wild relatives and wild food plants
- Develop a national seed policy that includes provisions for seed distribution mechanisms during and after disasters and wars
- Enhance technical expertise in plant taxonomy, agriculture and environmental systems management, and monitoring and evaluation
- Provide adequate funding and financial support for programmes and projects focused on managing natural sites and on-farm conservation
- Develop effective mechanisms to enhance cooperation and coordination among various relevant agencies.

***Ex situ* (genebanks)**

- Improve storage conditions in genebanks by providing electricity, preservation equipment and materials, and conducting seed quality tests
- Establish a centrally organized seed health system by providing resources and expertise
- Enhance the national genetic resources information system, documentation and data exchange, and encourage the use of available information and accumulated knowledge
- Allocate operational budgets to cover the expenses of genebanks
- Implement seed regeneration and multiplication programmes for accessions at risk of loss
- Develop the capabilities of genebank personnel for routine genebank operations including information management systems

- Provide NGRC with young male and female professionals and enhance their scientific and technical capacities in various crucial areas such as laboratory conservation using biotechnologies, genetic data and information management, plant taxonomy and characterization (particularly wild relatives), among others. It is also important to foster NGRC to assume coordinating responsibilities across the different areas and activities.
- Develop an awareness-raising strategy and plan highlighting the importance of the country's genetic resources and biodiversity
- Establish and strengthen communication, cooperation and coordination among all relevant local, regional and international organizations involved in genetic resources and genebanks
- Conduct inventory and survey operations for crop wild relatives, in coordination with on-farm or *in situ* activities.

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Author contributions

Maeen Ali Al-Jarmouzi prepared the study proposal, collected, organized, analyzed the data, wrote and improved the manuscript's drafts. Khalil M. Alsharjabi contributed to reviewing and improving the study proposal, collecting the data, writing the manuscript, editing and improving the manuscript's drafts at different stages. Luigi Guarino provided support through guidance, reviewing and improving the manuscript draft, enhancing the translation of the manuscript and providing important references.

Conflict of interest

The authors declare no known conflicts of interest or any financial or personal relationships influencing the work or materials appearing in the article.

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