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Use of plant genetic resources in Yemen and suggestions for potential improvement

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Abstract: The study aimed to determine the present state of the use of plant genetic resources in Yemen during the period 2007–2023 and to identify potential improvements, relying on historical descriptive information as well as on primary and secondary information sources, with a focus on the case of the National Genetic Resources Center. For genebank-conserved accessions, the study identified limited achievements, the most important being the characterization and evaluation of 1,100 accessions of different crops. Significant progress was also made with the initiation of hybridization research programmes for various crops. However, the study identified several gaps and obstacles hindering the use of plant genetic resources and concluded with recommended measures to address them with the ultimate goal of effectively and efficiently using plant genetic assets to improve food and agriculture security in the country. In this regard, projects such as the 'Rainfed Agriculture and Livestock' funded by the World Bank, are taking steps to promote on-farm conservation of landraces of cereals and food legumes, including the establishment of Seed Producers Associations in five governorates.

Keywords: Agriculture, Food, Genetic Resources, Use, Yemen

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Introduction

Over the past few decades, efforts have increased in collecting, documenting and conserving genetic resources in various countries with their different plant, animal, forestry, pastoral and aquatic components, including microorganisms and invertebrates. These resources are considered a national wealth and an indispensable economic resource for any country, not only because of their importance in food security but also because they are vital for sustainable development. The Convention of Biological Diversity (UNEP, 1992) and the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2004) are two binding global agreements calling the countries for concerted efforts to ensure the conservation of and access to biological resources, including plant genetic resources (PGR), to facilitate their sustainable use, along with fair and equitable sharing of benefits arising out of their utilization.

Many countries, including Yemen, have recognized the importance of genetic resources and have set out to establish centres, specialized units and genebanks since the 1970s, especially in the field of PGR. Over the past few decades, it has been possible to carry out many surveys and collect seeds and other types of samples of many diverse plant crops and species for conservation and herbaria. These accessions show a distinctive and rich plant genetic diversity in the country reflecting topographic, geographic and climatic diversity as well as the diversity of ecosystems and farming systems.

The flora surveys in Yemen identified a total of 2,838 plant species, including 2,602 that grow naturally, 129 cultivated plant species, 107 introduced crops, and 608 species identified as endemic (whose presence is limited to Yemen only) or semi-endemic species (whose

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presence is limited to the Arabian Peninsula only) (Al-Khulaidi, 2013).

Aljarmouzi *et al* (2023) mentioned that the National Genetic Resources Center (NGRC) in Yemen plays a pivotal role in collecting, conserving, documenting and characterizing PGR. Currently, the genebank conserves 6,849 seed accessions from 45 different crops. These crops encompass cereals such as sorghum, maize, millet, wheat and barley, totalling 4,701 accessions. Moreover, the genebank safeguards an extensive collection of legumes (1,215 accessions), including lentils, beans, cowpeas, peas and fenugreek. Additionally, it conserves a diverse selection of vegetables (561 accessions), such as onions, tomatoes, chilli peppers, cucumbers, zucchini, mallows, radishes, eggplant and okra. NGRC's efforts extend to the conservation of oil-producing crops (97 accessions) such as sesame and peanuts, as well as less commonly utilized crops like black seed (*Nigella sativa*), henna (*Lawsonia inermis*), coriander (*Coriandrum sativum*), caladium (*Caladium bicolor*), arugula (*Eruca sativa*) and mustard (*Brassica juncea* L.).

Furthermore, in various regions, field genebanks have been established by agricultural research stations to complement NGRC's endeavours, holding an extensive assortment of crops ranging from date palms, mangoes, citrus fruits, almonds, grapes, bananas, papayas, as well as forage and forest species. As Aljarmouzi *et al* (2023) reported, a total of 917 accessions are maintained in field genebanks. These field genebanks are strategically located across different regions, including 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 Seiyun). Collectively, NGRC and its associated field genebanks demonstrate a coordinated commitment to the comprehensive collection, conservation, documentation and characterization of Yemen's national PGR.

The process of collecting, conserving, documenting and characterizing PGR is not a goal by itself, but it aims to achieve sustainable use of those resources. In this regard, the use of genetic resources, especially the materials conserved in seed and field genebanks as well as *in vitro* storage, has remained one of the most important challenges facing the management of agricultural research and genetic resource institutions (Aljarmouzi *et al*, 2023). According to the Yemen national report in the Second Global Plan of Action for Plant Genetic Resources (GP2) of the UN's Food and Agriculture Organization (FAO, 2011), the issue of genetic resource utilization was considered one of the most prominent weaknesses in the implementation of programmes and plans for PGR in Yemen (FAO, 2019b).

The extent to which collected and conserved seeds and other accessions of different plant species and crops in genebanks are being utilized remains unclear. This issue needs to be addressed through studying, understanding and tracking any changes that may affect it, especially considering the current conditions and transformations that the country is witnessing. Identifying the challenges and obstacles is crucial to developing a clear vision for advancing the use of PGR – an objective this paper aimed to achieve.

Materials and methods

In this study, the authors relied on historical descriptive information regarding the use of PGR. This was done by collecting and reviewing national and international documents, reports and other surveys and studies related to PGR, in addition to relying on authors' previous works, personal knowledge and experiences, as team members directly involved in the conservation and use of genetic resources in Yemen (Aljarmouzi *et al*, 2023).

To prepare this paper, the authors used the methodological approach followed by the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA), and the guiding indicators approved for assessing the implementation of the GP2 (FAO, 2011). About 50 of those indicators were used, mostly to evaluate the current state of PGR use in Yemen during the period 2007–2023, according to the areas and activities included in the GP2, as well as the medium-term plan of the Agricultural Research and Extension Authority (AREA) in Yemen, and the annual plans of NGRC, operating under AREA, Dhamar. Based on its general objective, this current study assessed the utilization state of PGR, focusing on the most relevant aspects of four main themes: 1) notable achievements, 2) major changes and trends, 3) gaps and challenges, and 4) developing proposals for future PGRFA activities.

Results and discussion

Most important achievements

Expanding characterization and evaluation activities and developing collecting of germplasm

There is no doubt that improving the characterization and evaluation of the conserved accessions allows and increases the efficiency of their use, considering that proper documentation is required, also to register landraces and to enable their protection by property rights. AREA, through NGRC and its affiliated regional research stations and specialized research centres located in the different agroclimatic zones, has implemented many research programmes and projects related to the characterization and evaluation of local varieties of cereals, vegetables and fruit tree crops. The main studies carried out are summarized in Table 1 and their results were published in the *Yemeni Journal of Research and Studies* (YJARS), issued biannually by AREA.

Table 1. Research and studies published in the *Yemeni Journal of Research and Studies* (YJARS) on the characterization and evaluation of germplasm accessions in the Agricultural Research and Extension Authority (AREA) and its affiliated research stations and centres. Source: Prepared by the authors based on the articles published in the YJARS.

Title of the study	**Crop(s)**	**No. of accessions**	Reference
Evaluation of some local germplasm of lentil, collected from some areas located in the northern and central highlands	Lentil	22	(Lutf, 2000)
Comparing sorghum varieties for resistance to sorghum midge in the Tehama region of Yemen	Sorghum	5	(Muharram *et al*, 2001)
Shibam -2: a new faba bean variety with small-seed for the northern highlands region of Yemen	Faba Bean	1	(Lutf, 2000)
Genetic analysis of some traits of maize plants under water stress conditions	Maize	15	(Muqbil and Abdullah, 2002)
Evaluation of several local peanut germplasm accessions	Peanuts	9	(Sodi and Fouad, 2003)
Evaluation of grain yield of barley varieties with the participation of farmers in the northern highlands	Barley	8	(Saif, 2004)
Evaluating the productivity efficiency of some introduced maize hybrids	Maize	11	(Noman, 2004)
Evaluating of local landraces of eggplant in Wadi Hadhramaut	Eggplant	32	(Hassan, 2005a)
Evaluation of local landraces of carrots in Wadi Hadhramaut	Carrot	15	(Hassan, 2005b)
Grain yield comparison of wheat varieties in the Yemeni northern highlands with farmers participation.	Wheat	20	(Saif and Al-Shamiri, 2005)
Evaluation of yield and agricultural characters of eight wheat varieties	Wheat	8	(Saif *et al*, 2005)
Evaluation of local landraces of sweet melon in Wadi Hadhramaut	Watermelon	44	(Hassan, 2006)
Study of heritability percentage of some quantitative characters in F2 lentil hybrids	Lentil	12	(Zaid and Maqbool, 2006)
Yield efficiency of the wheat promising variety Qaa Elhaqal-7 in Yemeni central highlands region	Wheat	4	(Habib *et al*, 2007)
Evaluation of the local landraces of tomato in Wadi Hadhramaut	Tomato	25	(Hassan and bin Zeghew, 2007)
Purification and evaluation of the local wheat variety (Arabi)	Wheat	1	(Habib *et al*, 2007)
Evaluation of different varieties of fenugreek under rainy conditions in the northern highlands of Yemen	Fenugreek	5	(Zaid, 2007)
Evaluation of local genotypes of local pumpkins in Wadi Hadhramaut	Pumpkin	21	(Hassan and bin Zeghew, 2007)
Evaluation and description of local landraces of common bean	Beans	37	(Zaid *et al*, 2008)
Evaluation of genetic landraces of okra in Wadi Hadhramaut	Okra	31	(Hassan and bin Zeghew, 2008)
Evaluation of yield and other agronomical characters of local wheat mutants under rain-fed conditions	Wheat	9	(Saif *et al*, 2008)
Evaluation of the performance of five cowpea varieties under rain-fed conditions in the southern uplands of Yemen	Cowpea	5	(Al-Duwailah, 2009)

Continued on next page

Table 1 continued

Title of the study	**Crop(s)**	**No. of accessions**	Reference
Evaluation of radiated seeds of Sonalika wheat variety resistant to yellow rust	Wheat	1	(Basha *et al*, 2009)
Improving the quantitative and qualitative traits of Gemmiza-9 wheat variety by mutation induction	Wheat	3	(Saif *et al*, 2010)
Use of gamma rays to induce desirable mutants in local lentil variety (D2001)	Lentil	7	(Zaid and Saif, 2010)
Evaluation of the genotypes of coriander, nigella and cumin in Wadi Hadhramaut	Coriander, nigella and cumin	66	(Hassan and Al-Saqqaf, 2011)
Yield and quality evaluation of seven potato varieties in Wadi Hadhramaut	Potato	7	(Hassan *et al*, 2011)
Evaluation of different barley varieties for yield and other agronomical characters under rain-fed conditions	Barley	46	(Saif and Al-Shamiri, 2011)
Evaluation and selection of some introduced forage lines of common vetch for Yemeni northern highlands	Vetch	15	(Zaid, 2011)
Evaluation of yield and some agronomical traits of cowpea varieties under spate irrigation at Yemen southern coastal region	Cowpeas	15	(Al-Bakri and Sodi, 2012)
Early performance of some Mexican peaches and nectarines in Yemen highlands	Peach	12	(Al-Dalas *et al*, 2012)
Productivity evaluation of four finger millet cultivars (Eleusine coracana) under the central highlands conditions	Millet	4	(Doss *et al*, 2013)
Effect of mutants on quantitative and qualitative characteristics of local Bakkur barley under rain-fed conditions	Barley	10	(Saif *et al*, 2014)
Effect of pure line selection on the growth and yield characterization of local sorghum variety Qaira'a	Sorghum	1	(Noman and Dirham, 2014)
Morphological characterization of some plant genotypes of date palm in Shabwa Governorate, Yemen	Date palm	9	(Abdullah and Saeed, 2014)

Regarding the field collections, teams of researchers undertook the characterization of varieties of mango, coffee, date palm and grapes in different regions of Yemen. As a reference standard, the International Plant Genetic Resources Institute (IPGRI) descriptors were used. For example, in 2021, a team of researchers at the Northern Highlands Research Station (NHRS) characterized 45 genotypes (14 grape, 20 apricot, 3 pear, 4 fig and 4 peach genotypes).

In 2022, five grape varieties and five pomegranate varieties were characterized. The results of the cluster analysis confirmed the distinct diversity among grape and pomegranate varieties both of which are among the most popular fruit crops in Yemen (Al-Dalas *et al*, 2022).

The same is true for coffee, as several genotypes have been described in Sana'a Governorate. A team of researchers at the Al-Wadi and Al-Sahra Research Station (WSRS) in Seiyun, Hadramaut, also characterized date palm varieties in the Yemeni governorates where the crop is cultivated (AREA, 2013).

As for mango, all varieties grown in Yemen have been characterized, including 26 varieties introduced by the Ministry of Agriculture and Irrigation and AREA (Al-Munaifi, 2022). In this context, it is worth noting that documentation and description of mango varieties spread in Yemen were also implemented by AREA with the support of the Sultanic Dewan of Oman and included in the collection (AREA, 2013).

Upon reviewing the NGRC technical reports and the project reports implemented through the centre, specifically those focused on characterizing accessions stored in the genebank (Table 2), significant weaknesses were identified. These included inconsistency in the data and repetition in the description of some accessions.

For example, 1,967 sorghum accessions, more than 1,320 millet accessions, 883 wheat seed accessions and 918 barley seed accessions were characterized (Table 2), and the most prominent results of this characterization can be summarized as follows:

- Every report from NGRC included activities related to the phenotypic characterization of genetic resource accessions.
- There was a repetition in the characterization for some accessions because of the weak management operations in the genebank, especially in documentation. The number of wheat and barley accessions characterized exceeds the actual number of accessions preserved in the genebank.
- The inadequate quality and accuracy of characterization data were clearly demonstrated, as it was noted that these reports depend on a limited number of descriptors that were studied or documented.
- Some technical reports were prepared in a systematic manner and were scientifically sound, but they were not published in the form of evidence or scientific articles in peer-reviewed scientific journals.
- The results on varietal characterization were not documented with photos highlighting the characteristics of the local landraces and genotypes that were studied or referred to verbally in the reports.

In this context, it is also worth noting that some accessions of millet, wheat and sorghum were genetically characterized using molecular markers to determine their degree of genetic relatedness, through the 'Rainfed Agriculture and Livestock' project (2006–2013) and the 'Agricultural Biodiversity and Adaptation to Climate Change' project (2014–2015), both funded by the World Bank in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) and NGRC.

Encouraging crop diversity

The information collected for this paper, through reviewing the main and secondary references, revealed that the optimal use of genebank holdings can take different forms to encourage crop diversity utilization in the country. Some important examples of PGR use are summarized below:

- Agricultural farming systems that rely on a limited number of crops lack resilience, and these systems can lose their production because of factors such as diseases and pests (Lin, 2011). Therefore, diversification in crop production must be encouraged to meet local and national needs as well as to improve prevailing dietary patterns.
- In cooperation between FAO and AREA, quinoa (*Chenopodium quinoa*) was introduced and evaluated in farmers' fields, starting in 2013 with the introduction of several types of quinoa. Many genotypes were evaluated on the research farms in Sana'a, Taiz, Dhamar and Al-Kadan under different environmental conditions. In 2014 and 2015, the productivity of three varieties was evaluated at the research farm in the central highlands, to obtain a variety with high fodder and grain productivity suitable for the conditions of the region (Daws and Al-Muallem, 2018).
- The WSRS in Seiyun, Hadhramaut Governorate, has evaluated and propagated Haidawan (*Boerhavia elegans*), a naturally growing local plant with significant nutritional value. This plant is commonly used as a food ingredient in the dietary meals of the Hadhramaut community, as well as in the Al-Mahra and Shabwa Governorates. One notable dish that features Haidawan is the 'Aseed' meal, a porridge made with mashed dates and sesame oil, locally known as 'Salit Juljul'. Haidawan is rich in bioactive compounds, including antioxidants and essential nutrients, which contribute to its health benefits. In addition to its use in Aseed, Haidawan seeds are often ground into flour and incorporated into various traditional recipes. The seeds are also recognized for their potential to enhance the nutritional profile of foods such as biscuits (Kanzal and Madhi, 2012).
- Introducing varieties of beans, lentils, peas, wheat, and barley into governorates where the cultivation of such crops has declined because of economic and social factors, for example in Dhamar Governorate (in the districts of Jahran, Ans, Utomah, and Al-Hada), Sana'a Governorate (in the Bani Matar district), and Al-Mahwit

Table 2. Number of accessionsof the main crops in Yemen, preserved in the genebank at the National Genetic Resources Center (NGRC), Dhamar, and characterized and evaluated between 2007 and 2021. Source: Prepared by the authors based on the technical reports of NGRC (2007–2021).

Crop	Year										Total
	2007	2008	2009	2010	2011	2012	2013	2014	2019	2021	
Sorghum	-	-	638	-	-	277	110	227	57	658	**1,967**
Millet	197	289	442	-	-	130	-	130	15	117	**1,320**
Maize	73	-	120	-	-	50	-	50	4	36	**333**
Wheat	61	-	202	154	-	97	-	97	35	237	**883**
Barley	57	-	332	84	-	112	-	110	7	216	**918**
Cowpea	59	-	170	-	-	88	-	18	18	-	**353**
Lentils	53	-	108	-	-	58	-	17	3	78	**317**
Peas	23	-	26	-	-	-	-	16	3	89	**157**
Beans	-	-	-	-	-	-	-	-	-	93	**93**
Total	**523**	**289**	**2,038**	**238**	-	**812**	**110**	**665**	**142**	**1,524**	**6,341**

Governorate (in Shibam and Al-Dhula'a districts), Ibb Governorate (in Yarim district), Hajjah Governorate (in Kuhlan Af'far District) and Amran Governorate (in Qa'a Al-Bawn). Expanding the cultivation of legume crops is one of the priorities of agricultural policymakers at present, especially considering war and siege conditions. It is worth noting in this context that the introduction and encouragement of the cultivation of these crops and their varieties have taken place through several projects, such as the 'Food Security Project', funded by the Islamic Development Bank (IsDB), the Kuwait Fund for Arab Economic Development and the State of Qatar. Additionally, the 'Participatory conservation and sustainable use of local landraces to improve the livelihood and resilience of farmers to climate change in Yemen' project, funded by FAO (FAO, 2019a), has introduced and spread legume varieties in areas with very limited legume cultivation. One of the most important obstacles facing the expansion of legume cultivation is the reluctance of farmers to grow these crops that need guarding and protection because people uproot the plants and eat the green immature pods or fruits directly, especially since the number of farmers who grow these crops is limited so far.

- Introducing varieties of almond and coffee and encouraging farmers in Sana'a Governorate (Haraz, Al-Haymah and Bani Matar districts) to grow these crop varieties to increase crop diversity (Y30, 2023). The same is also noted in the case of Ibb Governorate (Al-Saddah, Al-Nadira and Wadi Banna districts) and in Taiz Governorate (Al-Mawaset, Mawiya and Al-Shamaytain districts) (UNDP, 2021).

- In Dhamar Governorate (Utomah District), the Agriculture Office (AO) implemented many activities encouraging crop diversification. In addition to the expansion and spread of coffee and almond trees in the district stated above, new types of fruits have also been introduced, such as kiwi, blackberry, pomegranate, Sa'adi grape and Annona fruit crops. It was also noted that some innovative farmers in other governorates began individually to grow cardamom (Sana'a Governorate) and ginger (Al-Mahwit Governorate).

- The 'Rainfed Agriculture and Livestock' project funded by the World Bank in 2006–2013 included an activity related to promoting on-farm conservation and sustainable use of landraces of cereals, food legumes and vegetables, implemented jointly by ICARDA and AREA. This project provided examples of added-value technologies and alternative sources of income along with institutional arrangements. It has established 70 seed producer associations in five governorates to multiply and distribute seeds of landraces of sorghum, millet, wheat, barley, maize, lentil and faba bean.

Supporting breeding and genetic improvement programmes

The genetic material that has been – or is being – collected can be used to identify or select distinctive traits to develop crop varieties as needed, or to expand the genetic base of a breeding programme. Such traits may include earliness of the local varieties (of cereal and leguminous crops), or drought resistance and salt tolerance in some other local varieties, and good-quality attributes needed by breeding programmes to develop new high-yielding and climate-resilient varieties.

In this regard, the NGRC in Dhamar provided seed samples of many local varieties in response to requests from researchers and graduate students in various Yemeni agricultural regions to implement genetic improvement activities. However, these requests are still very limited compared to the available genetic material preserved in the genebank (Table 3).

Plant breeders at AREA agricultural research stations have implemented many breeding programmes using mutations through external projects funded by the International Atomic Energy Agency (IAEA), or through local projects funded by the annual government budget, and the work on these programmes is still ongoing. Distinctive successes have been achieved in this aspect, especially in sesame and barley. Three varieties of sesame were released: Hazza-1 and Hazza-2, both distinguished by their red seed colour and superior

Table 3. Crops and number of genebank accessions provided by NGRC upon request for research and breeding purposes. Source: Prepared by authors based on the data of the genebank of the National Genetic Resources Center in Dhamar.

Year	Crop	No. of accessions
2010	Lentil	5
	Sorghum	5
	Wheat	2
	Barley	4
	Lentil	5
	Bean	2
2011	Maize	10
2013	Millet	20
	Sorghum	175
	Millet	40
	Maize	37
	Wheat	34
	Barley	33
	Cowpea	35
	Lentil	19
	Fenugreek	14
	Peas	11
	Bean	10
	Maize	5
2014	Okra	35
	Wheat	24
	Cowpea	45
	Lentil	15
	Sorghum	2
	Beans	2
	Peas	1
	Total	**590**

productivity compared to local varieties, and Hazza-3, noted for its white seed colour, high yield and high oil content. Varieties of wheat, barley, fenugreek and lentils were also released in the northern highlands as part of the mutation programme.

Between 2013 and 2020, a total of 93 research activities were conducted in the field of variety evaluation and improvement across AREA branches, including regional research stations and national centres (Table 4).

In 2021, thanks to AREA, many varieties of several crops, including wheat, barley, corn, lentils, beans and peas were released by the High Committee for Registration of Agricultural Varieties and Technologies (HCRAVT), which includes representatives of various relevant authorities. These varieties were delivered by AREA to the public Corporation for Improved Seed Multiplication (GSMC) in a special ceremony sponsored by Ministry of Agriculture and Irrigation (Table 5).

The Genetic Resource Center (GRC) of the College of Agriculture, Sana'a University also implemented many activities such as the evaluation of landraces and breeding by selection method during the period 2014–2019, the most important of which were the following (personal communication, Dr Mohammed Al-Aswadi, GRC Director, College of Agriculture, Sana'a University, 2022):

- Production of maize hybrids
- Improvement of wheat productivity (Al-Himyari variety and Al-Bawni variety)
- Improvement of barley varieties productivity (Sakla and Al-Aswad (the Black))
- Improvement of four sorghum varieties productivity (Al-Lahmani, Al-Jameli, Al-Shahedhi and Al-Safara)
- Improvement of local lentils products
- Improvement of local peas productivity.

These advancements are integral to genetic improvement programmes aimed at enhancing traits such as earliness, drought resistance and heat tolerance. The productivity of these varieties has been significantly improved through the purification and maintenance of local varieties well-adapted to Yemen's predominantly arid climate. The improvement process involves selecting plant heads based on distinctive characteristics such as size, weight and yield.

Supporting seed production and distribution

To ensure the use of available PGR, effective seed systems must guarantee that the seeds adopted by farmers for cultivation are available in sufficient quantity, of high quality, and can be obtained by farmers at the right time, in the right place and at reasonable prices.

During the past decade, AREA and GSMC received funding from FAO to produce and distribute seeds to farmers as part of humanitarian aid. These seeds include locally adapted varieties such as sorghum, millet, barley and lentils, which are crucial for maintaining agricultural biodiversity and resilience. These local varieties, inherited by farmers from their ancestors, are well-adapted to climate change and represent an important genetic resource for improving agricultural production. Therefore, the multiplication and distribution of these local seeds were vital for preserving genetic resources and ensuring their sustainable use.

It should be noted here that after problems occurred due to distribution of low-quality seeds of cereal crops by some humanitarian aid organizations, the Ministry of Agriculture and Irrigation stipulated that organizations and providers of seed distribution services to farmers must have the seeds screened and packaged in the stores and warehouses of the GSMC. FAO's support and funding for AREA and GSMC came within the framework of strengthening its capabilities to fulfil any resulting obligations or requirements from the execution of the Ministry's new instructions.

However, there was an increase in cultivated areas and the production of improved seeds for certain crops during specific years (2014–2017). These seeds were distributed to farmers based on their needs and the availability of funding from supporting organizations. It is worth noting that despite fluctuations observed

Table 4. Research activities related tothe evaluation of crop varieties and genetic enhancement implemented by the Agricultural Research and Extension Authority (AREA) research stations and centres (2013–2020). Source: Prepared by authors based on the reports of a collection of multi-year annual technical reports of the different AREA research stations and centres (2013–2020). CHRS, Central Highlands Research Station; SHRS, Southern Highlands Research Station; NHRS, Northern Highlands Research Station; WCRS, West Coast Research Station; SCRS, Southern Coast Research Station; ECRS, Eastern Coast Research Station; WSRS, Wadi and Al-Sahra Research Station; ERRS, Eastern Region Research Station; NGRC, National Genetic Resources Center.

Research activity	Research Station/Centre									Total
	CHRS	SHRS	NHRS	WCRS	SCRS	ECRS	WSRS	ERRS	NGRC	
Evaluation of cereal crop varieties (wheat, barley, sorghum, maize and millet)	21	2	6	2	-	-	2	5	6	**44**
Evaluation of varieties of legume crops (lentils, beans, peas, chickpeas, beans and fenugreek)	8	2	5	-	-	-	-	-	4	**19**
Evaluation of varieties of vegetable crops (potatoes, onions and carrots)	2	-	-	-	-	-	3	-	-	**5**
Evaluation of varieties of fruit crops (almond, peach, mango, palm, lemon, banana and papaya)	2	-	1	2	4	-	1	-	-	**10**
Evaluation of cash oil crop varieties (peanuts, sesame, quinoa, cotton, safflower and fescue)	2	-	-	3	3	2	1	4	-	**15**
Total	**35**	**4**	**12**	**7**	**7**	**2**	**7**	**9**	**10**	**93**

Table 5. Species and varieties registered in the High Committee for Registration of Agricultural Varieties and Technologies (HCRAVT), Plant Production Directorate, Ministry of Agriculture and Irrigation (MAI), Sana'a. Source: Prepared by authors based on the minutes of HCRAVT meetings.

Crop	No. of varieties	Names of varieties
Wheat	10	Bohouth-8, Bohouth-14, Bohouth-15, Bohouth-37, Bohouth-5, Sonalika Mohasan, Bohouth-10, Arabi, Nagi, Shibam-8 and Naeem-1
Barley	7	Ashmour-2, Qa'a Al-Haql-7, Bohouth-2002, Bohouth-28, Bohouth-26, Bohouth-7 and Kawkaban-1
Sorghum	1	Jera'ah Mohasan-98
Millet	6	Murakab Zabid, Kadan-1, Kadan-2, Kadan-3, Kadan-4 and Kadan 5
Lentils	2	Dhamar-1 and Dhamar-2
Peas	2	Amran-1 and Yahsub-1
Beans	3	Dhafar-1, Dhafar-2 and Shibam-1
Mango	10	Surdoud-5, Surdoud-7, Surdoud-11, Surdoud-13, Surdoud-18, Surdoud-21, Surdoud-36, Kechener, Totapuri, and Surdoud-108
Total	**41**	

in subsequent years, there was still a notable effort to expand distribution to beneficiary farmers (Table 6).

In 2016, the General Corporation for Grain Production Improvement (PCGDP) played a significant role in boosting the production of improved seeds across several governorates, particularly focusing on wheat, and selling them at reasonable prices. The Corporation entered into agreements with numerous farmers, providing them with seeds and essential production inputs such as fertilizers and irrigation to encourage the expansion of wheat cultivation. After the harvest, the Corporation purchased the crops from the farmers, deducting the costs of the seeds and production inputs provided. The quantities distributed by the General Corporation for Grain Production Improvement increased from 52 tonnes in 2018 to 640 tonnes in 2022 (Figure 1).

Since 2015, several international organizations in Yemen have launched rapid response programmes to support farmers during the ongoing conflict. These programmes involve purchasing and distributing seeds through national partners like GSMC and AREA. The seeds are usually sourced directly from farmers, especially for crops like sorghum and millet, or from research and multiplication institutions.

Changes and trends

The results of this study revealed the main changes and latest trends in the use of PGR in Yemen during the study period (2007–2023) compared to the previous period which was covered by the first (FAO, 1996) and second (FAO, 2009) country reports of Yemen on PGRFA issued by FAO. The most important of these changes and

Table 6. Area (ha) and quantities of produced improved seeds (tonne) in Yemen (2012–2022) for wheat, sorghum and millet. Average seeding rate (kg/ha): wheat (140), sorghum (20) and millet (15). NA, data not available. Source: Prepared by the authors based on unpublished data of the GSMC, Dhamar, Yemen.

Crop	Details	Year										
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Wheat	Cultivated area (ha)	326	444	473	292	332	392	NA	NA	NA	NA	NA
	Production (tonne)	652	888	946	584	665	785	720	718	570	385	346
	Area covered by improved seeds (ha)	4,664	6,350	6,757	4,171	4,750	4,906	NA	NA	NA	NA	NA
Sorghum	Cultivated area (ha)	92	117	101	115	234	241	NA	NA	NA	NA	NA
	Production (tonne)	92	117	101	115	234	241	178	338	232	108.6	141.4
	Area covered by improved seeds (ha)	4,600	5,850	5,050	5,750	11,070	12,050	NA	NA	NA	NA	NA
Millet	Cultivated area (ha)	36	5	33	27	55	42	NA	NA	NA	NA	NA
	Production (tonne)	36	5	33	27	55	42	16	153	30.3	43.5	49.8
	Area covered by improved seeds (ha)	2,400	333	2,200	1,800	3,666	2,800	NA	NA	NA	NA	NA

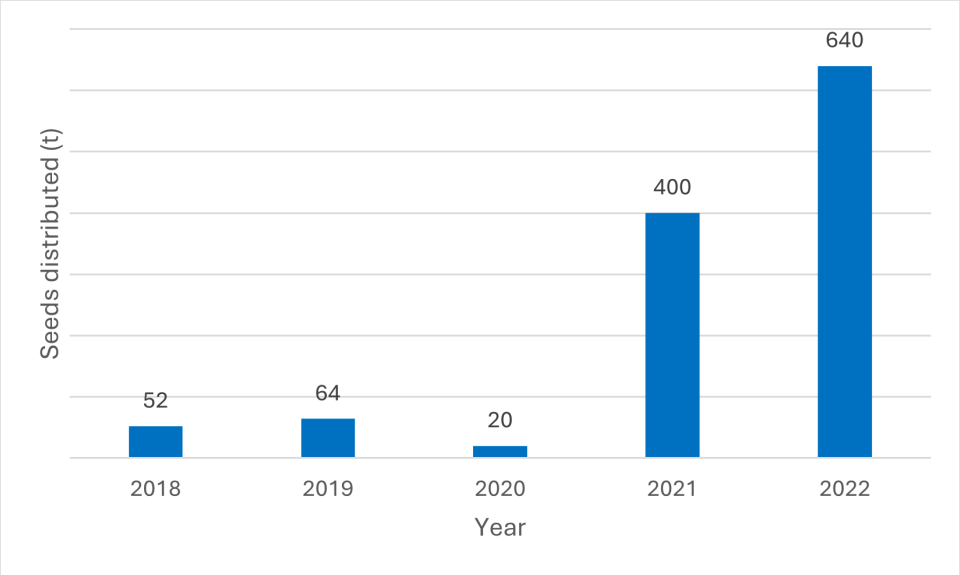

Figure 1. Quantity of wheat seeds (tonnes) distributed by the General Corporation for Grain Production Improvement (2018–2022)

trends can be summarized as follows:

- Considering the conditions of war and siege that the country has faced since the beginning of 2015, and with the growing awareness of protecting the country's sovereignty over its PGR, there has been growing interest in protecting local landraces from potential misappropriation of intellectual property rights. This defensive protection might be developed through the registration of landraces into national catalogues (Noriega, 2016). It would also be important to deposit samples in publicly accessible plant collections and document each accession with internationally recognized documentation standards, such as FAO/Bioversity International Multi-Crop Passport Descriptors (MCPD) (Alercia *et al*, 2015) and IPGRI/Bioversity crop-specific phenotypic descriptors.[1] Assignment of unique identifiers such as DOIs to accessions is also key to facilitating the exchange of germplasm passport information, ensuring that genetic resources are effectively managed and conserved. Therefore, in their crop improvement programmes, AREA prioritized the documentation of genebank accessions and registration of landraces. The Ministry of Agriculture and Irrigation also completed the steps to register many improved varieties of strategic crops. AREA submitted the required documents for sound registration procedures to the Plant Production Directorate of the Ministry, and the Higher Committee for Varieties Registration (HCRAVT) approved in its meetings the completion of their registration procedures. This included varieties of coffee, maize, wheat, barley, millet, sesame, and legumes such as lentils and peas.
- NGRC (Dhamar), in coordination and partnership with the Central Highlands Research Station (CHRS) (Dhamar) and Wadi and Al-Sahra Research Station

[1] Full collection available at https://hdl.handle.net/10568/56589

(WSRS) (Seiyun), characterized and evaluated varieties of sorghum, wheat, barley, lentils and cowpea (58, 35, 7, 3 and 18 accessions, respectively), which were collected from the selected districts in the Governorates of Dhamar, Hadhramaut and Al-Mahra as part of the activities of the project 'Participatory Conservation and Sustainable Use of Local Landraces to Improve Farmers' Livelihoods and Their Resilience in Adapting to Climate Change in Yemen' (2019–2023). This project was funded by the ITPGRFA Benefit-Sharing Fund.

- In 2021, AREA represented by its Northern Highlands Research Station (NHRS) (Sana'a), CHRS (Dhamar) and WCRS (Al kadan), and in coordination with NGRC, implemented the largest phenotypic characterization activity – within the framework of collections – of accessions preserved in the NGRC's genebank for cereal and legumes crops. More than 1,500 accessions were characterized, as a first step towards the characterizazion of groups with distinct characteristics. The data listed in Table 7 shows the number of samples sent from NGRC's genebank to the said research stations.

Table 7. Number of samples sent by the National Genetic Resources Center (NGRC) genebank to the Research Stations (2021). CHRS, Central Highlands Research Station; NHRS, Northern Highlands Research Station; WCRS, West Coast Research Station. Source: Prepared by authors based on data from NGRC's genebank (Dhamar).

Crop	CHRS	NHRS	WCRS	Total no. of samples
Sorghum	238	218	202	658
Wheat	138	99	-	237
Barley	98	65	-	163
Lentil	40	36	-	76
Peas	40	35	-	75
Bean	43	32	-	75
Beans	53	50	-	103
Millet	-	-	97	97
Maize	-	-	33	33
Coriander	-	38	-	38
Black seeds	-	28	-	28
Total	**650**	**601**	**332**	**1,583**

- There is no doubt that the scope of distribution and use of seeds has expanded over the past years due to the work of different organizations that worked in the country and provided farmers with seeds of different crops, which is undoubtedly a positive thing. However, this expansion was not accompanied from the beginning by any coordination with AREA. This has resulted in a gap between farmers, researchers and other sectoral line authorities. Although diversity is desirable and required to enhance the resilience of farmers, the introduction of species and varieties must be based on field evaluation tests and on the results and recommendations of AREA.

- NGRC participated in implementing projects that encourage increasing on-farm diversity in plant species and within species. These projects, funded by various organizations, include the 'Agricultural Biodiversity and Climate Adaptation Project' funded by the World Bank, the 'Food Security Project', funded by the Islamic Development Bank (IsDB), the Kuwait Fund for Arab Economic Development and the State of Qatar. Additionally, the 'Participatory conservation and sustainable use of local landraces to improve the livelihood and resilience of farmers to climate change in Yemen' project, funded by FAO.

- Limited efforts to introduce quinoa as a food/fodder crop through testing trials and assessments that took place in various agricultural regions.

- The breeding programmes at AREA relied on the selection from nurseries provided to Yemen by the international agricultural research centres, such as ICARDA, through regional projects and research programmes and networks for cooperation between those centres and national research institutions. Many activities were conducted in the research stations and on farmers' fields, and these projects, programmes and networks mostly targeted agricultural crops such as wheat, barley, lentils, peas, beans, cowpea, sorghum, millet and maize. Over the past decade, the activities of most international centres in Yemen have been disrupted due to the war, siege and later the COVID-19 pandemic, making the transfer and exchange of genetic materials difficult. These challenges have persisted to the present day.

- In 2021, breeding research programmes began hybridization in vegetables (tomato) and cereal (wheat) crops. This is a new trend that must be noted and praised. It came in response to the conditions caused by war, blockade and global crises such as the COVID-19 pandemic and the Ukrainian-Russian war, and the resulting tough economic conditions, especially considering the high seed import bill from abroad. This has become a major concern among decision-makers in searching for options that encourage researchers as well as the public and private sectors to move towards local seed production. The efforts in this respect are still modest because of the lack of experience and financial capabilities.

- In this context, it is important also to point to the efforts of the Potato Seed Company in producing higher grades of potato tubers and tissue culture multiplied potato varieties in partnership with the private sector during the past five years, to reduce the import bill by producing seeds locally, as well as achieving self-sufficiency in this important food crop.

- A decrease in the number of plant breeders in agricultural research for several reasons (including retirement, death, illness and migration) in addition to the effects resulting from the war, such as the cessation and irregularity of salary payment and the absence of operational budgets.

- The process of exchanging genetic resources with the regional and international centres was halted due to the war and siege, and the paralysis or ineffectiveness of the various public service institutions.

- There have been no changes in national policies that encourage the development and trade of local varieties

and underutilized crops, as the Agricultural Seeds and Fertilizers Law no. 20 of 1998 is still in place and primarily focuses on the regulation, production and marketing of adopted seeds and fertilizers, but it does not specifically address the development and trade of underutilized crops (Govt. of Yemen, 1998).
- There has been a positive and active change on the part of public and commercial sectors in the trade of local varieties and underutilized crops. This is often done with the support of external organizations within the framework of the emergency response and humanitarian aid programmes/projects, despite the parallel negative points that could accompany this endeavour. An example of this is the PCGDP establishment of a specialized market (in 2022) in the heart of the capital, Sana'a, to sell and trade types and varieties of different locally produced grains, including wheat, barley, legumes, and underutilized crops. This market complex still provides its services to both the private and public sectors. Although limited information is available about private sector activity in seed production, it can be noted that some agricultural input companies have contracted farmers to produce seeds as required by funding from international organizations working in Yemen on relief and humanitarian aid, through tenders to purchase quantities of seeds. There is also a significant activity by some companies working in propagation nurseries and producing seedlings or seeds of some crops. Examples of such companies include the 'Yemen Nabat' nursery producing tomato seedlings, as well as potato seeds using tissue culture.
- The PCGDP was established in 2016 with the aim of achieving self-sufficiency in grains. The corporation provided financial support to AREA, agricultural colleges, and seed producer associations to implement many research and production activities in addition to training and awareness raising of producers at the local community level.
- The area cultivated with improved, high-quality varieties remains limited, not exceeding 15% of the total cultivated land. Cultivation is still primarily focused on cereals and, to a lesser extent, legumes.

Gaps and challenges

This study showed that using existing PGR in NGRC's genebank and other genebanks in Yemen still suffers from many shortcomings, gaps and challenges for important aspects. Such gaps and challenges limit the process and hinder the effective use of the country's genetic resources for food and agriculture. These obstacles can be summarized as follows:
- Lack of trained and qualified technical personnel, especially in crop description and evaluation.
- Weak capabilities in using computer programmes to analyze characterization and evaluation results.
- Weak capabilities in using biotechnology, especially molecular characterization.
- Weak documentation of data and dissemination of information on characterization and evaluation.
- Research breeding programmes that promote crop diversification are limited. Although there were initial efforts to introduce quinoa, these attempts were not sustained. Yemen has a diversity of plant foods, yet agricultural research has not adequately explored these species.
- Limited use of the genetic material preserved in genebanks for plant breeding.
- Decrease in the number of plant breeders.
- Poor use of modern technologies in education.
- Weak characterization and evaluation programmes for underutilized plant species and wild food plants.
- Limited number of crop varieties released that are well adapted to local conditions, especially sorghum and millet varieties, despite the diversity and abundance of genetic material for these two crops in the national genebank.
- Weak capabilities of producing and distributing sufficient quantities of high-quality seeds of improved varieties of different crops by the government and private sectors, farmer community organizations, farmer groups and individual producers.
- Absence of a comprehensive national policy to regulate seed production and trading, whether governmental, private, commercial or non-profit.
- Weak funding for breeding, improvement and application of biotechnology programmes.
- Great weakness in encouraging and developing the trading of seeds of unexploited crop varieties.

Conclusion and recommendations

Based on the results and indicators presented above regarding the achievements, trends and challenges affecting the use of PGR in Yemen, it can be concluded that the utilization of national genetic resources remains weak and limited in contributing to food security, agriculture, the economy and sustainable development. To improve the use of these resources, several recommendations were formulated for future consideration including:
- Characterizing and evaluating local genotype groups of basic crops, underutilized crops, and wild relatives for specific and distinct traits selected according to need, importance or priority.
- Developing a documentation and information system for description and evaluation data and education programmes.
- Expanding the application of genetic characterization using biotechnology tools.
- Publishing the results of characterization and evaluation of the preserved genetic materials so that they are available to researchers, academics and those interested, and to encourage them to use and benefit from these resources.
- Issuing guides identifying the accessions preserved in genebanks.
- Strengthening staff technical capabilities in genetic characterization, evaluation and improvement through training and qualification programmes.

- Giving priority to activities related to plant breeding and providing the required financial support.
- Supporting the GSMC technically and financially to widen its coverage.
- Reviewing and developing a special law regulating the seed production and trading sector, and developing a national seed policy and strategy that defines tasks and roles of the various public and private partners.
- Increasing collaboration with international research institutes to leverage global expertise, share knowledge and access advanced technologies for the improvement of PGR.

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. Ahmed Amri provided support through guidance, reviewing and improving the manuscript draft, enhancing the translation of the manuscript and providing important references.

Conflict of interest statement

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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