Exploring the potential of Indonesia rice germplasm collection to support its utilisation

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Abstract. Indonesia is rich in rice germplasm that has the potential to support sustainable agriculture through a variety of development programs. This germplasm must be explored for its superior characteristics to be used optimally. This paper presents the efforts to explore the characters and genetic potentials of Indonesian rice germplasm collected at the Agricultural Genebank. Data were extracted from research reports from 2016−2022. Some rice accessions were characterised and evaluated through the characterisation and evaluation program. Of the 3,335 rice accessions managed by the Agricultural Genebank, 706 have been observed for their morpho-agronomic characteristics, 960 for molecular characteristics, and 113 for functional qualities. Resistance to biotic and abiotic stresses was evaluated in 700 and 250 accessions, respectively. A large number of data points have been generated. These valuable data were recorded, reported, and safely archived. Recommendations to address the remaining challenges and optimise germplasm utilisation are 1) expanding the characterisation-evaluation program to the whole collection and 2) developing an updated, communicative, and user-friendly information system to disseminate and facilitate the utilisation of rice germplasm collections. This study is useful for getting a comprehensive overview of germplasm management and setting further strategies for more efficient germplasm management.

1 Introduction

Rice plays a major role in global food security. With a continuously growing population, there is a strong demand for increasing rice production. Moreover, due to environmental pressure, this demand has to be met using less land, less water, and more severe environmental stresses. Thus, the demand for increased yields must be met through genetic improvement [1]. Fortunately, Indonesia is rich in rice diversity. The diverse agro-ecosystems and the long history of agricultural culture have shaped the diversity of the rice genetic pool. Genetic diversity of rice germplasm was reported in islands throughout Indonesia [2], including East Kalimantan [3,4], Java [4,5], and many other areas. Genetic diversity was also reported on swamp rice [6], upland rice [7], and black rice [8].

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Genetic resources are essential for food security and sustainable agriculture [9], and their diversity is crucial for variety development [10]. Germplasm utilisation is the ultimate objective of crop management [11]. However, utilising genetic resources for variety development is complex and challenging. For breeders and researchers, insufficient information on desired potential traits, the need for efficient screening methods, and legal issues to comply with for access remain challenging [1,12]. On the other hand, for germplasm holders, a series of processes are required to support utilisation [13].

In gene bank operations, characterisation and evaluation are the main programs that add value to the collection and increase its utilisation [13]. This program allows us to understand the structure of germplasm collections better. Novel genes and alleles that are important for genetic improvement can be identified. The lack of adequate characterisation and evaluation data is the main reason for underutilisation [14]. In addition, the variation and diversity of the collection can be analysed, and interrelationships among accessions can be identified. This program will also help detect duplicates, misidentification, and errors and facilitate exchange, sharing, raising awareness, and appreciation [15,10].

The Indonesian Center of Agricultural Biotechnology and Genetic Resources Research and Development (ICABIOGRAD) under the Ministry of Agriculture (MoA) was designated for research and development on agricultural genetic resources. Equipped with a gene bank and other supporting facilities, the institution was responsible for conserving agricultural plant germplasm [16]. The germplasm management in ICABIOGRAD was the primary source for implementing Sustainable Development Goal 2.5.1, conserving genetic resources as supporting materials for a sustainable agricultural system [17].

Considering the crucial importance of germplasm for sustainable agriculture, the ICABIOGRAD set up a program to explore the potential of germplasm collections and support their utilisation. This study was subjected to assess the approaches taken in the Agricultural Genebank in exploring the potential of rice germplasm collections. The characterisation and evaluation program data conducted at the Agricultural Genebank was used as the main reference. The program's feasibility was assessed based on its implementation and relevant considerations. A comprehensive view of the potential of germplasm collection, the current environmental challenges, and the approach to dealing with the demands for the collection's usefulness are expected to provide a comprehensive picture that can be used as a reference in further management.

2 Methodology

This desk study assessed the germplasm management approaches to exploring rice's potential for supporting variety development. Data and information were collected from official and recommended sources. The main source of the data was the program reports of the ICABIOGRAD Genebank during 2016–2022. Archived annual program reports of the Agricultural Research Operational Plan (ROPP) and Agricultural Research Team Plan (RPTP) were used as the main data sources, focusing on activities in the characterisation and evaluation programs. Other unpublished records and student internship reports were considered supporting data. Each activity's basic considerations, approaches, implementation, and accomplishments were evaluated to create a comprehensive view of the program and develop recommendations for improvement and a cost-efficient germplasm management system.

3 Results and discussion

As of 2022, 3,333 rice accessions were conserved in the ICABIOGRAD Genebank. Despite the crucial nature of the characterisation and evaluation program, until 2015, only a few rice accessions were characterised [18]. Several activities were evaluated and improved when a new management approach began in 2016. Rice germplasm was explored for its potential traits through two main programs of characterisation and evaluation. With funding from the state budget (APBN), these two programs have been routinely carried out in ICABIOGRAD through the agricultural research operational plan. The program consisted of several activities under the characterisation program and others under the evaluation program.

3.1 Rice germplasm characterisation program

Proper characterisation and evaluation are crucial to supporting germplasm utilisation. This program can be carried out using different methods. However, using an advanced approach is highly recommended [10]. In the ICABIOGRAD Genebank, the characterisation programs targeted morphology, agronomical characteristics, molecular characteristics, and nutritional value (Table 1).

Table 1. Morphology-agronomical characterisation of germplasm collection performed in the ICABIOGRAD Genebank, 2016–2021.

Characters	Number of accessions observed						
	2016	2017	2018	2019	2020	2021	Total
Morpho-agronomical characters	-	150	150	143	150	-	593
Molecular characterisation	-	-	-	192	384	384	960
Nutritional qualities	30*	60 [a] **	50 [a] **	68 [a] ***	-	-	208

[a]Non-official program; *anthocyanin content; **grain-physical-chemical (7 characters); ***amylose content and gel gelatinization

3.1.1 Morphological and agronomical characterisation

Characterisation describes accession characteristics by observing germplasm's distinct, identifiable, and heritable characteristics. It is recommended that plant characterisations be carried out as soon as possible [13]. However, due to limited resources, this activity is often overlooked. In ICABIOGRAD, the characterisation was generally conducted in parallel with the regeneration program. Because the main focus is rejuvenation, only a few characters in a few accessions were observed [18]. The target characters focus mainly on agronomic traits related to yield potential. During 2012–2016, through a collaboration program with the Indonesia Center for Rice Research (ICRR), observation was targeted for more characters according to the rice descriptor [19]. From 2017 to 2020, many new accessions entered the genebank and needed multiplication before acquisition. The characterisation was officially programmed and targeted at those new accessions.

Aside from those officially planned programs, rice characterisation was also conducted through an internship program, a practical learning experience for university students. During 2018–2021, 10 internships from 5 universities joined the rice germplasm characterisation program in the Agricultural Genebank, and 940 rice accessions were observed for their grain characters (Table 2).

Table 2. Rice grain characterisation through internship program 2018–2022.

Origin of target accessions (province)	Number of accessions	Home university of the student
Nangroe Aceh Darussalam	180	Sebelas Maret University, Solo
Nangroe Aceh Darussalam	7*	Unidentified**
North Sumatra	100	Sebelas Maret University, Solo
North Sumatra	39*	Unidentified**
Riau	25	Islamic State University, Jakarta
South Sumatra	30	Gadjah Mada University, Yogyakarta
West Sumatra	91	Muhammadiyah University of Yogyakarta
Banten	16	Muhammadiyah University of Yogyakarta
East Java	80	Muhammadiyah University of Yogyakarta
Central Kalimantan	133	Sebelas Maret University, Solo
Central Kalimantan	39*	Unidentified**
South Sulawesi	98	Gunadarma University, Jakarta
East Nusa Tenggara; West Nusa Tenggara***	102	Gunadarma University, Jakarta

*Newly, not-acquired accessions; **performed by group works from different universities; ***not differentiated between the two provinces

3.1.2 Molecular characterisation

In genetic terms, characterisation refers to detecting variation due to differences in either DNA sequences, specific genes, or modifying factors [20]. Genetic markers have evolved from morphological to cytological and continue to be biochemical and DNA markers [21]. These markers are widely used and have proven to be powerful tools for analysing germplasm resources and assessing genetic variation [22].

Among different types of DNA markers utilised for crop plants, simple sequence repeats (SSR) are the marker of choice due to their abundance in the plant genome, high polymorphism rate, and high reproducibility [23]. This marker was also used to study rice collection in the ICABIOGRAD Genebank. Simple sequence repeat markers associated with some particular traits, such as heading date, were utilised for germplasm characterisation. Aside from SSR, other markers, such as single nucleotide polymorphism markers (SNPs), are also currently used [25].

3.1.3 Characterisation of nutritional value

Recent advancements in social lifestyles, especially the awareness of healthy food, have influenced research and various developments. The breeding program is no longer dominated by the major aim of tolerance to environmental stresses. The healthy lifestyle and the increasing awareness of malnutrition and micronutrient deficiencies have driven a shift in the focus of breeding programs from yield and disease resistance to nutritional quality [26]; [27]. Giving attention to this current shift, the ICABIOGRAD acknowledges the need for characterisation of the functional quality of the germplasm collections. The functional quality characterisation was carried out on several nutritional quality characteristics. Several accessions have been observed for their anthocyanin content, amylose content, and related eating qualities (Table 2).

From the morphological and agronomic characterisation program, various data were obtained, including superior characteristics that support cultivation, such as plant type, lodging, heading date, and harvesting date; characters related to yield potentials, such as tiller number, plant height, panicle characteristics, and seed characteristics; and characters that affect consumer preferences, such as grain colour and grain shape. A similarity analysis from the molecular characterisation program can provide information on the diversity and phylogenetic distance of the observed accessions. Functional quality characterisation provides information on accessions with superior characteristics such as anthocyanin content, low amylose, and other eating quality characteristics according to consumer preferences.

3.2 Rice germplasm evaluation for environmental stresses

Germplasm evaluation, which typically deals with assessing quality parameters and response to the environment, is essential to identify germplasm with a particular potential trait for their future utilisation. The strong influence of the El Niño-Southern Oscillation (ENSO) puts Indonesia at high risk for hazards associated with excessive rain during La Nina and drought during El Nino [28,29]. In addition, this climate change also affected changes in pest and disease profiles, the arrival of invasive species, and the decline of arable land [28,30]. Global climate change also affects the behaviour of insect pests as they adapt to their environment [31]. Considering the strong influence of environmental factors on crop production, studies on biotic and abiotic stresses have been the focus of the germplasm evaluation program at ICABIOGRAD.

3.2.1 Evaluation of biotic stresses

In rice, among the major pests found in Indonesia are brown planthopper/BPH (*Nilaparvata lugens*), bacterial leaf blight/BLB (*Xanthomonas orizae*), blast, and *tungro*. The BPH is not only a major pest in Indonesia but also in the Asia-Pacific [32]. Several outbreaks of BPH occurred following crop failure [33]. In regions where rice is widely grown, the population of this insect has changed biotypes, reaching four different biotypes [34]. For BLB, several strains of *Xanthomonas oryzae* pv. *oryzae* were found in Indonesia. Hifni et al. [35] reported 11 strains, with strain IV considered the most infectious. Blast, a pathogen caused by *Pyricularia grisea* is among the main diseases in upland rice [36]. This disease affects rice plants at all growth phases and causes crop failure, thereby threatening global food security [37]. Kadeawi et al. [38] reported around 201 isolates collected from rice ecosystems on several islands in Indonesia.

Table 3. Germplasm evaluation program for tolerance to abiotic and biotic stresses in rice germplasm.

Targeted trait	Number of accessions observed						
	2016	2017	2018	2019	2020	2021	Total
Tolerance to abiotic stresses							
Aluminium (Al) toxicity					100	100	200
Drought					100	100	200
Iron (Fe) toxicity	40						40
Tolerance to biotic stresses							
Brown planthoppers (*Nilaparvata lugens*)	100	140	150	100	100	100	690
Blast (*Pyricularia grisea*)	100	100	100	100	100	100	600
Bacterial leaf blight (*Xanthomonas oryzae*)	100	150					250

3.2.2 Evaluation for abiotic stresses

The dwindling of agricultural land in Indonesia leaves marginal, suboptimal land less suited to agriculture. Several issues exist on this typical land, including acidic soil and water problems. The dominance of inceptisols, ultisols, and oxysols, which occupy 73% of the land area, makes Indonesian soils mostly acidic [39]. Acidic dry land occupies 108,8 million ha [40], approximately 55% of the total terrestrial area in Indonesia [41], a major contributor to marginal soils. With this large area of acidic soil, Indonesia provides the largest acidic sulphate soils in the world [42].

Acidic soils reduce soil fertility and increase the availability of toxic elements such as aluminium (Al) and iron (Fe). Since acidic soil is dominant, Al and iron toxicity become crucial constraints. Al toxicity was most commonly found in ultisol upland soils, while iron toxicity was mostly found in wetlands. Iron toxicity typically occurs in wetland rice grown on acid ultisols and oxisols and in acid sulphate soils rich in reducible Fe [43]. In Indonesia, iron toxicity occurs in swampy areas [44,45] and other wetland areas.

The impact of ENSO is pronounced in water problems. Effects of El Niño and La Niña spur on floods and droughts. However, drought hazard is generally more pronounced [46]. Indonesia has experienced drought several times during El Niño [46]. This hazard is among the crucial problems in Indonesia's agricultural system; rice is the main food crop severely affected by drought [47]. However, since dry land dominates in Indonesia [48], the next agricultural farming in Indonesia will mainly depend on this dry land [49]. In this situation, crops that are adaptable to drought are essential.

In ICABIOGRAD, the evaluation programs for abiotic stresses in rice were targeted for tolerance to drought, aluminium toxicity, and iron toxicity. As many as 200 accessions were evaluated for tolerance to Al toxicity and drought, and 40 accessions were evaluated for tolerance to iron toxicity (Table 3). Depending on their applicability, the trials were conducted in a laboratory, a greenhouse, and/or the field.

3.3 Remaining challenges and important steps required to optimise germplasm utilisation

Several characterisation and evaluation programs have been carried out at ICABIOGRAD, and a large amount of data has been generated. Potential characters can be derived from each accession's agronomical and morphological characteristics. Plant type, lodging, and culm diameter can be associated with good vigour; heading and harvesting dates are associated with maturity. While tiller number, plant height, panicle characteristics, grain weight, and grain number are generally associated with yield potential. Moreover, characters that affect consumer preferences, such as grain colour and grain shape, high anthocyanin content, and low amylose content, have also been produced. From the molecular characterisation program, a similarity analysis can be carried out to gain information on the diversity and phylogenetic distance of the accessions. Moreover, from the rice evaluation program, we can find accessories with tolerance to BPH, blast, and BLB and accessories that are tolerant to drought and acidic soil with Al and iron toxicities.

The availability of such data is precious, especially for variety development. Users can find accessions with certain superior characteristics and utilise them directly or indirectly through breeding programs. With the availability of pool gene sources, new superior varieties can be developed with superior characteristics, such as high yield, early maturity, tolerance to particular abiotic stresses, and resistance to particular pests and diseases.

Despite the achievements that resulted from these characterisation and evaluation programs, several problems remain to be addressed. Among the things that need to be considered is that the scope of these programs is still limited, both in terms of the scope of target accessions and the target traits that have been observed. The current developments in lifestyle and climate change pose new challenges. A more thorough characterisation and evaluation will need to be carried out. On the other hand, the data that has been generated from those programs needs to be managed in such a way that it can be utilised optimally. To optimise the use of existing data, information regarding accession advantages must be available and accessible. This data should be organised into a good data system. Creating an information system to facilitate users accessing and utilising this data is also necessary.

However, considering the limitations of resources, the availability of human resources, and the limited budget, an implementation strategy needs to be carried out. Several recommendations can be implemented to address these issues. The funding problem required for expanding the scope of characterisation and evaluation can be overcome by collaborating with various parties. Characterisation activities can be carried out simultaneously with rejuvenation activities. For human resources, genebanks can open internship programs for university students. This internship program is a mentoring activity, so the trainees do not need to pay.

For evaluation programs, because this program requires quite high costs, collaborators willing to share financing are needed. Genebank may collaborate with researchers and/or breeders. Researchers and breeders need germplasm that can be used as material for developing varieties. Researchers and breeders can collaborate to evaluate germplasm collections from genebank collections. Apart from sharing work and data, this system also shares financing. By collaborating with users, evaluation activities can be carried out with the collaborators' human resources and budget. Collaborators can search for the desired accessions, while the genebank will benefit from the shared data. This type of collaboration between the genebank and the user was recommended. The collaboration will facilitate the utilisation of collections and allow the detection of misidentifications and errors in genebank operations [11]. It is also necessary to create an information system to facilitate users' access to and utilise this data.

4 Conclusions and policy recommendations

The usefulness of rice germplasm is determined by the availability and accessibility of information on the collection. Numerous accessions have been characterised and evaluated at the Agricultural Genebank, and a large amount of data has been generated. The valuable data was recorded, reported, and archived in a database. Despite those achievements, several problems remained to be addressed, including the need to expand the scope of characterisation and evaluation activities and optimise the utilisation of existing data and germplasm collection.

Several recommendations can be made to optimise the utilisation of the genebank collections by continuing, expanding, and completing the characterisation-evaluation program for the entire collection and by optimising the availability and accessibility of the existing potential data for further use. The efforts to expand the scope of the characterisation-evaluation program can be carried out through several approaches: (1) harmonisation of characterisation and rejuvenation activities and (2) collaborating with users. Efforts to increase the visibility of data and the potential of accessions can be carried out by developing an adequate information system equipped with appropriate, easy-to-use, and user-friendly supporting applications to facilitate access to germplasm and its related potential data.

It is probably the first study highlighting the characterisation and evaluation program from a planning perspective. An overview of the rationale underlying an activity, the implementation of the activity, and the benefits of the resulting output shows the performance of an organisation. This study should be carried out periodically to determine the organisation's direction, strategy, and policies towards better, more effective, and efficient performance.

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