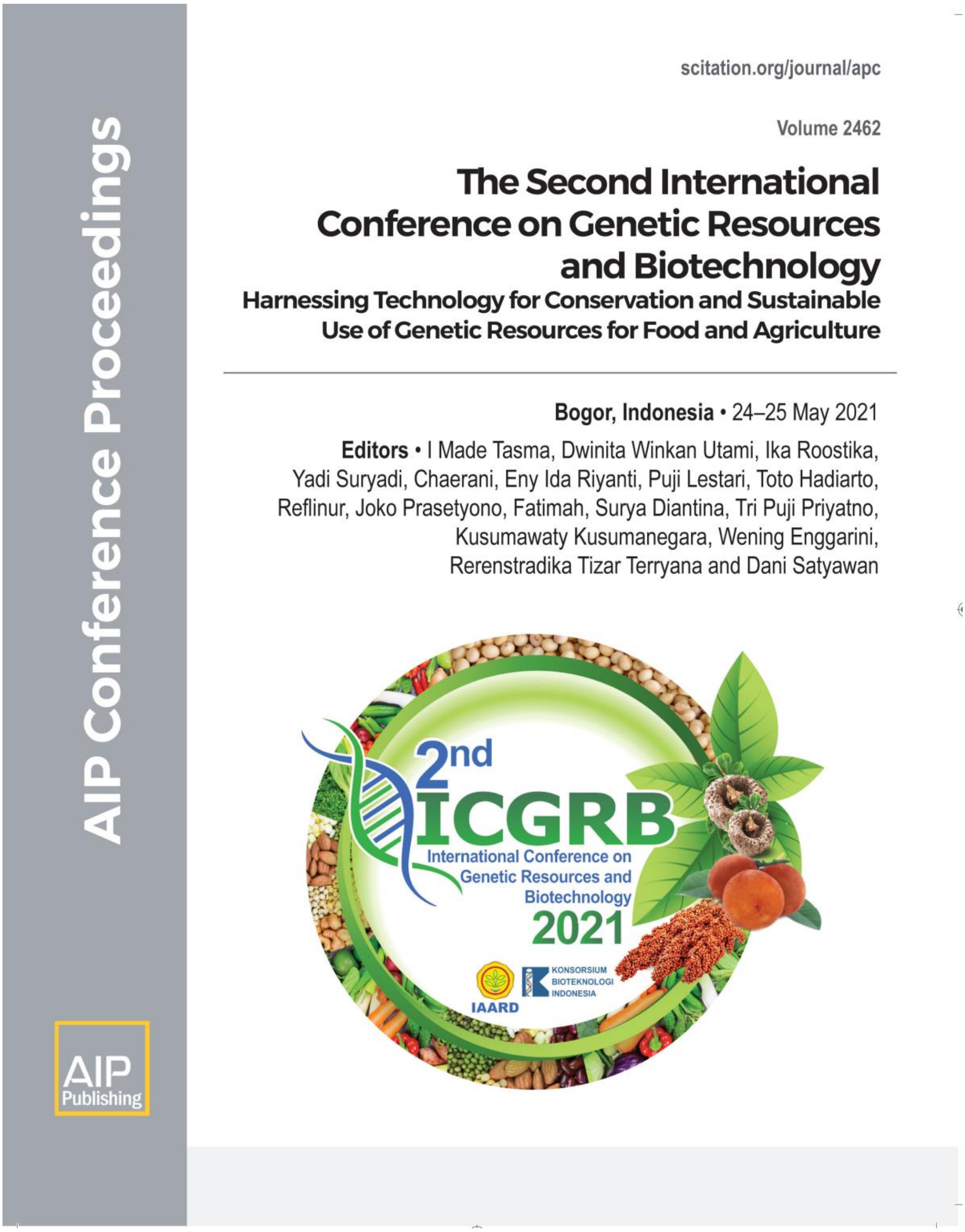

January 2022

THE SECOND INTERNATIONAL CONFERENCE ON GENETIC RESOURCES AND BIOTECHNOLOGY: Harnessing Technology for Conservation and Sustainable Use of Genetic Resources for Food and Agriculture

Committees: The Second International Conference on Genetic Resources and Biotechnology

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Preface: The Second International Conference on Genetic Resources and Biotechnology

The Second International Conference on Genetic Resources and Biotechnology, which is the continuation of the first event held in 2018, focuses on topics related to advances in biotechnology to create more opportunities for effective conservation and sustainable utilization of genetic resources for food and agriculture. This year conference's theme is Harnessing Technology for Conservation and Sustainable Use of Genetic Resources for Food and Agriculture. The conference was organized by Indonesian Agency for Agricultural Research and Development (IAARD), Ministry of Agriculture, Indonesia, in collaboration with Indonesian Biotechnology Consortium and held on 24th-25th of May 2021virtually due to the pandemic of COVID-19.

The conference aims to share and exchange current scientific information and technological developments on biotechnology and their applications for conservation and sustainable use of genetic, to encourage and promote quality, efficiency, and modernization of management and utilization of genetic resources, and to facilitate national and international collaboration among participants. There are five scopes discussed in this conference. They are effective management of conservation and sustainable use of genetic resources for food and agriculture, application of genomics and molecular markers for genetic resource conservation and crop adaptation to climate change, application of innovative crop improvement techniques for conservation and sustainable use of plant genetic resources for food and agriculture, plant cell and tissue culture for conservation and effective utilization of genetic resources, and the use of microbial genetic resources as biological control agents of agricultural pests and diseases, and for soil bioremediation.

Five speakers from the United States of America, Japan, India and Indonesia were invited to discuss about their expertise and knowledge on relevant subjects in the plenary sessions. This conference was attended by more than 100 participants including 75 presenters and 44 listeners worldwide. They came from diverse governmental, private, or academic institutions and also scientific communities. The presented materials have undergone peer review processes and only qualified papers were selected. Furthermore, all papers were subjected to double blind peer-review and expected to meet the scientific criteria of significance and academic excellence to be published in a conference proceedings indexed in a well-known, reputable service.

We would like to express our sincere gratitude to our speakers, presenters and all participants for their contributions in this conference. We would also like to express our appreciation for the generosity of our sponsors that support this conference: PT CropLife, PT ITS Science Indonesia, PT Fajar Mas Murni and PT Prima Instrument Analitika. Lastly, special thanks to all committee members for their exceptional work and contributions in the conference and publication.

Chair of Organizing Committee

Dr. Toto Hadiarto

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Harnessing plant genetic resources through biotechnology for food security in Indonesia

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Harnessing Plant Genetic Resources through Biotechnology for Food Security in Indonesia

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Abstract. Plant genetic resources (PGR) with high genetic diversity are valuable assets as the basis of global and national food security. This review article provides a comprehensive review about harnessing PGR through the application of biotechnology for food self-sufficiency in general and was addressed in Indonesia. Some topics concerning the challenge of food self-sufficiency related to the status of PGR in Indonesian Agency for Agricultural Research and Development-Indonesian Center for Agricultural Biotechnology and Genetic Resources Research and Development Gene Bank (IAARD-ICABIOGRAD Gene Bank), the utilization of PGR in Indonesia, relevant biotechnology to harness PGR, supporting national legislation for national and global levels, and the future perspective were discussed. Many challenges including climate change, land degradation, increasing human population, and biodiversity loss have been attempted and need a high effort to achieve sustainable food production today. In a conservation perspective, PGR in the country was predominantly for research and breeding that are a complement to the propagation and cultivation. Considering its potential role in food security, a total of 30 crops are conserved *ex situ* by IAARD-ICABIOGRAD Gene Bank which is assigned to manage the germplasm and some other crop-based research institutes. An effective crop genetic improvement through implementation and application of biotechnology should be raised through basis and advance researches *in vitro* and molecular biology such as gene and genomic technologies and other omics, genetic engineering including genome editing would expectedly increase the utilization of PGR. As consequence, some governmental policy framework and laws are important support for national PGR program to harness PGR in Indonesia. Therefore, it will be a major opportunity that biotechnological approaches will be incorporated into the national agricultural program in complement with national legislation to food security in Indonesia.

INTRODUCTION

Plant genetic resources (PGR) play an important role in enabling crops and livestock to withstand global climate change and to ensure food safety and security of the world's rapidly rising population that could be a complex network as a major challenge [1]. Among the 250 thousand plant species known to humankind, more than 30,000 are edible of which about 7,000 have been used for food. Around 120 species are cultivated today, and just 3 species provide more than 50% of human food which are dominated by rice, wheat, maize, millet, and sorghum as main crops [2]. On the other hand, the world population could increase by 2.25 billion people and reach 9–11 billion by 2050 [3–4]. At the global level, agricultural production and consumption in 2050 were projected to be 60% higher than in 2005/2007. The perceived limit to producing food for a growing global population remains a source of debate and preoccupation despite the agriculture sector's historical ability to meet such demand. Therefore, agricultural production needs to expand faster than population growth without further damage to the environment. The growing population should then strive for sustainable food consumption, as social, environmental and health impacts are very important. The sustainable production of more food for human consumption requires biotechnology that makes better application of limited resources not only modern but also classical biotechnology. A substantial

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investment is needed in research and innovation to achieve food security and food [1]. Based on this condition, agricultural production with the benefit of PGR must also keep pace with it and coercive attempts to sustainably feed such the rising world's population should be mainly concerned.

Conservation and utilization of PGR are important components of *ex situ* collections like in gene bank which can facilitate breeding programs [5]. Halewood *et al*. [6] described the total number of accessions conserved *ex situ* worldwide has increased by approximately 20% since 1996, however, only less than 30% of the total number of accessions were distinct and much of the overall increase in the number of accessions might be the result of exchange and unplanned duplication. About 75% of crop genetic diversity was lost in the last century as farmers worldwide switched to genetically uniform, high-yielding varieties and abandoned multiple local varieties [2]. The genetic erosion is also undergone due to modern intensive agriculture activities, such as replacement of local varieties by modern varieties make it uniformity and consequently has a narrow genetic base. Genetic erosion or the loss of alleles/genes in plant genetic diversity should be anticipated through the conservation of PGR to meet growing environmental challenges as well as climate change [7].

Collection and characterization of existing germplasm is not only important for utilizing the appropriate attribute in breeding programs but also essential for protecting the unique identification of a genotype worldwide [8]. Genetic diversity among the populations and their genetic relationships aids in conservation and parental selection in the improvement programs. Identification of populations with a high level of genetic variation will become a valuable resource for broadening the genetic base since it enables the identification of superior alleles for several traits [9]. The significant progress has been made in the development of tools and techniques to assess and monitor PGR within agricultural production systems. Increasing the genetic diversity within production systems as a way to reduce risk, particularly in light of changes in climate, pests, and diseases is now being concerned in several countries. More effective policies, legislation, and regulations governing the *in situ* and *on farm* management of PGR, both inside and outside protected areas still need to concern, and closer collaboration and coordination are needed between the agriculture and environment sectors. Many aspects of *in situ* management still require further research and strengthened research capacity are required in such areas as the taxonomy of crop wild relatives (CWR) and the use of molecular tools to conduct inventories and surveys [10].

Indonesia known as a country with a wealth of PGR including landraces, local varieties, introduced accessions, improved varieties, and promising breeding lines possess useful genes of interest targetted in plant breeding programs, such as resistance genes against pest attack and plant diseases in certain crops. Landraces are a repository of a gene pool that enrich biodiversity and maintain and stabilize the ecosystem in a sustainable way to make it functional [11]. A systematic landrace and local varieties evaluation may define patterns of diversity, which will facilitate identifying alleles for enhancing yield and abiotic stress adaptation, thus raising the productivity and stability of staple crops in vulnerable environments. However, some germplasm of local rice varieties of the wetland rice field systems has been disappeared, since they have not been being planted by farmers due to lack of competition with modern varieties. To deal with the loss of genetic resources, therefore, conservation, identification, and cataloging effort activities for certain crops through either *in situ* or *ex situ* are urgently required for future protection of Intellectual Property Rights (IPR) and utilization of superior alleles conferred by local crop varieties.

Advances in research techniques and their greater availability during the past decade have resulted in some significant new insights into the extent and distribution of genetic diversity, both in space and time [10]. A well-designed strategy with emerging technologies and timely development ensures sustainable food production. Employing advanced biotechnology and breeding techniques can be enriched by exploring new supporting technologies including molecular markers, genetic engineering, and genome editing, as well as through co-development and transfer of technologies by Indonesia with several countries [12]. Molecular markers and DNA barcoding have been suggested as useful molecular techniques to complement traditional taxonomic expertise for fast species identification and biodiversity inventories [13]. As a result, superior varieties would be easily developed on a broad genetic base involving genes from alien and wild species. ICABIOGRAD as one of the research institutes under IAARD has been concerning the conservation and utilization of PGR. Harnessing PGR in Indonesia is potentially beneficial for food security in future. Dealing with this program, the Indonesian Government has facilitated ICABIOGRAD, IAARD, with supporting research facilities such as gene bank, laboratory, and experimental field station for IPRs conservation, *in vitro* as well as molecular biology laboratory. This review article provides a comprehensive review about harnessing PGR through the application of biotechnology for food self-sufficiency in Indonesia.

CHALLENGE OF FOOD SELF-SUFFICIENCY

Agriculture and food production today are faced with many challenges, such as climate change, land degradation, increasing human population, and biodiversity loss. According to Baer-Nawrocka and Sadowski [14], the particularities of agriculture, as a sector that ensures food supply, result from many factors, including the multilateral interaction between the environment and human activity. In addition, the extent of human intervention in the food production process is usually measured with the amount of capital expenditure or in other words, the food production potential, and the resulting food security depend on both natural and economic factors. This means the capacity to produce an adequate volume of agricultural raw materials is affected, on the one hand, by natural conditions (primarily including soil and climate) and, on the other hand, by anthropogenic factors, such as progress in organization and in technical, chemical, and biological sciences. Furthermore, Baer-Nawrocka and Sadowski [14] emphasized that as agriculture develops, the human impact becomes increasingly important, although the natural environment continues to play a major role resulting in the scale of human intervention in food manufacturing processes is roughly measured with the amount of capital expenditure, for example it depends on the economic development level of a country. Ultimately, the food production capacity and the resulting food security are determined by natural and economic factors.

Concerning direct utilization, PGR need to be constantly enriched, sustainably conserved, maintained, and documented. Various strategies and methods subjected to the PGR conservation have been approached, such as *ex situ*, *in situ*, and *on farm* conservation. However, those activities are prone to the problems of genetic erosion which can be derived from a natural process, caused by artificial intervention, or by both. According to Van de Wouw *et al*. [15], genetic erosion is commonly known to have resulted from modern intensive agriculture activities, such as replacement of local varieties by modern varieties, habitat destruction, overexploitation of species, population pressure, and environmental degradation. Those factors make it uniform and consequently have a narrow genetic base/the genetic variability of species, lowering the ability to adapt to alter environmental conditions. The use of land to preserve habitats for wild relatives remains undervalued compared with alternative uses such as clearing for agricultural and urban use.

The availability of natural resources is a prerequisite that should be taken into consideration for human consumption to supply daily food demand and available foods with the expectation that the ability of a household, a population or region in maintaining its own food requirements could easily be reached and enable the country become the food-self sufficiency. At the beginning, food security focused on food reserves that allowed survival to famine. The increase in the level of human development helped discover that insufficient purchasing power of the poorest segments of the population is another factor for food insecurity [14].

According to Andriamparany *et al*. [16], to meet their daily needs, a population usually depends on natural resources and wild foods. However, the increasing demand, climate, and environmental changes issues threat to turn food become more expensive and difficult to produce [17]. Thus, food self-sufficiency should be ensured by supporting the agricultural sector focusing on improving production efficiency and strengthen research allowing the development of production models with the presence of food self-sufficiency. By building its food-self sufficiency, a region can increase the stability of its food system. The probability of a household being self-sufficient increases with the number of crops grown, so crop diversification serves as a strategy for improving food self-sufficiency at the family level [18]. Similar challenges in self-sufficient food production are also faced in Indonesia.

STATUS OF PGR IN IAARD-ICABIOGRAD GENE BANK

PGR is an essential source for achieving and maintaining food security. Together with land and water, PGR is a major component that forms the basis of food and agricultural security [19]. The availability of diversity of genetic sources allows crops diversification, agricultural methods, and plant breeding and development. Genetic diversity, which represents the variation within and between populations of a plant species, is the basis for variety selection and development [20]. Conversely, reduction of genetic diversity means reducing and narrowing choices in several aspects in the development of varieties. The awareness of the limited number of agricultural plants available for maintaining food security has led to global determination to undertake conservation efforts of genetic diversity effectively and wisely. This becomes the spotlight and attention of the international world [21].

In Indonesia, PGR is conserved through several programs under the Ministry of Agriculture. Under IAARD, PGR is conserved in Implementing Units. Some perennial PGR are conserved on farm under the monitory of the Assessment Institute for Agriculture Technology (AIAT). *Ex situ* conservation is performed by ICABIOGRAD and some crop-based research centers, along with their mandate. Given a mandate to researching conservation of agricultural genetic resources [22], ICABIOGRAD is facilitated with conservation supporting facilities of seed storage/preservation (seed bank), field conservation plots (field gene banks), and *in vitro* conservation laboratory. Programs and activities are developed to implement the mandate on supporting the conservation and sustainable use of the accessions and germplasms (AG), starting from acquisition and registration, germplasm management, characterization and evaluation, documentation and data management, and distribution for utilization [23]. A total of 10,876 PGR accessions are conserved in seed bank, field gene bank, and *in vitro* conservation facility (Table 1). Those gene bank collections consisted of improved varieties, breeding lines, and local varieties as well as wild relatives. The local varieties are collected from the different islands and different provinces throughout Indonesia.

TABLE 1. List of PGR accessions conserved in the IAARD-ICABIOGRAD Gene Bank.

Type of conservation	Crop group	Crop name	Number of accessions
Seed bank preservation	Cereals	Rice (*Oryza sativa*), wild rice (*Oryza* sp.), wheat (*Triticum aestivum*), maize (*Zea mays*), sorghum (*Sorghum bicolor* [L.] Moench.), Job's tears (*Coix lacryma-jobi* L.), and foxtail millet (*Setaria italica*)	5,080
Seed bank preservation	Legumes	Soybean (*Glycine max* [L.] Merr.), ground nut (*Arachis hypogaea*), mung bean (*Vigna radiata*), Bambara ground nut (*V. suterranea*), cowpea (*V. unguiculata*), pigeon pie (*Cajanus cajan*), lab-lab bean (*Lablab purpureus*), velvet bean (*Mucuna pruriens*), Jack bean (*Canavalia ensiformis*), winged bean (*Psophocarpus tetragonolobus*), and rice bean (*V. umbellata*).	3,055
Seed bank preservation	Others (industrial and horticultural crop)	sesame (*Sesamum indicum* L.), eggplant (*Solanum melongena*)	242
Field gene bank	Tubers	Cassava (*Mannihot esculenta*), sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), blue taro (*Xanthossoma* sp.), arrowroot (*Marantha arundinaceae*), canna (*Canna edulis*), intoxicating yam (*Dioscorea hispida*), lesser yam (*Dioscorea esculenta*), purple yam (*D. alata*), elephant foot yam (*Amorphophallus campanulatus* Bl.), and other tubers	2,450
In vitro conservation*	Tubers	Cassava (*M. esculenta*), sweet potato (*I. batatas*), taro (*C. esculenta*), blue taro (*Xanthossoma* sp.)	525*

*Plantlet is maintained and conserved in the medium term under growth-limiting condition of artificial culture media until 2020.

Around 8,377 accessions of the orthodox seeds of 20 crops are conserved under long-term storage conditions at -20°C and short-term conditions at 18°C with 40% relative humidity for base collections and active collections, respectively. Whereas, a total of 2,450 tubers collection consisted of 10 crop species are conserved in field gene bank at experimental station (ES) under the management of ICABIOGRAD. Considered as relatively safer to maintain clonal crop germplasm, *in vitro* approach is used to conserve tubers crops. Plantlet is maintained and conserved in the medium term under growth-limiting condition of artificial culture media. Until 2020, a total of 525 plantlets are conserved *in vitro*, consisted of sweet potato, cassava, and taro. In these media, the plantlets resist for 6–24 months.

THE UTILIZATION OF PGR IN INDONESIA

In the conservation perspective, several ways to use PGR including research, breeding, propagation, and cultivation. In Indonesia, the main use of PGR is for research and breeding purposes that are usually conducted by governmental research centers/institutes, universities, and some private companies. However, in the common society and for direct impact to the economy, propagation of seedling and the cultivation are great deal interest. The breeding program for crop improvement has long been developed produced numerous highly successful new varieties of crops over the centuries. According to the previous report [24], crop improvement program has been focusing on several important traits subjected to increase of crop resistance against both biotic stresses, including pests and diseases, and abiotic stresses such as drought tolerance, and to modify the quality of crops for instance increase of fatty acid and sugar contents. In general, breeding strategies through conventional breeding, irradiation-induced mutation, and biotechnology have been applied on various crops or trees, such as food crops, horticultural crops, estate crops, and forest trees, to support crop improvement programs in Indonesia based on the PGR utilization.

The utilization of PGR for food and agriculture in Indonesia have been implemented in IAARD through the research institutes working on commodities in coordination with the National Commission on Genetic Resources (NCGR), *Komnas SDG*. The PGR program consisting of working activities related to the conservation and utilization of genetic resources through the breeding program. With the PGR program it is expected that the Sustainable Development Goals (SDGs) of the PGR can be achieved and efforts on PGR conservation, discovering, and utilizing of novel qualities in PGR as well as the rescue of under-utilized species can be efficiently and effectively facilitated. Thus, future use of improved PGR is being expected for sustainable use especially at the farm level which would be beneficial for the farmers. However, the utilization of PGR in Indonesia faced some constraints, such as lack of characterization and evaluation, lack of documentation (useful information on the conserved germplasm), lack of capacity (qualified personnel, funds, training, and facilities), weak policy development, lack of integration between conservation and utilization program, lack of coordination among researchers, breeders, gene bank managers, and farmers [24].

To deal with those obstacles, several work activities have been undertaken and become current priorities for Indonesia to enhance the use of PGR in Indonesia, such as (1) strengthened capacities and improved training in plant breeding, (2) increased collaboration among researchers, breeders, gene bank managers, and farmers to better integrate conservation and use of PGR, (3) emphasized on using and developing underutilized species, (4) implemented participatory approaches to plant breeding, (5) explored marketing opportunities for products of local varieties and diversity-rich products, (6) promoted the use of landraces/farmer's varieties in seed supply systems, and (7) improved the regulatory and policy frameworks to facilitate greater use of PGR.

Indonesia has been massively implementing participatory crop improvement programs for many years. The advance and rapid development of technology for crop improvements, such as molecular breeding and genetic engineering, will transform the use of PGR significantly in the future. Biotechnology-based breeding strategy applied in Indonesia was recently implemented through (1) the application of *in vitro* culture techniques for selection in a breeding program, such as double haploid or anther culture, embryo rescue, and protoplast fusion techniques, (2) molecular breeding strategy to speed up breeding cycle with high precision through the application of DNA-based marker, and (3) genetic engineering to solve other problems which could not be done by the conventional breeding application. As explained in the Country report on the State of PGR [24], those breeding program strategies were aimed to increase the important traits on different crops, such as cassava, citrus, oil palm, papaya, potato, soybean, rice, and tomato for resistance to pests and diseases, tolerance to drought, phosphate deficiency, aluminum toxicity, iron toxicity, sugar content, oleic acid, delay ripening, and amylose free starch.

The application of *in vitro* culture techniques includes somaclonal variation, *in vitro* selection, anther culture, embryo rescue, and protoplast fusion. Somaclonal variation was conducted to increase the genetic variation of rice, ginger, patchouli, artemisia, and vanilla. *In vitro* selection for biotic resistance and abiotic tolerance were conducted on vanilla, abaca, rice, and soybean. The anther culture techniques were used to make pure strain through spontaneous doubled haploid/dihaploid induction of individual on rice and maize. Embryo rescue techniques were used for wild relative's hybridization with cultivated vanilla and mung bean. On the other hand, research on protoplast fusion was conducted for biotic resistance on eggplant, citrus, and patchouli [24].

Meanwhile, the use of molecular markers for crop improvement consisting of mining of new alleles and genes for biotic and abiotic stresses, transferring of the trait(s) from wild or agronomically inferior donor source which is called "prebreeding"or "germplasm enhancement" and marker-assisted selection. In addition, molecular breeding-based crop improvement could potentially help breeders to overcome the conventional breeding unsolved persistent problems, especially in solving the common problem of the phenotypic expression faced in the selection process of promising lines. The power of molecular breeding strategy will help the selection processes on the basis of the phenotypic expression and identification of certain alleles or loci targetted by breeders simultaneously. The previous report has emphasized that the utilization of PGR for crop improvement conducted in Indonesia through the application of molecular breeding program were achieved, for example, is the two improved rice varieties, known as Conde and Angke which were released by the Minister of Agriculture and several other elite rice lines resistant to bacterial and fungal disease [24].

Similarly, genetic engineering for crop improvement has also been conducting in various institutes in Indonesia. Up to date, genetic engineering technology has reached a stage where scientists can take one or more specific genes from nearly any organism, including plants, animals, bacteria, or viruses, and introduce those genes into another organism which resulted in various transgenic crop commodities conferring introgressed genes responsible to important traits such as resistance to pests and diseases, tolerance to drought, increase sugar content, delay ripening, and amylose free starch [24].

RELEVANT BIOTECHNOLOGY TO HARNESS PLANT GENETIC RESOURCES

The implementation of biotechnological tools impressively advances agricultural production since past decades, even though some remaining crucial issues should be further solved. Plant biotechnology techniques and its application in Indonesia were showed in Table 2. Biotechnology highly contribute to solve major issues of agriculture specifying on food production, i.e. to advance crop breeding related to high yield and other important traits, to help reduce bottleneck of genomic data to crop traits, as well as to increase plant adaptation and tolerance to biotic and abiotic stresses for sustainable PGR production. In addition to breeding program, fields of plant biology, novel PGR, genome modification, genomics, and other omics technologies have demonstrated to be new solutions for food security under changing environmental conditions. In the previous era, a number of new gene and PGR candidates anticipated to direct to improved crop yields and other important agricultural traits must pass long development phases with trial and error of field evaluation. Therefore, quantitative and automated phenotypic screening methods combined with biological computation and genetics would possibly enabling rapid screening of the most promising population lines at an early stage [25, 26]. As demonstrated in by Moshelion and Altman [30], by the development of a high-resolution, high-throughput diagnostic screening was able to study whole-plant physiological performance serving as phenotypic screening. Via this tool, hundreds of plants subjected to multiple combinations of stressful conditions are likely to be screened simultaneously at specific stages of life cycles of interested plants. Finally, the phenotypic screening/selection can dramatically accelerate the process of development in plants [27–30].

Biotechnology obviously makes breeding possible to actualize the potential of PGR into new varieties with high yields, resistance to pests and diseases, as well as environmental. This paradigm is in line with the concept of the Evergreen Revolution initiated by the Food and Agriculture Organization at the World Food Summit in Rome 1996 [31] and current industrial revolution 4.0. Conventional breeding has been addressed to increase crop productivity through yield potential and disease and pest resistance. Through molecular biology and genome sequencing supported low cost and rapid assessment. Several plant varieties are developed for resilience to biotic and abiotic stresses, nutrition, and nitrogen efficiency [32]. Plant biotechnology also seems focus on seed-varietal improvement using genetically modified (GM) technology and molecular-assisted breeding, that can produce products/varieties with enhanced yields in a more sustainable manner. A total of 40 GM crops and 509 GM events, which cover 41 GM commercial traits for food, feed and/or for cultivation have been approved in several countries [33], and these approved GM varieties include food/feed crops (maize, rice, soybean, colza, wheat, bean, chicory, eggplant, tomato, sweet pepper, flax, potato, squash, apple, melon, papaya, and plum) [34]. In addition, genome editing will facilitate the engineering of complex traits, e.g. stacked disease tolerance and pest resistance mechanisms, tolerance to abiotic stress, and nutritional and organoleptic properties [6]. Thus, genetic engineering included genome editing is useful to be deployed to improve crop breeding not only in developed countries but also in Indonesia which has a high diversity of PGR.

In Indonesia, the ultimate purpose of PGR conservation and utilization is to contribute to national development and sustainable agriculture by developing and strengthening national programs. The Indonesian government set food self-sufficiency and food security as one of the main program on the agricultural sector. All PGR programs are under the coordination of the IAARD, Ministry of Agriculture which is supported by several crop-based research and development centers/institutes and extensions assessment center with 33 units extensions of AIATs located in all 33 provinces throughout Indonesia. IAARD is mandated for national breeding and complemented with universities and other private sectors. Given its mandate, IAARD has contributed to improved varieties and technology transfer [35].

Genetic breeding and development programs are focused on production of high yield plant variety in order to meet self-sufficiency. Especially for food crops, there is a very strict requirement on high-yield, as mandated by ICABIOGRAD collaborated with other research institutes and relevant stakeholders. This requirement leads to the continuous utilization of a narrow genetic base from previously released varieties. The use of biotechnology in breeding program for various commodities in Indonesia has been carried out since 1995 until now. High-yielding varieties have been produced through marker-assisted selection (rice, chilli pepper, sugar palm, and soybean) and *in vitro*-mutation breeding (sorghum and rice). Meanwhile, the use of genetic engineering techniques has resulted in transgenic sugarcane and potato varieties that have obtained food, feed, and environmental safety assessment. Currently, the transgenic potato variety is in the process of releasing varieties [12, 35, 36].

TABLE 2. The plant biotechnology techniques and application in Indonesia.

Type of techniques	Commodities	Purpose
Genome re-sequencing	Palm oil	Productivity
	Soybean	Productivity, tolerance to Al stress and resistance to soybean pod sucker
	Corn	Tolerance to drought stress
	Jatropha	Oil content
	Banana	Resistance to Fusarium wilt
	Potato	Resistance to potato virus Y and potato leaf roll virus
	Chili	Resistance to anthracnose disease
	Cocoa	Fruit quality and resistance to dieback
	Palm	*Kopyor* coconut
De novo sequencing	Arenga	Productivity and early maturation
Genome wide association mapping	Rice	Tolerance to biotic and abiotic stresses Yield components and flowering
Marker-assisted breeding	Rice	Productivity and resistance to BPH, BLB, blast and Zn biofortification
	Soybean	Productivity and maturation
	Chili	Resistance to anthracnose disease
	Shallot	Resistance to Fusarium
Molecular diagnostic	Nutmeg	Sex determination
	Arenga	Early maturation
DNA fingerprinting	Rice	Genetic identity
	Durian	Genetic identity
	Sweet potato	Genetic identity
	Mango	Genetic identity
RNA total sequencing	Nutmeg	Sex determination
Genome editing using CRISPR	Rice	Resistance to fall
	Chili	Resistance to pepper yellow leaf curl virus
	Citrus	Resistance to huanglongbing disease
Genetic engineering	Rice	Kalium and nitrogen use efficiency
	Sugarcane	Resistance to stem borer, drought tolerance, and productivity
	Sweet potato	Resistance to sweet potato weevil
	Tomato	Resistance to tomato yellow leaf curl virus dan cucumber mosaic virus
	Potato	Resistance to Phytophthora late blight
	Papaya	Resistance to papaya ring spot virus
Protoplast fusion	Citrus	Fruit quality
Endosperm culture	Citrus	Seedless
Anther culture	Rice	Productivity and drought tolerance

SUPPORTING NATIONAL LEGISLATION OF PGR FOR NATIONAL AND GLOBAL LEVELS

Thousands of species of the PGR including cultivated plants and wild relatives have been utilized for food and medication in Indonesia. The development of PGR via exploration, characterization, evaluation, documentation, and utilization needs cooperation at national and global levels [37]. In favor to harness PGR, several governmental policy frameworks and laws support the national PGR program of conservation and utilization (Table 3). Notable, Indonesia ratified the International Treaty of Plant Genetic Resources for Food and Agriculture (ITPGRFA), and the Nagoya Protocol in 2006 and 2013, respectively. The access and exchange of Plant Genetic Resources for Food and

Agriculture (PGRFA) included in Annex 1 of ITPGRFA follow the multilateral system, while the remaining plant species access is in accordance to the bilateral agreement of Nagoya Protocol of Convention of Biological Diversity (CBD) along with relevant national legislation. Indonesia agrees with the ITPGRFA principle to sustain the use of PGRFA, and their equal and fair benefit-sharing arising from the utilization to harmonize with CBD. The diverse PGR is a valuable asset for not only breeders but also scientists for enhancing the quality and food production in Indonesia.

TABLE 3. Regulations related to management and utilization of PGR in Indonesia.

Regulation	Year
Government Regulation No. 7/1999 on Preservation on Plant and Wild Animal Species	1999
Government Regulation No. 8/1999 on the Utilization of Wild Plant and Animal Species	1999
Law No. 29/2000 on Plant Variety Protection	2000
Government Regulation No. 14/2002 on Plant Quarantine	2002
Law No. 18/2004 on Estate Crops	2004
Government Regulation No. 13/2004 on the Denomination, Registration, and Use of Initial Variety for Development Essential Derived Variety	2004
Government Regulation No. 14/2004 on Term and Procedures of Protection of Plant Variety Protection and the Use of Protected Varieties	2004
Government Regulation No. 21/2005 on Biosafety of Genetically Engineered Products	2005
Law No. 4/2006 on Ratification of the International Treaty of Plant Genetic Resources for Food and Agriculture	2006
Agriculture Ministerial Decree No. 67/2006 on Conservation and Utilization of Plant Genetic Resources	2006
Ministry of Agriculture Regulation No. 37/2006 on Seed Systems	2006
Presidential Decree No. 22/2009 on National Nature Conservation Day	2009
Ministry of Agricultural Regulation No 15/2009 on Manual of Genetic Material Transfer Agreement	2009
Ministry of Agriculture Regulation No. 37/2011 on Preservation and Utilization of Plant Genetic Resources	2011
Ministry of Agriculture Regulation No. 5/2012 on Importation and Expenditure of Horticulture Seeds	2012
Law No. 11/2013 on Ratification of the Nagoya Protocol	2013
Ministry of Agriculture Regulation No. 127/2014 on Seed Distribution	2014
Law No. 13/2016 on Patent	2016
Law No. 11/2019 on National System of Research and Technology	2019
Law No. 21/2019 on Quarantine of Animal, Fish and Plant	2019
Law No. 22/2019 on Sustainable Agricultural Cultivation	2019
Ministry of Agriculture Regulation No. 38/2019 on Plant Variety Release	2019
Ministry of Agricultural Regulation No. 50/2020 on Manual on Inspecting and Controlling on Plant Variety of Genetic Modified	2020

Harnessing PGR is conducted through research and development on the genetic and/or their biochemical composition using biotechnology, as spelled out in the Nagoya Protocol [38]. Therefore, the approach for PGR utilization include in the use of both conventional and biotechnology, from breeding, *in vitro*, to genomics and other omics [12]. According to national laws, Indonesia allows the transfer of technology and biotechnology among countries, but the benefit-sharing should consider the biological safety procedure to prevent the negative impact of research and releasing biotechnological organisms [39]. Indonesian Government consistently regulates environmental protection to PGR management for food security and people welfare [40]. Even though Indonesia is a member of ITPGRFA and active in the CBD, to transfer out materials genetic overseas is controlled by the government with Law No. 11 [41] and Ministry of Agriculture Regulation (MAR) No. 15/2009 for genetic resources (GR) [42], and, MAR No. 127/2014 for seed [43]. All laws related to PGR generally address the principles of sustainability, fair, and the greater welfare of Indonesian people [44].

Previous concepts of the management and use of PGR were not adopted anymore by Indonesia, namely Common Heritage of Mankind which prioritized public need [45], or intangible property/intellectual property [46] focusing on the reward of creativity to push innovation and invention [47]. The principle of PGR management and utilization, therefore is changed due to the sovereign right, along with the increasing demands on aspects of sustainable environment and PGR. Under Law No. 29/2000, Indonesia also adopts the sui generis system through Plant Variety Protection or Plant Breeder Right as legal protection of intellectual property right in plant breeding. Indonesia rich with genetic resources is benefited with this concept, of which national sovereignty reflects idealism that the country of origin has legal ownership of the PGR found in Indonesia territory, and therefore can control their collection and use. Furthermore, the use of PGR should considers the economic, social and environment linked to the conservation and sustainability of PGR. Particularly, social aspect in the PGR utilization is related with food security which can be achieved if self-sufficient food production can be fulfilled. This food security is a key issue as its relation to social defense, social stability, national defense as well as economic stability [44, 48].

In the context of providing food, increasing food production is important to support food diversification in the national level. In line with the Global Plant Action (GPA)-Food Agriculture Organization (FAO), an effective national PGR program in Indonesia provides the enabling policies, support strategies, and concrete action plans important for setting well-defined goals and priorities, allocating resources, and responsibilities and identifying and strengthening linkages among all relevant stakeholders in the country [49]. High priority is given to establish national committees or similar coordinating bodies to ensure the involvement of all stakeholders. The ultimate purpose of PGR conservation and utilization is to contribute to national development and sustainable agriculture by developing and strengthening national programs including food self-sufficiency.

FUTURE PERSPECTIVE

The high diversity of PGR in Indonesia needs to be maintained in *ex situ* conservation as a key element to achieve the future goal of food estate in 2045. The gene bank of PGR collection could be enriched for their accession number and greater diverse species on the strategic commodities included in the national program of PGR. In addition to the PGR, the remarkable technologies of 4.0 industrial revolution are thought to be attributable on gene bank management and operating system including the IAARD-ICABIOGRAD Gene Bank. The IAARD-ICABIOGRAD Gene Bank needs to increase in several aspects such as the number of collection, plant species included wild relatives, preservation methods, networking with domestic and international, services, and legal base. Development of new varieties using both conventional breeding and new breeding technique will be efficiently performed to increased productivity and other important agricultural traits.

Plant agricultural biotechnologies should be more prioritized their role to harness PGR in Indonesia as a result of the implementation of advanced molecular marker-assisted crop breeding and genetic engineering. At the genotypic level, genomics, and other omics-based markers would be more used to result in impressive advances and became routine in crop improvement. While in the phenotypic level, agricultural techniques especially precision agriculture will be continuously improved and developed to enhanced quantity and quality in agricultural yield. Next-generation sequencing (NGS) and high-throughput selection systems are also developed to enable rapid screening for desired traits. Since the yield gap between researcher recommendation and farmers practices is still challenged, thus future directions should cover biotechnological approaches on bridging the genotype-phenotype gap by improving quantitative and automated selection and screening methods, bridging the genome-environment gap, more attention on epigenetic molecular events evolutionarily most relevant to plant adaptation to changing environments, and promoting transparent dialog between molecular biologists and plant physiologists on the one hand and farmers, breeding companies, and the public on the other hand to solve the challenges and incorporate the economic, sociological, legal, and ethical hurdles [30]. Thus, in the framework of PGR protection and utilization in the laws and regulations in Indonesia, intellectual property rights of material from research and development should be included as content material [44].

Many biotechnological tools promote national and global PGR sustainability, and could not stand alone to shape the future on food production. At present the whole social, legal, and economic arenas, food system along with other aspects is open widely to revolutionary developments. The disruptive technologies, in particular biotechnology, have a great transformative potential to attain the paradigm shift scientific society calls [34]. As stated by Mazzucato [50], to acknowledge government to finances fundamental research and development is often a tremendous force for technological innovation. Importantly, the output generated from food crops is necessary to be a reference for breeders in developing new varieties of rice as an example, by market preferences which can provide economic impact on communities based on the economic valuation [51]. Furthermore, the adoption of an integrated approach with the right counterparts and supporting government together with relevant stakeholders is highly considerable to achieve substantial progress in plant biotechnology and self-sufficient food production in the future. Therefore, scientific knowledge must be deployed to construct a better future, with fair and equal benefit sharing, well-governed societies, and respect for the environment in Indonesia. Overall, the combination of comprehensive novel molecular biology tools, technologies for screening, and economic evaluation should be the main goal of the biotechnological revolution to harness PGR in the agricultural sector [30] in many countries including Indonesia.

CONCLUSION

The potency of highly diverse PGR in Indonesia needs to be harnessed for plant improvement and development and sustainable agriculture. Food security in Indonesia is challenged and modern biotechnological research will be essential to solve the obstacle. Advance technologies *in vitro* and molecular biology such as genomics and other omics, genetic engineering, genome editing, and other modern biotechnological approaches are important to bridge the gap of genotype-phenotype, genotype-environment for food production. Scientists in the IAARD which is mandated for PGR management, have developed many products, releasing new plant varieties and technologies with the vision of the intellectual property-based innovation ecosystem for PGR. Legal technology ecosystem is important for PGR and the genetic information, allowing to the protection of PGR-based innovation.

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