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Setting conservation priorities for the wild relatives of food crops in Indonesia

Wiguna Rahman · Joana Magos Brehm · Nigel Maxted

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Abstract Crop wild relatives (CWR) have been increasingly used as a genetic resource in crop improvement programs, thus, their conservation is essential for future sustainable agriculture and food security. Generally, CWR are threatened but their conservation has just recently come to global attention. Ex situ conservation (to ensure the availability of material to plant breeders and reintroduction programs) and in situ conservation (to permit their natural evolution) need better planning to ensure success. However, Indonesia as one of the important areas for CWR diversity does not yet have specific plans to conserve these resources. The basis for CWR conservation planning is having a prioritized inventory of CWR upon which to focus CWR conservation actions in Indonesia. Therefore, the initial CWR conservation planning steps reported in this paper are CWR checklist development and subsequent prioritization to permit better allocation of resources and time for

conservation action. A total of 1968 taxa were recorded as wild relatives of food crops in Indonesia. About 571 (29%) of those taxa are national endemics and 864 (44%) are narrow regional endemics. After prioritization based on the socio-economic value of the related crops and potential utilization for plant breeding, 234 taxa were established as a priority for conservation. Ninety-five of these priority taxa are important at the national and global levels (such as wild relatives of rice, banana, mango, breadfruit, sugarcane, taro, coconut, sweet potato, melon, sorghum, citrus, and aubergine), 69 are important at the national and regional levels (such as wild relatives of tropical fruits and sugar crops), and 70 taxa are important at global level only (such as wild relatives of yam, figs, and raspberry). Those priority taxa are now the target for further CWR conservation action both of ex situ and in situ gap analyses and the establishment of a systematic conservation planning strategy for effective conservation action in Indonesia.

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Keywords Conservation planning · Crop improvement · Crop wild relatives · Prioritization · Socio-economic value

Introduction

Crops, as the result of man-assisted evolution, have been managed since the Neolithic periods (Gepts 2004). Cultivated varieties evolved from their ancestors, a process known as domestication syndromes (Meyer et al. 2012). Trait evolution continues with the creation of modern varieties that now has entered the post-domestication or super domestication era. Advanced technologies can now resolve selection barriers that naturally occur (Arnold 2004; Gepts 2004; Vaughan et al. 2007; Meyer and Purugganan 2013; Milla et al. 2015). Concomitant with Darwin's theory of evolution (survival of the fittest), some crop varieties cannot adapt to new environments, such as new abiotic condition (temperature, soil properties, precipitation) or biotic interactions (new strains of disease or pests), or cannot comply with human preferences (yield quantity or quality) (Arnold 2004; Abbo et al. 2014; Milla et al. 2015; Turcotte et al. 2015). With the uncertainty of future climate conditions and increasing food demand from growing populations, the development of new and more resilient crop varieties is becoming a necessity as one of the critical issues of agriculture to feed the 9 billion people in the world estimated for 2050 (Godfray et al. 2012). Broader genetic diversity of resources are thus required due to the genetic bottleneck of modern cultivars of the major crops (Hyten et al. 2006; McCouch et al. 2007). Thus the genetic resources of crop wild relatives have very promising potential (Maxted et al. 2006; Ford-Lloyd et al. 2011).

Wild relatives of crops have been increasingly used as genetic resources for crop improvement (Hajjar and Hodgkin 2007; Maxted and Kell 2009; Dempewolf et al. 2017) as new techniques and methods of speeding plant breeding have been developed (Fedoroff et al. 2010; Schaart et al. 2016; Dempewolf et al. 2017; Zhang et al. 2017; Watson et al. 2018). Based on a literature survey, Dempewolf et al. (2017) showed that until recently most of the wild relatives have been used to provide traits to cope with susceptibility of crops to biotic stress (pests and diseases resistance). In the future, the use of CWR will increasingly be used for others purposes as information characterization, at a genomic level, becomes widely available (Smith 2016). However, one of the constraints to their use in breeding programs is the lack of availability of breeding material as collections from diverse locations

are generally limited in ex situ collections in gene banks (Castañeda-Álvarez et al. 2016) and in situ are largely non existent (Maxted et al. 2016). Therefore, more effort for both ex situ and in situ conservation should be a global priority.

Magos Brehm et al. (2017) suggested several steps for development conservation strategies of CWR at a national level. This scheme has been adopted by many countries to develop their national CWR conservation strategy. The Crop Wild Relatives Global Portal (<http://www.cropwildrelatives.org/cwr-strategies/>) and Magos Brehm et al. (2017) list the nations or regions that have already created or initiated systematic conservation of CWR. The initial steps in systematic conservation planning of CWR includes the creation of a checklist, prioritization and inventory of the priority CWR (Magos Brehm et al. 2017). The publication of national CWR inventories is a growing response to the need of international collaboration on CWR conservation as Ford-Lloyd et al. (2011) suggested. Kell et al. (2016) highlighted the relationship between national and regional CWR checklists and inventory of priority CWR in Europe. They explained the importance of national conservation strategies to initiate or complement regional cooperation in CWR conservation. Maxted et al. (2016) showed the interconnection between national, regional, and global approaches on conservation planning and action of CWR.

National strategies for CWR conservation in the Southeast Asia region have not been developed yet. Nevertheless, Castañeda-Álvarez et al. (2016) identified the Southeast Asia region as a global priority area for further collecting of CWR for ex situ conservation. The conservation strategy should be linked the importance of CWR at national, regional, and global level. At national and regional level, CWR can be used to increase genetic diversity of crops due to genetic erosion. While, at the global level, tropical wild relatives from this region are needed for future cultivar development as the future climate is predicted to change in the tropical belt (Sperling et al. 2004; Seidel et al. 2008). There are evidences of crops genetic erosion in this region through genetic uniformity of most cultivated cultivars that reduced the used of local cultivars, for example rice (Thrupp 2000; Pfeiffer et al. 2006) and taro (Prana et al. 2010) or by converted traditional agricultural systems to modern monoculture systems that reduced the crops diversity on farm

(Michon and Mary 1994; Rerkasem et al. 2009). Thrupp (2000) stated the effect of genetic uniformity of rice had caused outbreaks the epidemic of tungro virus in Indonesia and Philippines in the year 1970 and caused three millions tons of rice yield loss in Indonesia in 1974. There is also evidence on the tropical belt that has widening since 1979 by at least 2 degrees latitude (Seidel et al. 2008). However, there are also evidences that genetic diversity loss also happened for CWR in Southeast Asia as many of their natural habitats were destroyed and degraded (Kartawinata et al. 2001; Sodhi et al. 2004; Engle and Faustino 2007; Wilcove et al. 2013).

All countries in the Southeast Asia were included as the global biodiversity hotspots, i.e. Indo-Burma, Sundaland, and Wallacea (Myers et al. 2000; Mittermeier et al. 2011) as seen in Table 1. It means that Southeast Asian countries are containing high endemism of their biodiversity but at the same time they have high degree of extinction risk. Among the Southeast Asian countries, Indonesia was estimated to contain the highest number of vascular plants with

more than 40,000 plants (Butler 2016; Willis 2017), the highest number of global priority CWR (Vincent 2016), and the second top of threatened plants after Malaysia (IUCN 2019).

CWR conservation links biodiversity conservation and the future of food security. It is therefore of most importance for Indonesia to initiate systematic conservation planning for its CWR. This paper aims to report the results of the initial steps on conservation planning of wild relatives of food crops in Indonesia, including the creation of a CWR checklist, its prioritization, and inventory of priority CWR.

Methods

The CWR checklist development

The generation of the CWR checklist follows (Magos Brehm et al. 2017) using a monographic approach as there is no complete checklist for Indonesian plant species (compiling a list of all crops and then the

Table 1 Biodiversity hotspots area, estimated number of vascular plants, number of threatened plants, and number of global priority CWR taxa by country in Southeast Asia

No.	Country	Biodiversity hotspot area ¹	Estimated number of vascular plants ²	Number of threatened plants ³	Number of global priority CWR taxa ⁴
1	Brunei Darussalam	Sundaland	8402	127	4
2	Cambodia	Indo-Burma	8260*	37	16
3	Indonesia	Sundaland and Wallacea	41,628	458	84
4	Laos	Indo-Burma	11,839	56	27
5	Malaysia	Sundaland	21,769	727	52
6	Myanmar	Indo-Burma	9930	61	50
7	Philippines	Philippines	12,603	254	36
8	Singapore	Sundaland	2100**	62	7
9	Thailand	Indo-Burma	16,422	159	54
10	Timor Leste	Wallacea	NA	2	2
11	Vietnam	Indo-Burma	14,894	231	49

¹Based on Myers et al. (2000) and Mittermeier et al. (2011)

²Based on Willis (2017) and Butler (2016)

³Based on IUCN (2019)

⁴Based on Vincent (2016)

*Based on Fauna and Flora International, 2019 (available at <https://www.fauna-flora.org/countries/Cambodia>)

**Based on National Parks, Singapore Government, 2018 (available at <https://www.nparks.gov.sg/biodiversity>)

related CWR taxa which exist in a specific geographical area). All major cultivated food crops in Indonesia were first extracted from the six volumes of Plant Resources of South East Asia (PROSEA). Food crops include cereals (Grubben and Soetjtohardjono 1996), pulses (van Der Maesen and Somaatmadja 1992), edible fruits and nuts (Verheij and Coronel 1992), vegetables (Siemonsma and Piluek 1994), plants-yielding non-seed carbohydrates which are starchy and sugar crops that are mostly vegetatively propagated crops (Flach and Rumawas 1996), and vegetables oils and fats (Van der Vossen and Umali 2002). Spices and stimulants/beverages were not included in this study. Crops with global priority CWR identified by Vincent et al. (2013) were also included. These included crops listed in the Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO 2009) and other globally important crops listed in FAO statistics (FAO 2017). Based on those crops listed and the potential occurrences of their relatives in Indonesia, six groups of crops can be defined. They are: (1) nationally and globally important crops (NGI); (2) nationally minor important and underutilized crops which have native wild relatives in Indonesia (MUC); (3) globally important crops but with no significant cultivation at national level and with native wild relatives in Indonesia which were named as less popular crops (LP); (4) the group of crops which are important at national and global levels but have no native CWR [exotic important (EI)]; (5) the group of crops which are nationally important but neither important at global level nor having native relatives [national important (NI)], and (6) the group of crops which are considered global priority crops but are not significantly cultivated at national level and have no native relatives [global important (GI)]. Only the first three crop groups, i.e. NGI, MUC, and LP were considered to generate the CWR checklist as the crops are important at national, regional, and global level and they have wild relatives in Indonesia. The list of genera with numbers of taxa for each crop group is included in Supplementary data, Table S1.

Multiple volumes of Flora Malesiana series I (van Steenis 1948) and other taxonomic revisions or monographs (for the families not yet covered by Flora Malesiana) were used to extract the wild relatives of the previously generated crop list. The list of taxonomic references can be found in Supplementary data,

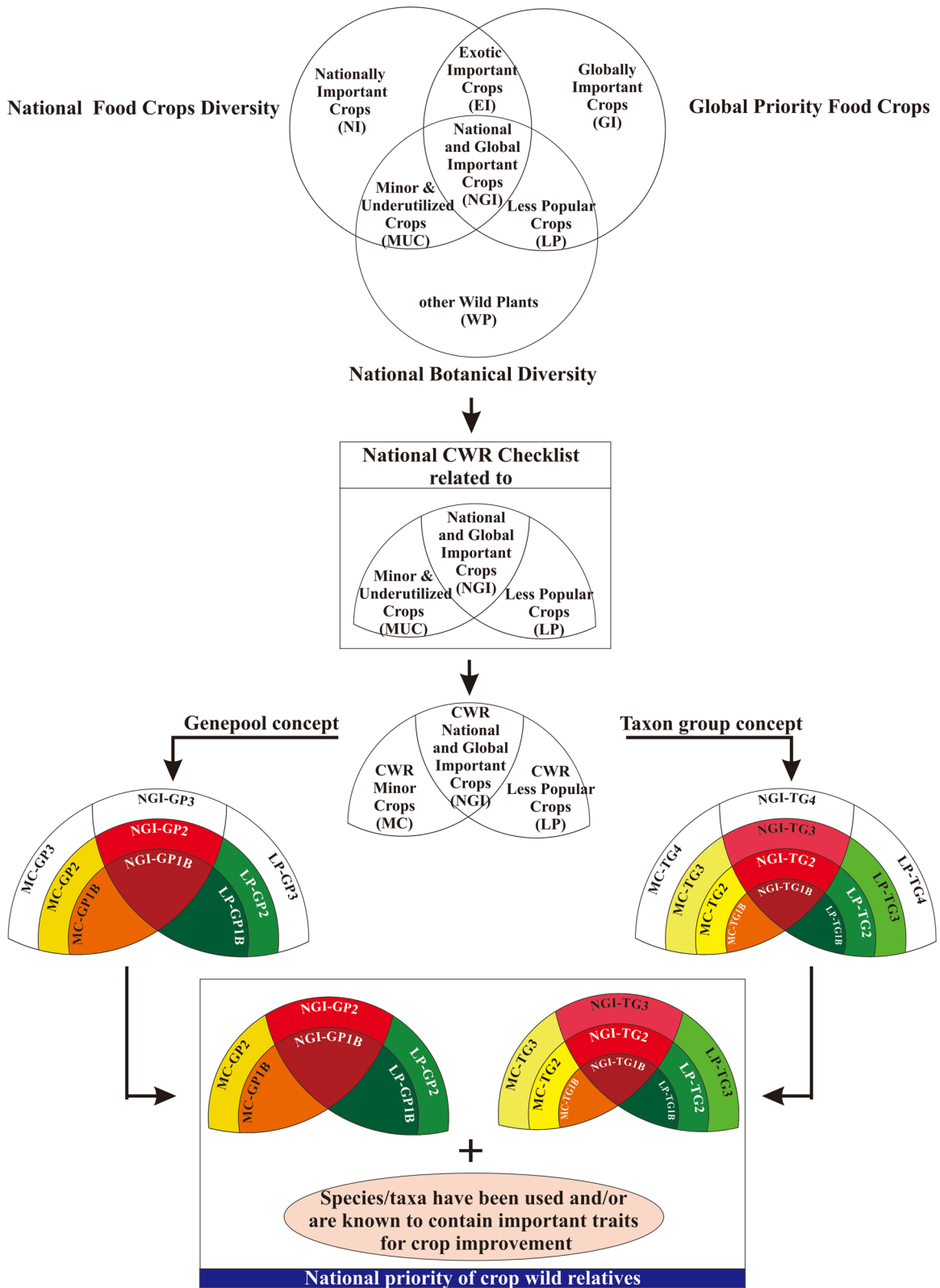
Fig. 1 Creation of the CWR checklist of food crops of Indonesia and methodology for prioritizing CWR for conservation

Table S2. Only native and archaeophytes, taxa being present in Indonesia for over 500 years, were considered.

All taxa that belong to the same genus of a crop were used to extract CWR. This method was used by other authors (Maxted et al. 2006, 2007; Kell et al. 2015). The taxonomic rank and names were cross-checked with the global plant names database, such as plant list (The Plant List 2013) and USDA germplasm resources information network (GRIN) taxonomy for plants (available at <https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearchcwr.aspx>). Based on this harmonization, some unaccepted infraspecific taxa were then excluded from the checklist, while the synonyms were amalgamated. The list of CWR was compiled using the CWR checklist and inventory descriptors (Bioversity International and University of Birmingham 2017) in the freely downloadable Excel template (Thormann et al. 2017). Ancillary information were compiled to generate additional information to CWR checklist, this comprised: family; genus; species; author; infraspecific sub rank; sub taxon name; related crop; common name of related crops; concept type of relatedness (gene pool or taxon group); concept level of relatedness (GP1B, GP2, GP3, TG1B, TG2, TG3, or TG4); global distribution; global distribution status (endemicity); distributional reference; and gross production value of related FAO crop/crop group (FAO 2017).

CWR prioritization for conservation

Several criteria and methods of CWR prioritization have already been published (Maxted et al. 1997; Magos Brehm et al. 2010; Kell et al. 2015, 2017; Rubio Teso et al. 2018). Kell et al. (2017) reviews the mostly used CWR prioritization criteria and methods and suggests the use of three main criteria: the socioeconomic value of the related crop, the wild relative potential utilization for crop improvement, and the threat status. In this study only two of the three criteria listed above were used, as threat status of many Indonesian CWR taxa is not yet known. Figure 1, illustrates the prioritization steps used in Indonesia.



The first selection criteria, based on socioeconomic value of the related crop, grouped the crops into six different groups of crops. The process of grouped crops was mentioned before in the generation of CWR checklist. Only the MCU crops were further divided, based on the latest national agricultural census (Statistics Indonesia 2013), into minor crops (MC) which is MUC crops that listed in the agricultural census and underutilized crops (UC) which is MUC crops that did not include in the census result (Supplementary data Table S3). The criterion that chose in the agricultural census is the number of farmer household that cultivated crops. It means that MC crops have more significant number of farmer that cultivated them than the UC. Then, only CWR taxa related to NGI, MC and LP crops were selected for further prioritization since the crops are nationally, regionally, and globally important and their wild relatives were found in Indonesia. See the discussion for further explanation for the prioritization and exclusion of taxa related to underutilized crops.

The next step considered the prioritization of the wild relatives of the NGI, MC, and LP crops based on the potential utilization of the wild relative for crop improvement. This criterion used the gene pool concept (Harlan and de Wet 1971) or the taxon group concept (Maxted et al. 2006) when the information of gene pool was not available. Taxa which belong to the primary or secondary gene pools (GP1b and GP2) or taxon groups 1–3 (TG1b, TG2, and TG3) were selected as well as those wild relatives that either have been used in crop breeding programs or that are known to contain traits of interest for crop improvement (Kell et al. 2017). This was the case for the wild relatives of rice and sorghum. All priority CWR were then separated based on previous grouping categories to three different levels of priority, namely first priority which are those wild species related to the NGI crops, the second priority are those related to the MC crops, and the third priority are those related to the LP crops.

Result

CWR checklist and their endemism

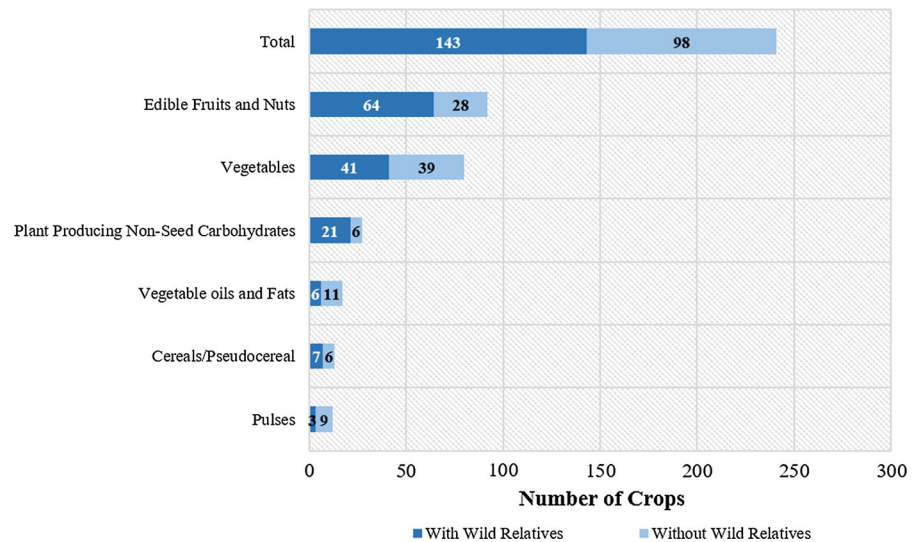
About 241 major food crops are cultivated in Indonesia based on PROSEA (Fig. 2). Almost 60% of these

have native wild relatives in Indonesia. The edible fruits and nuts group contains the largest number of crops in Indonesia (38%), followed by vegetables (33%) and the plants yielding non-seed carbohydrates (starchy and sugar crops) (11%). In contrast, the pulses contain the smallest number of crops with native wild relatives in Indonesia (25%). Proportionally, the plant-yielding non-seed carbohydrates has the highest number of CWR present in Indonesia (78%) and most vegetables are introduced species without wild relatives in Indonesia.

The checklist of wild relatives of food crops contains 1968 native taxa. It consists of 53 families, 106 genera, 1890 species, and 78 infraspecific categories (subspecies/variety) (Table 2). It accounts for about 4.73% of the total number of higher plants estimated for Indonesia. Those taxa relate to 33 FAO crops/crop groups. Unspecified FAO crop groups such as vegetables contain 221 taxa distributed among 26 genera and the tropical fruits 571 taxa within 28 genera. While specific crop groups, such as figs (279 taxa) and blueberries (170 taxa) are the top two genera with the highest numbers of wild relatives. Of the cereal group, millet contains 33 taxa within 4 genera, while rice and sorghum have 7 and 4 related taxa, respectively. Edible fruits and nuts have the largest CWR with 1308 taxa that are related to 43 crops within 13 FAO crop groups. Pulses only have three genera and 15 taxa. Plants-yielding non-seed carbohydrates cover seven FAO crop categories that contain 20 genera and 235 taxa. Vegetables contain 243 taxa within 30 genera that are separated within five different FAO crop groups. While, vegetable oils and fats contains 126 taxa that are related to five crops.

Based on the global distribution status, about 571 taxa (29%) of the CWR checklist are endemic to Indonesia (Fig. 3a). They are distributed in the seven major groups of Indonesian islands [Sumatra, Java, Kalimantan (Indonesian Borneo), Sulawesi, Lesser Sunda islands, Moluccas, and Papua (Indonesian Papua)], of which 484 are strictly endemic to those islands groups. Indonesian Papua and Sumatra are the islands with the highest number of national endemics with 147 and 111 endemic taxa, respectively. These endemic taxa mostly belong to wild relatives of blueberries and tropical fruits (Fig. 3b). Almost 44% (864 taxa) are narrow regional endemics, i.e. taxa that have a restricted distribution in three or less countries. Most of the narrow regional endemic taxa are located

Fig. 2 Overview of national food crops with and without wild relatives in Indonesia



solely on the islands of Borneo (politically divided between Indonesia, Malaysia, and Brunei Darussalam) with 212 CWR taxa and Papua (politically divided between Indonesia and Papua New Guinea) with 193 CWR taxa. These taxa are mostly wild relatives of tropical fruits, figs, and persimmons. Most of the native oilseed relatives (*Shorea* spp.) were found in the island of Borneo since this is the centre of their species diversity.

Based on the socio-economic value of the related crops, CWR taxa on the checklist can be grouped into the following: national and globally important crops (NGI); minor crops (MC); less popular crops (LP) and underutilized crops (UC). The UC group contains 633 taxa within 52 genera (Fig. 4). While the LP group contains 632 taxa within 20 genera, the MC group covers 533 taxa within 19 genera and the NGI group has 170 taxa among 15 genera.

Priority CWR

The Fifty-five crop genera containing 1335 taxa of native wild relatives of NGI, MC, and LP crops were further prioritized based on the closeness of their genetic/taxonomic relationship degree to the related crop as an indication of their potential use in crop improvement. As a result, 50 taxa were categorized using the gene pool concept, while 1285 taxa were categorized using the taxon group concept. Fifty-one taxa are primary taxa (GP1B or TG1B), 176 taxa are

secondary taxa (GP2, TG2, or TG3), and 1108 taxa are tertiary taxa (GP3 or TG4) (Fig. 5).

A total of 234 priority taxa belonging to 26 families and 36 genera were then identified (Table 3). These priority taxa consist of 227 of the primary and secondary taxa with 7 additional taxa that belong to wild relatives of rice (4 taxa) and sorghum (3 taxa) that known to contain important traits for crop improvement. The priority CWR taxa were then grouped into three levels of priority. The first priority which is related to the NGI category (13 genera, 95 taxa), the second priority is related to the MC category (18 genera, 69 taxa), and the third priority is related to the LP category (4 genera, 70 taxa). The number of priority wild relatives of mango and breadfruit are the highest among CWR related to NGI crops. Durian and Jengkol have the highest number of priority taxa within MC crops. While, figs and yam have most priority wild relatives among the LP crops. Full list of priority taxa as seen in Supplementary data, Table S4.

Discussion

Setting CWR conservation priorities is an essential step in their conservation planning at the national, regional, and global levels. The present results showed that the checklist of wild relatives to food crops in Indonesia covers about 4.73% of the total vascular plants (Butler 2016; Willis 2017) estimated to occur in Indonesia. This study focused only on the wild

Table 2 List of crop genera that contain native wild relatives in Indonesia

Crop category (Ref: PROSEA)	Crop (FAO designation)	Genera (number of CWR)	Total taxa
Cereals (Grubben and Soetjptohardjono 1996)	Millet	<i>Cenchrus</i> (3), <i>Echinochloa</i> (4), <i>Panicum</i> (17), <i>Setaria</i> (9)	33
	Rice	<i>Oryza</i> (7)	7
	Sorghum	<i>Sorghum</i> (4)	4
Edible fruits and nuts (Verheij and Coronel 1992)	Avocados	<i>Persea</i> (3)	3
	Blueberries	<i>Vaccinium</i> (170)	170
	Dates	<i>Phoenix</i> (1)	1
	Figs	<i>Ficus</i> (279)	279
	Fruits (unspecified)	<i>Potentilla</i> (18)	18
	Grapes	<i>Vitis</i> (2)	2
	Melons	<i>Cucumis</i> (2)	2
	Nuts	<i>Canarium</i> (33), <i>Gnetum</i> (18), <i>Macadamia</i> (1), <i>Terminalia</i> (30)	82
	Oranges	<i>Citrus</i> (5)	5
	Persimmons	<i>Diospyros</i> (119)	119
	Raspberries	<i>Rubus</i> (28)	28
	Stone fruit	<i>Prunus</i> (28)	28
	Tropical fruits (unspecified)	<i>Anacolosia</i> (3), <i>Antidesma</i> (37), <i>Artocarpus</i> (31), <i>Averhoa</i> (4), <i>Baccaurea</i> (32), <i>Bouea</i> (2), <i>Chrysophyllum</i> (2), <i>Clausena</i> (5), <i>Cynometra</i> (5), <i>Dimocarpus</i> (3), <i>Durio</i> (21), <i>Flacourtia</i> (7), <i>Garcinia</i> (98), <i>Lansium</i> (3), <i>Litchi</i> (1), <i>Manilkara</i> (5), <i>Mangifera</i> (45), <i>Nephelium</i> (12), <i>Pandanus</i> (41), <i>Pometia</i> (2), <i>Pouteria</i> (20), <i>Rhodomyrtus</i> (5), <i>Salacca</i> (7), <i>Sandoricum</i> (4), <i>Spondias</i> (5), <i>Stelechocarpus</i> (2), <i>Syzygium</i> (159), <i>Ziziphus</i> (10)	571
	Plant yielding non-seed carbohydrates (Flach and Rumawas 1996)	Bananas and plantain	<i>Ensete</i> (1), <i>Musa</i> (25)
Roots and tubers		<i>Amorphophallus</i> (29), <i>Curcuma</i> (19), <i>Cyperus</i> (63), <i>Cyrtosperma</i> (6), <i>Eleocharis</i> (16), <i>Nelumbo</i> (1), <i>Plectranthus</i> (6), <i>Stachys</i> (1), <i>Tacca</i> (5)	146
Sugarcane		<i>Saccharum</i> (3)	3
Sugar crops		<i>Arenga</i> (12), <i>Borassus</i> (2), <i>Caryota</i> (6), <i>Metroxylon</i> (1), <i>Nypa</i> (1)	22
Sweet potatoes		<i>Ipomoea</i> (1)	1
Taro		<i>Colocasia</i> (2)	2
Yams		<i>Dioscorea</i> (33)	33
Pulses (van Der Maesen and Somaatmadja 1992)	Beans, dry	<i>Vigna</i> (7)	7
	Beans, green	<i>Cajanus</i> (6), <i>Lablab</i> (1)	7
Vegetables (Siemonsma and Piluek 1994)	Asparagus	<i>Asparagus</i> (1)	1
	Eggplants (aubergines)	<i>Solanum</i> (10)	10
	Okra	<i>Abelmoschus</i> (9)	9
	Spinach	<i>Amaranthus</i> (2)	2
	Vegetables (unspecified)	<i>Archidendron</i> (39), <i>Benincasa</i> (2), <i>Breynia</i> (6), <i>Canavalia</i> (6), <i>Cleome</i> (2), <i>Coccinia</i> (1), <i>Emilia</i> (1), <i>Enydra</i> (1), <i>Hibiscus</i> (23), <i>Hydrocotyle</i> (2), <i>Ipomoea</i> (22), <i>Momordica</i> (5), <i>Monochoria</i> (2), <i>Neptunia</i> (4), <i>Ocimum</i> (3), <i>Oenanthe</i> (1), <i>Parkia</i> (5), <i>Pilea</i> (28), <i>Polyscias</i> (17), <i>Portulaca</i> (1), <i>Psophocarpus</i> (1), <i>Rorippa</i> (3), <i>Rungia</i> (9), <i>Sonchus</i> (2), <i>Sonneratia</i> (4), <i>Trichosanthes</i> (31).	221
Vegetable oils and fats (Van der Vossen and Umali 2002)	Coconuts	<i>Cocos</i> (1)	1
	Oilseeds	<i>Aleurites</i> (1), <i>Shorea</i> (117), <i>Triadica</i> (1)	119
	Olives	<i>Olea</i> (6)	6

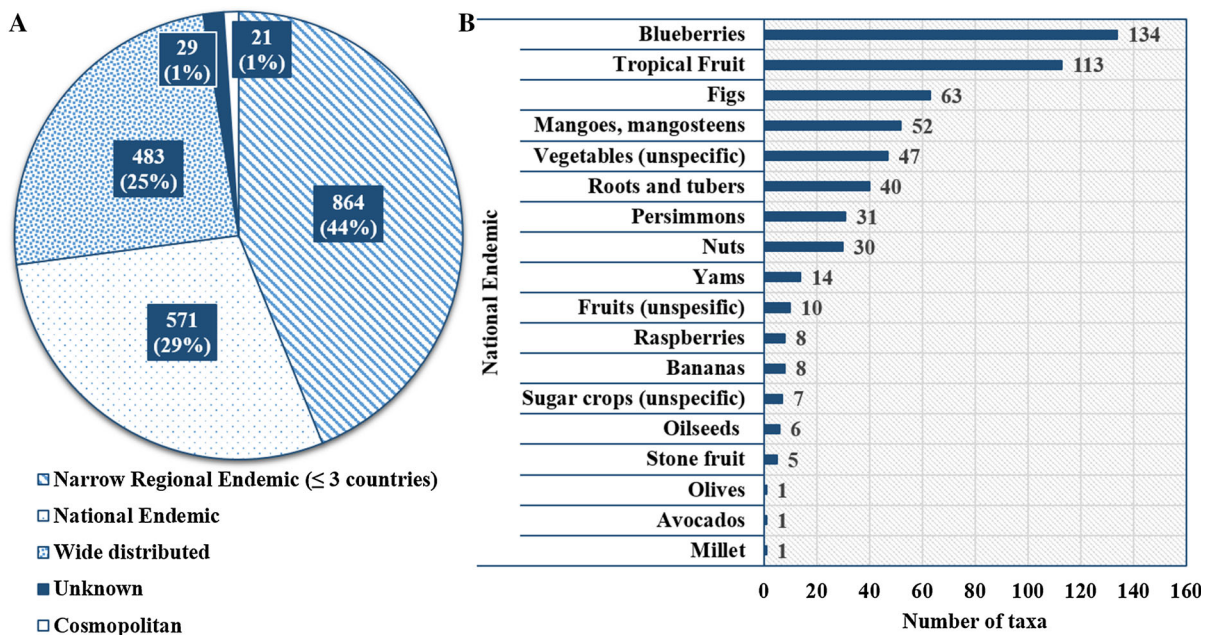


Fig. 3 a The endemicity of wild relatives of food crops in Indonesia. b The number of endemic CWR under similar FAO crops/crop groups

relatives of food crops but this does not mean that the socioeconomic importance of other crops was neglected. The conservation of the wild relatives of food crops has a direct link to support food security and other global agendas such as the sustainable development goals (SDG), Aichi targets, Global Strategy for Plant Conservation (GSPC), and the International Treaty on Plant Genetic Resources for

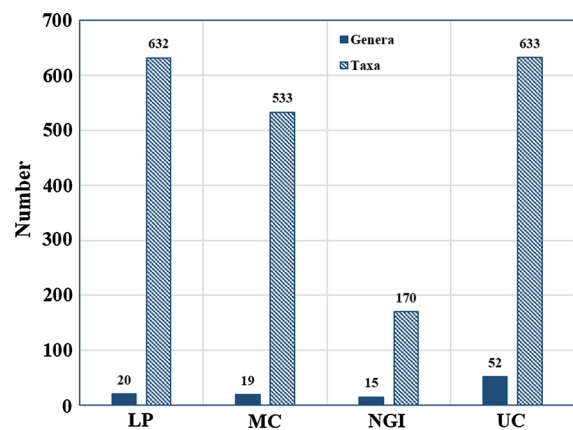


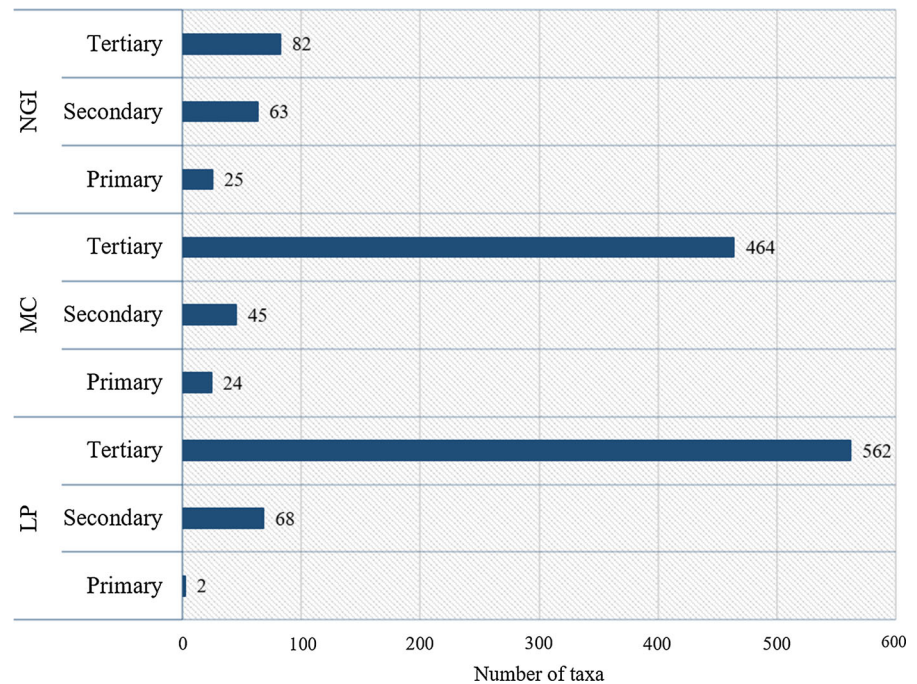
Fig. 4 Number of genera and taxa for each of the crop groups in the Indonesia CWR checklist. Less popular crops (LP), minor crops (MC), national and globally important crops (NGI), and underutilized crops (UC)

Food and Agriculture (ITPGRFA). The number of taxa in the present checklist was higher compared to the CWR checklist of food crops only in countries such as Norway (Phillips et al. 2016), Portugal (Magos Brehm et al. 2008), USA (Khoury et al. 2013), SADC region (Allen et al. 2019), and Zambia (Ng’uni et al. 2019) but lower compared to China (Kell et al. 2015).

This paper also aims to raise the awareness of Indonesian stakeholders to include CWR as valuable assets for conservation and breeding programs. As indicated by Maxted et al. (2007), nature conservation and agricultural stakeholders in Indonesia still pay less attention to CWR due to different focused of object targets and responsibilities. For example, recent legal documents of national protected animals and plants by Indonesian ministry of environment and forestry only listed rare or threatened plant species (Ministry of Environment and Forestry 2018). Only four taxa related to underutilized crops are included on the list and in this case only because they are threatened or rare and not because they are CWR. On the other hand, national gene banks managed by ministry of agriculture lack CWR accessions (Kurniawan et al. 2004).

This is another case where countries with a rich flora has difficulty in prioritizing which plant taxa

Fig. 5 Number of taxa that belongs to different levels of relatedness to related crops for the three priority crop groups: national and globally important crops (NGI); minor crops (MC); and less popular crops (LP). Primary taxa are GP1B and TG1B, secondary taxa (GP2, TG2, and TG3), tertiary taxa (GP3 and TG4)



should have immediate conservation action due to the lack of information and proper evaluation (Barazani et al. 2008). On the other hand, Indonesia is under the pressure to report on their achievements towards the GSPC targets. Targets 7 and 8 of the GSPC focus on threatened plants, while CWR conservation is referred in target 9 (Sharrock 2012). However, the threat status of many plant taxa, including CWR, has not been determined at global or national levels. Therefore, in conservation programs that focus only on already known threatened taxa, CWR does not get proper priority.

Another important issue on CWR conservation is endemism. In the prioritization process, Kell et al. (2016) and Labokas et al. (2018) showed a variation in national CWR priorities among the European countries. Some of them only prioritize their national endemics. In this study, we show that the endemics were not always the priority for conservation, more depended on the level of relatedness of the taxa to crops (Maxted and Kell 2009). For example, the highest numbers of national endemic CWR in Indonesia are related to blueberries, but none of those taxa are priorities for conservation as they belong to different subgenus to the crop (*Vaccinium myrtilus* L. and other North American blueberries). There are unique characteristics in some CWR; the closest related taxa are

the common and/or widely distributed taxa. For example weedy types of *Sorghum bicolor* (L.) Moench in Africa (Maxted and Kell 2009) or *Oryza rufipogon* Griffith in Indonesia (Soerjani et al. 1987). Soerjani et al. (1987) stated that *O. rufipogon* is easy to intercross with the rice in cultivation. Londo et al. (2006) also stated that *O. rufipogon* is the wild ancestor of cultivated rice. Its wide distribution means that this species can occupy various habitats. It can be implied that these widespread species have great genetic diversity and some of them probably contain rare and important traits. As they frequently occupy anthropogenic areas (roadside, farm, settlements, or irrigation channels), they are more vulnerable to land use changes or other anthropogenic disturbances. Therefore, they are also important to conserve.

In terms of endemism, the island of Sumatra and Indonesian Papua were the richest areas containing national endemic CWR. This finding was similar to Roos et al. (2004) who treated general higher plant species in five major islands (Borneo, Java, New Guinea, Sulawesi, and Sumatra). They found that New Guinea (the geographical entity) containing the highest endemic species, followed by the island of Borneo, then Sumatra, Sulawesi and Java. They conclude that the balance between speciation, migration and

Table 3 Summary of priority taxa of wild relatives of food crops in Indonesia

Genera	Crop	Crop common name	No. CWR taxa	
			Priority	Native total
First Priority (related to NGI crops)				
<i>Artocarpus</i>	<i>Artocarpus altilis</i> (Parkinson) Fosberg	Breadfruit	19	31
	<i>Artocarpus heterophyllus</i> Lamk	Jackfruit	1	
<i>Citrus</i>	<i>Citrus aurantiifolia</i> / <i>Citrus aurantium</i> / <i>Citrus limon</i> / <i>Citrus sinensis</i>	Lime/Lemon/Oranges	1	5
	<i>Citrus maxima</i> (Burm.) Merr.	Grapefruit	1	
<i>Cocos</i>	<i>Cocos nucifera</i> L.	Coconut	1	1
<i>Colocasia</i>	<i>Colocasia esculenta</i> (L.) Schott	Taro	2	2
<i>Cucumis</i>	<i>Cucumis melo</i> L.	Melon	1	2
<i>Ipomoea</i>	<i>Ipomoea batatas</i> (L.) Lamk	Sweet potato	2	23
	<i>Ipomoea aquatica</i> Forsskal	Water lettuce	9	
<i>Mangifera</i>	<i>Mangifera indica</i> L.	Mango	29	45
<i>Musa</i>	<i>Musa acuminata</i> Colla	Banana and plantain	9	25
	<i>Musa balbisiana</i> Colla		2	
<i>Oryza</i>	<i>Oryza sativa</i> L.	Rice	7	7
<i>Saccharum</i>	<i>Saccharum officinarum</i> L.	Sugarcane	3	3
<i>Solanum</i>	<i>Solanum melongena</i> L.	Aubergines	1	10
<i>Sorghum</i>	<i>Sorghum bicolor</i> L.	Sorghum	4	4
<i>Vigna</i>	<i>Vigna radiata</i> (L.) Wilczek	Mungbean	2	7
	<i>Vigna umbellata</i> (Thunb.) Ohwi & H. Ohashi	Rice bean	2	
Subtotal			95	165
Second Priority (related to MC crops)				
<i>Amaranthus</i>	<i>Amaranthus tricolor</i> L.	Amaranth	1	2
<i>Archidendron</i>	<i>Archidendron jiringa</i> (Jack) Nielsen	Jengkol	19	39
<i>Arenga</i>	<i>Arenga pinnata</i> (Wurmb) Merrill	BlackPalmSugar	1	12
<i>Averrhoa</i>	<i>Averrhoa carambola</i> L.	Star Fruit	1	4
	<i>Averrhoa bilimbi</i> L.	Bilimbi	1	
<i>Dimocarpus</i>	<i>Dimocarpus longan</i> Lour.	Longan	1	3
<i>Diospyros</i>	<i>Diospyros discolor</i> Willd.	Velvet apple	1	119
<i>Durio</i>	<i>Durio zibethinus</i> L.	Durian	16	21
<i>Garcinia</i>	<i>Garcinia mangostana</i> L.	Mangosteen	7	98
<i>Gnetum</i>	<i>Gnetum gnemon</i> L.	Gnetum	6	18
<i>Lansium</i>	<i>Lansium domesticum</i> Correa	Langsat	1	3
<i>Metroxylon</i>	<i>Metroxylon sagu</i> Rottboell	Sago	1	1
<i>Momordica</i>	<i>Momordica charantia</i> L.	Bitter gourd	1	5
<i>Nephelium</i>	<i>Nephelium lappaceum</i> L.	Rambutans	1	12
<i>Ocimum</i>	<i>Ocimum americanum</i> L.	American Basil	1	3
<i>Parkia</i>	<i>Parkia speciosa</i> Hassk.	Bitter bean	5	5
<i>Pometia</i>	<i>Pometia pinnata</i> Forst. and Forst.	Matoa	1	2
<i>Salacca</i>	<i>Salacca zalacca</i> (Gaertner) Voss	Snakefruit	1	7
<i>Syzygium</i>	<i>Syzygium aqueum</i> (Burm.f.) Alston	Water apple	1	159
	<i>Syzygium malaccense</i> (L.) Merr. and L.M.Perry	Malay apple	1	
	<i>Syzygium cumini</i> (L.) Skeels	Jambolan	1	

Table 3 continued

Genera	Crop	Crop common name	No. CWR taxa	
			Priority	Native total
Subtotal			69	513
Third Priority (related to LP crops)				
<i>Cajanus</i>	<i>Cajanus cajan</i> (L.) Millsp.	Pigeon pea	3	6
<i>Dioscorea</i>	<i>Dioscorea alata</i> L.	Yams	23	33
<i>Ficus</i>	<i>Ficus carica</i> L.	Figs	31	279
<i>Lablab</i>	<i>Lablab purpureus</i> (L.) Sweet	Lablab bean	1	1
<i>Rubus</i>	<i>Rubus idaeus</i> L.	Raspberry	12	28
Subtotal			70	347
Total			234	1025

extinction means the larger island are richer than the smaller ones.

In this study, the first priority taxa, i.e. those related to NGI crops, and third priority taxa, i.e. those related to LP crops, show that Indonesian priority CWR are linked to global priority CWR conservation. That is because those related crops have higher economic value, wider cultivation range, and intensive breeding programs. For some crops, the origin of domestication or the centre of diversity area were different to that of their production area (Khoury et al. 2016). Hyten et al. (2006) found that the bottleneck effect syndrome (a syndrome where a crop becomes more genetically uniform leading to lowering of resilience capacity to environmental changes) mostly happened during the process of domestication. However, this syndrome is increasingly found in modern cultivars since only limited accessions were used in their development. Moreover, Khoury et al. (2016) also found that the cultivation of exotic crops in many countries has increased. Therefore, those countries depend on CWR resources from elsewhere for global crop breeding programs.

The wild relatives of minor crops were placed in the second priority group due to their significant cultivation area, economic role and other socio-cultural factors, although those are only limited to particular regions. Moreover, they are probably cultivated on their original area of distribution (domestication area). It means that these CWR can be their progenitors/ancestors. Conservation of those progenitors will keep the wild relatives available for breeders in ex situ collections and sustain their in situ evolution in the wild. These taxa could be a starting point to initiate

regional CWR conservation programs, as global investors are less interested in investing in these crops for the research and development. For the Southeast Asia region, tropical fruits, such as *Averrhoa carambola* L. (star fruit), *Dimocarpus longan* Lour. (longan), *Durio zibethinus* L. (durian), *Garcinia mangostana* L. (mangosteen), *Nephelium lappaceum* L. (Rambutans), *Lansium domesticum* Corrêa (Langsat), and *Salacca zalacca* (Gaertner) Voss (Snakefruit) could be given priority as they have wild relatives and are mostly endemic to the region.

Underutilized crops (UC) are important to diversify our food sources as suggested by Massawe et al. (2016). FAO (1993) indicated that about 10,000–50,000 plant species are edible but only 150–200 of them are used globally as human foods. Those UC can potentially become important future food sources as for example what happened with quinoa (*Chenopodium quinoa* Willd.) that now has global recognition as an important food after promotion by FAO (Massawe et al. 2016). However, in this study, the wild relatives of these crops not considered as priority taxa. This does not mean that these taxa have no need for any conservation action. Like any wild plants, these taxa could be threatened, as well. The reason is these crops are still under the domestication process (or need a pipelining process to become a crop) which means that they might not yet need their relatives to increase their genetic variability.

To define the degree of importance of CWR on crop improvement of their related crops, the gene pool (GP) and taxon group (TG) concepts were used. Based on the inventory of CWR, 1338 taxa belonging to similar

genera to the priority crops (NGI, MC, and LP). To further reduce the number of taxa to be prioritized, taxa belonging to GP1B, GP2, TG1B, TG2, TG3, and those known to contain important traits or that have already been used in crop breeding programs were selected as the priority taxa for conservation. These results showed that only 17.71% of those taxa included in NGI, MC and LP crops are priorities. Heywood (2008) noted that the TG concept is still the best proxy for practice to define the relationship of crops and their wild relatives when information of their gene pools is lacking. However, he also noted that this concept is less likely to be applied for those taxa that are taxonomically less studied or when the classification does not have general agreement. Moreover, many plant genera have no subdivisions. In this study, plants that are still poorly understood taxonomically in Indonesia are CWR belonging to genera *Diospyros* (Ebenaceae) (119 taxa) and *Syzygium* (Myrtaceae) (159 taxa). While, genera that have no subdivision are *Arenga*, *Averhoa*, *Nephelium*, and *Salacca*. Therefore, only TG1B were selected as priority taxa for those genera.

The Second Global Plan of Action of PGRFA (Commission on Genetic Resources for Food and Agriculture FAO 2011) noted that the inventory of PGRFA is a critical initial step for their conservation. Based on Magos Brehm et al. (2017) and Bioversity International (2018), only 47 countries and five regions have published their CWR checklists and inventories. Most of these publications come from European countries (19 countries and two regions (Euro-Mediterranean and Nordic). In Asia, just 12 nations and one region (Fertile Crescent) published their CWR checklist. While, in the Americas (only 6 countries), Africa (nine countries and two regions (North Africa and SADC), and Australia and Oceania (only one country) have published their CWR checklist. This current inventory will add the number of Asian countries that published their CWR inventory.

Conclusion

One year left to 2020 as the GSPC second phase and the Strategic Plan for Biodiversity 2011–2020 (UNEP 2010) will be asked for their targets. Effective CWR conservation addressed by the GSPC targets (target 9) and the Aichi targets (targets 13) are still challenging

to reach. Until recently, only 47 countries and 5 regions have their own CWR checklist and inventories. This study will add to that number. About 1968 wild relatives to food crops are included in the current checklist. After prioritization, 234 taxa that belong to 26 families and 36 crop genera were established as priority for conservation in Indonesia. The first priority includes 95 CWR taxa that are important at the national and global levels, such as the wild relatives of rice, banana, mango, breadfruit, sugarcane, taro, coconut, sweet potato, melon, sorghum, citrus, and aubergines. The second priority includes 69 taxa that are related to the crops that important at the national and regional levels such as many tropical fruits (mangosteen, durian, star fruit, snake fruit, longan, langsat, Malay apple, or rambutans) and sugar crop (*Arenga* and Sago). The third priority consists of 70 taxa that are related to the crops that are important at the global level but less so at the national level, such as yam, figs, raspberry, and pigeon pea.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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