Impact of tree breeding on managing forest genetic resources: a review with a particular reference to *Acacias* and *Eucalyptus* grown in Indonesia

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Abstract. Declining genetic resource for some species is evident due to biotic and abiotic pressures which are aggravated by inappropriate management of conservation and utilization. Although breeding is one of good practices for increasing the utilization of genetic resources, inadequate breeding strategy could be the source of the diminishing genetic resources. *Acacias* and *Eucalyptus* are among the species experiencing good progress in genetic improvement due to its fast growth and high value wood for industries. Besides improving productivity, breeding program should be continued to overcome the increasing threats of pest, disease, and climate change. However, there appeared to be some problems with the developing advanced generation breeding, particularly those related to small genetic diversity as an impact of the decreased genetic resources and the improper breeding activities. Therefore, ensuring the sustainable benefits of germplasm for future uses, managing genetic resources and breeding practices should be properly linked. This paper reviews the impact of current adopted breeding strategy of *Acacias* and *Eucalyptus* on the declining genetic resources. It also discusses some possible ways to improve breeding strategy while maintaining genetic resources for the targeted species.

1. Introduction
Forest genetic resource (hereinafter referred as FGR) is one of essential components to achieve humane development goals as the resources involve both ecological functions and multiple economic uses. The existence for FGR is increasingly important to fulfill current and future needs, such as increasing productivity, anticipating pest and disease epidemic, and projecting climate changes. On the other hand, declining FGR in some species is now evident due to biotic and abiotic pressures which are aggravated by inappropriate management of conservation and utilization. According to FAO report, Africa and Asia are two regions with the highest of forest species diversity and almost half of the forest species reported by countries are threatened[1].

The concept of FGR is also often used in a practical sense to designate some genetic units such as clones, varieties and populations that hold special interest for conservation or use[1]. Breeding is one of good practices for increasing the utilization of FGR. Through breeding process, traits of interest could be genetically improved to simultaneously increase the economic value of the species and to meet the growing demand of forest products. However, unlike breeding for crops, tree breeding program is commonly constrained by long rotation and tree size with the consequences of requiring high cost and a long breeding cycle. Various breeding strategies are then developed to overcome the
constraints and to achieve the genetic gain of targeted traits faster and higher. Conventional breeding techniques are still commonly practiced in some important species due to the limitation of indirect application of molecular breeding in operational scale.

Approximately 700 tree species are subjected to some level of selection and improvement globally, and progeny tests have been established for no more than two-thirds of these species [1]. Acacias and Eucalyptus are among the species selected as commercial wood production due to its fast growth and high value wood for industries. Some species are undergoing intensive breeding and providing good results, such as Acacia mangium, A. auriculiformis, A. crassicaarpa, Eucalyptus pellita, E. grandis, and E. urophylla. Interspecific hybridizations were also successfully practiced for improving the target traits of interest, such as the hybrids of A. mangium × A. auriculiformis[2][3] and E. urophylla × E. grandis [4][5]. Most of the breeding strategies adopted for Acacias and Eucalyptus species were primarily initiated by exploring genetic materials in wide natural distributions, mostly in Eastern Indonesia, Papua New Guinea and Queensland-Australia. The development of advanced generation breeding also indicated a high dependence on genetic materials from the original population to maintain adequate genetic diversities[6][7]. Thus, the existence of FGR is important to support the sustainability of the breeding program for Acacias and Eucalyptus.

Genetic diversity is a key component in managing FGR for short-term and long-term breeding programs. The degree of achievement in breeding program will be dependent on the degree of genetic diversity within population or species of interest [8][9]. However, theoretically there is a conflicting interest between the target to increasing genetic gain and maintaining genetic diversity along the breeding cycle, particularly due to selection practices. Selection will increase gain, but at the same time reduce the diversity of the successive advanced generation populations. While increasing the utilization of FGR, an improper breeding strategy may be a potential source of the decreasing genetic resources. The potential impact will become more serious in the breeding of fast growing tree species such as Acacias and Eucalyptus due to shorter breeding cycles within generation and intensive breeding process. Therefore, an appropriate linkage between intensity of selection and genetic diversity is necessary to balance and ensure future uses of FGR in next generation breeding. In this case, maintaining genetic diversity will become the best insurance of improving productivity and overcoming future threats from biotic (e.g. pest and disease) and abiotic (e.g. climate change) pressures, in which breeding practices is considered to be one of the solutions for these problems.

This paper reviews the impact of tree breeding on managing forest genetic resources of Acacias and Eucalyptus species. The review is focused on the impact of current adopted breeding strategy for intensive breeding of Acacias and Eucalyptus species in Indonesia, such as Acacia mangium, A. auriculiformis, A. crassicaarpa, and Eucalyptus pellita on the declining of their forest genetic resources. Finally, the paper also discusses some possible ways to improve breeding strategy while maintaining genetic resources of the targeted species.

2. Adopted breeding strategy: a technical overview

2.1. Recurrent selection system

Most of the breeding strategies for Acacias and Eucalyptus apply some versions of recurrent selection system (hereinafter referred as RSS). This system involves the whole process of selection, mating and propagation to produce genetically improved seed and breeding materials which are repeated over successive cycle of generations. Genetic gain is then accumulatively increased in successive advanced generation breeding[10]. In this case, shorter breeding cycle per generation will contribute to the achievement of more potential genetic gain per unit time. As fast growing tree species with short rotation, the breeding of Acacias and Eucalyptus will be technically feasible to adopt the RSS. In addition, as early flowering and fruiting species at around 3 to 5 years of age, Acacias and Eucalyptus take a shorter time to complete the breeding cycles. Regardless these two factors of short rotation and early reproduction, the broad and adequate genetic diversity of targeted species for breeding would be preferred to adopt the flexibility of RSS in efficient and effective ways.
In terms of pedigree control, RSS for general combining ability (hereinafter referred to as RSS-gca) and interspecific hybrids (RSS-ih) are commonly adopted for Acacias and Eucalyptus rather than simple RSS based on phenotypic mass selection. The breeding of Acacia species has adopted RSS-gca with half-sib families due to low success rate in controlled pollination, while for Eucalyptus both of RSS-gca and RSS-ih have been commonly used as controlled pollination and vegetative propagation are relatively easy to apply. With the identified pedigree control, genetic gain for the trait of interest is substantially increased over the cycles of generation breeding through selection and mating in the population.

Like other species, breeding of Acacias and Eucalyptus species are commonly directed to achieve genetic gain as great and fast as possible. Short cycle of breeding, early flowering and fruiting, and adequate genetic resources will encourage the application of RSS in the breeding program of these species. This is because the frequency of favorable alleles could be progressively increased over successive breeding cycles. The genetic gain obtained from breeding for Acacias and Eucalyptus species have been mostly encouraging. A significant increase in genetic gain in growth (around 13% per breeding cycle) over successive advanced generations has been achieved [6]. In this case, the goals of breeding are mostly to increase gradual improvement over successive generations of breeding rather than creating new varieties. However, current development in inter-specific hybridization, such as in Acacias (A. mangium × A. auriculiformis) [11][12] and Eucalyptus (E. urophylla × E. grandis) [13] revealed that the development of new varieties in Acacias and Eucalyptus possible and could highly increase tree productivity.

2.2. Breeding seedling orchard
Breeding seedling orchard (BSO) is one of strategies in the management of breeding population. This is commonly practiced to make a flexible strategy for combining progeny test and seedling seed orchard in which the genetic testing and seed production will be applied in the same population [14]. This is also the type of low-input breeding as it is inexpensive, convenient, simple and robust [15]. Following results of testing, selection in the breeding population is practiced through roguing the underperformed genotypes to convert progressively into seedling seed orchard. Most of breeding of Acacias and Eucalyptus have adopted the BSO in which the time span between testing and seed production is shortened and only a small effective area is required.

Another strategy in the management of breeding population is the use of a single large population. This strategy is mostly practiced in the beginning of breeding program of Acacias and Eucalyptus species due to low-cost and simple management by establishing one single large breeding population consisting of many families (>100 families) from some different provenances. However, this strategy is gradually improved through the changes from managing single large population to sub-population with the practical reasons to simplicity of pedigree control [16]. Sub-population management could be practiced through two concepts of multiple-population and sub-lining system [17]. Considering the large natural distribution of some Acacias and Eucalyptus species, particularly those species grown in eastern part of Indonesia, western part of Papua New Guinea and northern part of Queensland-Australia, such as A. mangium, A. crassicarpa, A. auriculiformis and E. pellita, E. urophylla, the concept of sub-lining system is then commonly adopted for breeding of these species. One of the examples is the sub-lining system practiced by the Centre for Forest Biotechnology and Tree Improvement (CFBTI) for breeding of A. mangium, A. crassicarpa and E. pellita [18][19]. In this strategy, the breeding population was sub-divided into a number of sub-populations based on natural origin or provenances in which each sub-line consists of 40–70 families. The pedigree of population from each sub-line is then kept consistently to proceed into the successive advanced generation breeding.

As function of testing, the breeding population should meet some statistical requirements in order to provide accurate assessment of genetic parameters. Experimental design is then arranged properly to exploit genetic potential from the breeding population and high quality of seed production. Considering the source variations, genetic gain from breeding population could be accumulatively obtained due to the high existing genetic variation in the level of provenances, family and within family.
2.3. Plot configuration

The arrangement of plot configuration would become important component in generating experimental design to meet the function of testing and seed production in a breeding population. Instead of single tree plot, the multiple tree-plot, that is having more than one tree in each family within each replication, is commonly adopted in experimental design of breeding population which could be laid-out in forms of line tree-plot, squared tree-plot or non-contiguous tree-plot. In BSO, the number tree-plot used in the experimental design depends on a number of factors, such as variability within sites, topography, final stand density of mother tree and the crown development for optimum seed production. In this case, initial spacing and stand density of BSO will determine the number of tree-plot that is then followed by several progressive selective thinnings to meet the final density for seed production. However, in statistical point of view, the uses a singletree-plot has higher precision in estimating the genetic parameters for half-sib and full-sib families, and clonal testing as well [20][21][22].

The common plot configuration adopted for Acacias and Eucalyptus is multiple tree-plots. However, due to the differences in crown development and potential of inter-tree competition, the initial spacing for Acacias is wider than that for Eucalyptus. For example, in the existing breeding population as used in this study, the common initial spacing are $4 \times 2$ m for Acacias and $4 \times 1.5$ m for Eucalyptus[23]. In this configuration, the number of tree per plot for Eucalyptus would be greater than for Acacias in the same unit area.

2.4. Selection

Selection is the main part of activities in the establishment of breeding population to achieve the expected genetic gain for the traits of interest. The intensity of selection would be compromised with the two main factors, namely the estimate of genetic parameters and the amount of expected genetic gain. With regard to BSO, potential gain could be obtained based on between family selection and within family-selection or within-plot selection. Family selection can be regarded as more controllable as compared to within-plot selection. This is because the direction of selection in within-plot selection largely depends on the preference of the foresters, while that of family selection is theoretically oriented [24]. However, in practice, there are some sort of modifications on the selection concerning the magnitude of genetic diversity for next generation breeding and other future uses, such as combination of selection methods, intensity of selection and traits involved in selection.

Improving more than one trait of interest is also common target in a breeding program for forest tree species, particularly to meet the need to increase productivity for industries. Most Acacias and Eucalyptus species are commonly used to supply raw materials for pulp and paper in which the requirements of wood quality will involve many traits, such as growth, stem form and wood properties. Consequently, selection based on multiple-trait should be practiced in the breeding program of Acacias and Eucalyptus. Although the wood will be used for the same industry, selection in Acacias is more complicated than that in Eucalyptus due to some differences in morphological characters. Acacias trees have more heterogeneous stem characteristics including form (straightness and fork) and cylindricity.

Index selection is one of common available methods for practicing multiple-trait selection for combining growth, form traits and wood properties. By this method, the priority of each trait of interest, as selection criteria, would be determined on basis of the economic weight. The weight could be maintained in subsequent generation breeding in order to produce higher accumulative gain for the same trait of interest. Another method is tandem selection that is the selection based on trait by trait at a different successive of time or generation of breeding. This is commonly practiced in certain condition or if some target traits are negatively correlated each other. In this case, improvement of the target traits will be achieved gradually through step by step selection over generations of breeding. Another additional method is the two stage selection in which the selection is practiced through two stages of different selection criteria within the same breeding generation. This is commonly practiced during plus trees selection to collect genetic material for breeding in the next subsequent generation. For example, the several candidates plus trees are firstly imposed on growth traits within selected
population, and thereafter in the second stages they are finally determined as plus trees after verification on wood properties[19].

3. Potential risks of adopted the breeding strategy to sustainable genetic resources

The impact of breeding on managing genetic resources in this paper is discussed according two major facts. First, the current breeding program to improve certain traits is based on present need. On the other hand, the breeding objective might change in future. Second, following selection in the current breeding program, some undesirable genotypes based on present need will be eliminated by removing them from the breeding population. However, the eliminated genotypes might be useful in future as they may contain genes or gene complexes that are more desirable.

The breeding for Acacias and Eucalyptus has increased plantation productivity with the main objective to supply raw materials for pulp and paper mill. Selection had been done mainly for improving growth, stem form and wood properties. The increase in plantation productivity has been realized in operational scale in many cases. It is understandable that the past breeding programs had focused on growth and form as disease was not an important issue or trait of concern in the early breeding program of A. mangium. However, third rotation planting of A. mangium was no longer financially possible due to widespread infestation of wilt-leaf disease caused by Ceratocystis[25][26]. Another damaging disease in A. mangium plantation at certain areas is root-rot caused by Ganoderma[27]. So far, there are no effective methods to control these diseases. Breeding to find genotypes resistant to wilt-leaf and root-rot diseases is considered the most potential measures to control the diseases, even though it is not easy as the genetic variation in A. mangium including disease resistance seems quite low [27]. In this regard, screening for genotypes may comprise all genetic materials in the breeding population including those eliminated during the previous breeding cycles. New collection of genetic materials from natural population or seed exchanges with other research organizations may also be included to increase the size of base population for screening disease resistant genotypes.

According to the lessons learnt from the past breeding strategy of A. mangium, managing genetic resources is essential to ensure that future breeding activities, with apparent new problems and challenges, has an adequate genetic diversity of the base population. Another aspect to be considered is that breeding practices should adopt a more conservative strategy, by paying attention to the importance of gene conservation and diversity of genetic materials for future use. This strategy could be practiced in BSO through using a less intensity of selection, a less thinning and culling of the tree, and an effective experimental design which are followed by stocking an adequate number of genetic materials in seed bank. On the other hand, to obtain a higher genetic gain, intensity of selection could be increased through establishing a separated population of clonal seed orchard.

Regarding the conservation of genetic resources, there are some breeding practices that have influenced the decline of genetic resources. Recurrent selection system (RSS) has been adopted in the breeding program for many species including Acacias and Eucalyptus. One of the key reasons for adopting RSS is achieving accumulative genetic gain sustainably in successive breeding cycle. To ensure the genetic diversity in successive advanced generation, infusing genetic materials from new collection into breeding population may be carried out. The selection criteria of this procedures practiced in advanced generation breeding population, particularly in the target traits to improve, is very critical. If the targeted traits or the coefficient of weight for index selection is the same as that of the previous generation, the infused genetic materials will be less effective to increase genetic diversity. This is because most of the infused materials would be less productive as compared to the material selected from previous breeding. As a result, the infused materials would be mostly eliminated from the breeding population during the selection. Some studies on A. mangium and E. pellita reported that the new collection of families that were infused into second-generation breeding were less productive in growth and form traits as compared to the improved families selected from first-generation breeding [28][29][30][31]. In third-generation breeding population of A. mangium consisting of three classes of genetic materials, the number of infused families selected as the top rankings are very small at less than 24%[32]. This means that more than 75% of the new collection of genetic materials would be loss under the same criteria of selection in successive generation of breeding.
Adopting BSO in the management of breeding population is another serious potential source of genetic resource decline. In this BSO, the results of selection-based progeny testing should be followed by thinning or culling the undesirable genotypes from the breeding population for converting into seedling seed orchard. The number of genotypes should be culled depending on the target of improvement and seed trees density. The impact of removing the undesirable genotypes through thinning or culling will increase the productivity of improved seed quality, but reduce the genetic diversity in breeding population. Under the use of multiple tree plot design, the increase of BSO size will increase the number of culled genotypes, and consequently reduce the number of genetic material stocks.

The magnitude genetic diversity reduction would be larger when the BSO is designed using multiple tree-plots, either in line plot or squared plot. The plot configuration will be commonly determined on the basis of site heterogeneity and statistical requirements. These imply that more heterogeneous sites will need more sample trees to be planted in each plot (tree-plot). This is because a progeny testing is the first step assessment in BSO before converting it into seed orchard. The progeny testing will be evaluated by statistical analysis with high accuracy. The analysis will be conducted by the understanding that more samplings will lead to more accurate results. As a consequence, the larger number of trees within each plots are culled, regardless of the growth performance of those trees to be made as samples. In advanced generation of *A. mangium* breeding, the within-plot variation is low, indicating that the sampled trees are mostly performing similar growth in each plot [33]. However, thinning of the tree-plot should be practiced by retaining only one best tree in each plot to avoid the mating between relatives and reduce inbreed seed production in the tree orchard. Such a plot configuration in BSO followed by thinning within tree-plot will reduce the number of genotypes and decrease the genetic variation in the breeding population.

Following the adoption of BSO in managing breeding population, the genetic assessment is carried out followed by culling of undesirable genotype at the family and within family level. This indicates that the selection in BSO could be the main source of genetic resource loss in family and within family level basis. The number of losing genotypes in BSO due to selection depends on the magnitude of expected genetic improvement which is later dependent on intensity of selection (IS). Higher IS will provide higher genetic gain, with a consequence of reduction number of genotypes and diversity. Family selection is commonly practiced in BSO of *Acacias* and *Eucalyptus* because of higher genetic variation at family level [33][34][35]. The family selection is practiced on the basis of the estimate of genetic parameter, and therefore genetic gain as a response from the selection will be more controllable[24].

Within family selection is commonly practiced in BSO to obtain an additional gain through the uses of existing variation among the individual trees within the same family. Although this variation in *Acacias* species is commonly smaller compared to family variation [33][34], within family selection in the form of within-plot thinning is practiced as the first step of selection in BSO. Thinning in BSO is implemented gradually in several steps considering inter-tree competition and stimulation of the remaining tree growth. The within family selection will maintain genetic diversity [36], but it will reduce considerable number of genetic stocks. For example, in the case of four tree-plot or five tree-plot commonly used inline plot configuration in BSO of *Acacias* and *Eucalyptus*, around 75%-80% of the planted genetic stocks will be removed through culling to avoid the mating between relatives and reduce inbreeding. Another disadvantage is that the large reduction of the genetic stocks is imbalance with the small amount of achieved improvement from such within-family selection, particularly in advanced generation of breeding. Moreover, the gradual change of spacing due to the thinning will also affect the effectiveness of family selection, particularly when the final spacing for family selection in BSO will become larger than the spacing in operational plantation where the improved seed will be planted. Study in *E. pellita* reported some indications in potential loss of genetic gain due to such discrepancy of spacing[37].

Plus trees selected in the current breeding population that will be used to establish subsequent generations of breeding population will also lead to the declining genetic resources. This is because the plus trees are selected in very high intensity (ratio of selection <10%) in the breeding population[19]. The superior genotypes of plus trees will produce better quality of progenies tested in
the advanced generation with a consequence of increasing gap performance between the plus tree progenies and the new infused genetic material. The gap performance will increase with the increasing generation of breeding cycles. Under the same criteria of selection as described in previous paragraph, this gap will stimulate the elimination of more infused genetic material from the breeding population during the process of selection.

4. Possible ways of improving breeding strategy in managing genetic resources

Selection is one of the key components in the breeding strategy to obtain best genotypes for producing genetically improved seed. Nevertheless, there is a potential adverse effect that selection will reduce genetic diversity and genetic resources as described in some preceding paragraphs. With proper management practices, the negative impact of the breeding can be kept at a minimal level. Some possible ways to improve breeding practice could be considered in maintaining genetic resource quality and diversity.

4.1. Characterization as pre-breeding process

Understanding the characteristics of genetic resource is essential to explore the link between the merit of genetic resources and targeted end-product need. Forest genetic resource populations are often naturally distributed in a very vast area. Different populations may have distinct characteristics as an adaptability response to the particular environmental condition. In Acacias, the natural population of *A. mangium*, *A. crassicarpa* and *A. auriculiformis* are distributed in Maluku and southern Papua (Indonesia), in western part of Papua New Guinea, and in southern and Northern part of Queensland, Australia [38]. In other species of Eucalyptus, original populations of *E. pellita* are also distributed in some regions of Indonesia, Papua New Guinea and Australia [39]. Various provenance trials reported that there were significant differences among the provenances for some traits, such as growth, form, wood properties, wind tolerance in *Acacias* [29][30][31][32][33][34][35][36] and in *Eucalyptus* [48][49][50]. Considering the superior characteristic differences among the provenances, characterization is necessary to identify potential provenance to be improved as pre-breeding phase. By this pre-breeding phase, the genotypes elimination of low-quality provenances could be avoided.

4.2. Multiple populations system in management of breeding population

Breeding population may be established independently for each provenance with specific merit of character. In this case, multiple population system would be a better type in management of breeding population in which the specific genotypes are then treated for further successive improvement based on their specific merit of characters. Target of selection would be different among the population lines depending on their superior characters suited for increasing the end use productivity. The possibility of intra-specific hybridization among the population could also be conducted to increase genetic diversity due to the occurrence of random gene-recombination in propagation population. Although the characterization to set up the lines population would need more time and to be more complex, establishing more lines under the multiple population system will conserve more genetic resources with specific characters.

4.3. Clonal plantation development

Although the clonal plantation is often considered to have low genetic diversity, clonal selection to obtain superior clones would provide more positive impacts on conserving genetic resources. This is because clone selection might not be necessarily followed by culling undesirable genotypes in the breeding population, either in progeny trial or in clonal trial. In the case of producing improved seed, clones selected in the breeding population could be propagated and used for establishing clonal seed orchard in a separated population without directly converting the breeding population into seed orchard as practiced in BSO. Longer timespan for this clonedevelopment will not seriously affect the genetic gain per unit time, because the gains from the clonal deployment could be many times higher than the improved seed produced from BSO. Stand volume productivity from three selected clones of *E. 
and desirable, ch. some individual tree moving or culling perspectives species which BSO saving in seed during progeny testing in BSO could be approached while maintaining the number of genetic resources as mother trees. Single tree-plot configuration applied in second-generation BSO of A. mangium could almost doubled increase the genetic gain of multiple tree-plots [33].

4.5. Selection with no culling
With regard to BSO, selection is the main mean of improving the productivity of trees. However, selection is not necessarily followed by removing undesirable genotypes from the existing breeding population. The separation of the function of genetic testing, seed production and breeding population would contribute to the efficient uses of genetic resources in a breeding program. Progeny trial as a genetic test will be used only for the estimation of genetic parameters, thereafter the trial would be converted to ex-situ genetic resource conservation plot. A new seed production population (seed orchard) consisting of identified selected families in the progeny test could be separately established in a larger area.

Another option is to select plus trees from the progeny test, conservation plot or seed orchard, which is followed by propagation through cloning to establish clonal seed orchard or further clonal deployment, and by seed collection to establish the subsequent generation breeding cycles. Higher intensity in plus trees selection could be compromised with a range of target genetic diversity in the subsequent generation breeding population, such as clustering the selected plus trees based on the different levels in traits of interest. Although marker-assisted approaches in recent advanced molecular breeding will not likely replace conventional breeding in tree species, genomic selection seems to become a potential tool to support selection with no culling. This is because under this technology, selection could be potentially practiced in very early growth. Following these selections with no culling in breeding population, genetic resources explored for the breeding program could be more conserved either saving in seed bank or planting in conservation plot for anticipating the future uses.

4.6. Inter-specific hybridization
In Acacias and Eucalyptus, species hybridization is very common to be practiced to obtain new varieties with superior performance, such as in crossing involving A. mangium and A. auriculiformis [2] [3], E. urophylla and E. grandis [4] [5]. The progenies produced from the species hybridization could perform large variation in characters [3]. A few selected superior hybrid progenies are then vegetatively propagated for clonal test and operational plantation deployment. A simple hybrid breeding could be practiced in making efficient uses of genetic resources. This is because the parental trees for crossing are selected from the plus trees in respective species which are then vegetatively propagated to establish a clonal garden. Under this strategy, removing or culling genotypes could be avoided while creating opportunities to explore superior hybrid progenies.

5. Conclusion
Breeding practices have been recognized as important activities to significantly improve the forest tree productivity over the past 50 years. Many modified breeding strategies have being applied concerning the achievement of genetic gain faster in time and bigger in magnitude. Towards the future need and
challenges, the availability of genetic resources is essential to ensure the improvement sustainability of respective species through breeding. Efforts to achieve as fast as and as great as possible genetic gain lead to the adoption of inadequate breeding practices to meet the concerns in managing sustainable FGR.

Among many potential sources, breeding practice is one of unaware sources of the declined genetic resources. Impacts of some modified breeding strategies pose some potential risks in which the breeding activities are inadequate to maintain genetic diversity and genetic resources. Some breeding practices, e.g. imposing high selection intensity for the infused families in advanced generation breeding, multiple tree-plot configuration followed by thinning in breeding seedling seed orchard, and selection followed by culling the undesirable genotypes in breeding population, could strongly lead the reduction of genetic resources.

There are some possible ways that could be taken to minimize the negative impact of breeding practices to the decline of genetic resources. Pre-breeding through characterization of original population before establishing breeding population could be done to avoid the elimination of many genotypes from low level population under different specific targets of improvement. Following the pre-breeding, some breeding populations could be then established in sub-lining system separately for each different specific population. Clonal development could also be an effective breeding practice in managing the utilization of genetic resources. The linkages of progeny trials and seed production should be arranged in different populations subsequently to avoid thinning for removing the undesirable genotypes and other probably unknown potential genotypes. It could be then combined with single tree-plot rather than multiple tree-plot configurations. Developing conservative breeding strategy which incorporates biotechnology into breeding practices could compensate the high productivity for the declining FGR.

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