Phylogenetic positions of three Amorphophallus species natively growing in the Meratus Mountains, South Kalimantan, Indonesia

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Abstract. Mursyidin DH, Hernanda MA. 2021. Phylogenetic positions of three Amorphophallus species natively growing in the Meratus Mountains, South Kalimantan, Indonesia. Biodiversitas 22: 2821-2828. Information on genetic diversity and relationships (phylogenetic position) of germplasm is essential for conservation and breeding programs in the future. Here, we focused on determining the genetic diversity and phylogenetic positions of three native Amorphophallus species from the Meratus Mountains, South Kalimantan, Indonesia, using the rbcL marker. The results show that this germplasm has a medium level of genetic diversity (0.63). The phylogenetic analyses (NJ, ML, and MP) revealed that Amorphophallus from the region has a unique or specific relationship position. In this case, A. muelleri with an accession number of MT818204 and MT818205 are grouping and have close relatedness with A. muelleri previously deposited in GenBank (AF497087.1). Three samples of A. paeoniifolius (MT818202, MT818203, and MT818206) have also clustered with the same species (DQ012500.1; AF497091.1). An interesting result was shown by A. borneensis (MT818211) that demonstrated a close relationship with A. tinekeae (DQ012505.1) in NJ and ML analyses, not with a similar species (DQ012484.1) in MP analysis. Further, a bootstrap analysis on an earlier analysis supported the separation. Thus, this information is valuable in supporting the conservation and breeding programs of this germplasm, both locally and globally.

Keywords: Conservation, Genetic diversity, Phylogeny, Plant breeding, Wild species.

Abbreviations: NJ: Neighbor Joining; ML: Maximum Likelihood; MP: Maximum Parsimony.

INTRODUCTION

Amorphophallus, belonging to the Araceae family, is a large genus with over 200 species reported (Claudel et al. 2017). This genus is distributed mainly in Old World tropical forests, including Asia, Oceania, and Africa (Mekkerdchoo et al. 2016), from close to the coastal line to an altitude up to 900 m a.s.l. and adapts to low light intensities (Santosa et al. 2017). Amorphophallus exhibits a wide range of agro-ecological adaptation to dry and moist soils. It is abundant under trees shading home gardens, mixed gardens, secondary forests, and agroforestry, as well as open fields (Grob et al. 2002; Santosa et al. 2017). Because of its high abundance, around 70%, Southeast Asia estimated to be the center of diversity of this genus (Claudel et al. 2017).

For a long time ago, several Amorphophallus species have been used as a traditional medicine in several Asian countries, particularly in China and India (Dey et al. 2012, Gao et al. 2017a). Recently, this germplasm has attracted an economic interest, both for food resources and pharmaceutical products worldwide (Mekkerdchoo et al. 2016). Amorphophallus paeoniifolius, known as elephant foot yam or A. campanulatus (syn.), and A. muelleri are the two Amorphophallus examples with these economic values, particularly for commercial glucomannan and other substances, like ceramide (Mekkerdchoo et al. 2016, Zhong et al. 2018).

In general, Amorphophallus shows a high variation morphologically, so that it is very difficult to distinguish each other, especially at intrageneric level (Claudel et al. 2017; Gholave et al. 2017). Nowadays, various DNA markers can be useful to characterize germplasm with close genetic relationships (Terentieva et al. 2020). Of these, chloroplast DNA (cpDNA) or DNA barcode is an excellent marker to study the genetic diversity and relationships of plants because of its conserved gene order, maternal inheritance, and low mutation rate (Gao et al. 2017b). In this study, we have used the rbcL region of cpDNA to determine the genetic relationship or phylogenetic position of three wild Amorphophallus species from the Meratus Mountains of South Kalimantan, Indonesia.

Indeed, although rbcL provides low resolution compared with other cpDNA markers, particularly matK, it does offer several advantages, including its presence across the plant kingdom, unambiguous alignment, high primer universality, and high sequence quality (Dong et al. 2014). Furthermore, this barcode region is easy to amplify, sequence, and align in most terrestrial plants and provides a useful backbone to the barcode dataset, despite it having only modest discriminatory power (Holingsworth et al. 2011). Finally, rbcL generates high-quality sequence output with easily retrievable across phylogenetically divergent lineages, and it performs well in discrimination tests in combination with other loci (CBOL 2009).
On the other hand, determination of phylogenetic relationships among wild *Amorphophallus* species is very urgent to undertaken, mainly for germplasm conservation, evaluation, and utilization in future breeding programs (Gao et al. 2017b). According to Gao et al. (2017a), wild relatives of domesticated plants provide important gene reservoirs for improving commercial cultivars. In recent years, handful of phylogenetic studies have been undertaken on some *Amorphophallus* species using chloroplast DNA (cpDNA) regions (Gao et al. 2017b; Sedayu et al. 2010). However, the phylogenetic studies of *Amorphophallus* species in Indonesia, particularly South Kalimantan, have not been well performed, except in Java (Nikmah et al. 2016, Wahyudi et al. 2016), Bali, and Lombok (Kurniawan et al. 2011).

Thus, the objectives of our study were to (i) estimate the genetic diversity of the *Amorphophallus* native to the Meratus Mountains, South Kalimantan, Indonesia by *rbcl* cpDNA marker, (ii) determine the genetic relationships or phylogenetic position of this germplasm from the region with other *Amorphophallus* species included in GenBank database, and (iii) provide some recommendations on the conservation and utilization of this germplasm for local, regional, and national government, particularly in Indonesia.

**RESULTS AND DISCUSSION**

**Plant materials**

We have used a total of 80 samples of *Amorphophallus*, comprises six samples (including three species, namely A. paenonifolius, A. muelleri, and A. borneensis) collected directly from the Meratus Mountains, South Kalimantan, Indonesia (Table 1), and 74 other species, obtained randomly from GenBank database (Table 2).

**DNA extraction, amplification, and sequencing**

Total genomic DNA was extracted from collected leaf samples using the plant genomic DNA extraction kit (Geneaid Biotech Ltd., Taiwan) following a manufacturer’s protocol. The DNAs were quantified using a UV-VIS spectrophotometer (NanoVue, GE Healthcare, UK) and standardized on 1.0% (w/v) agarose gels. The *rbcl* gene was amplified and sequenced with primers *rbcl*-F (5’-ATGTCACCACAAACAGAGACTAAAGC-3’) and *rbcl*-R (5’-GTAAATCAAGT CCACCCRCG-3’) from Gholave et al. (2017). Amplifications were conducted using the SimpliAmp Thermocycler PCR (Applied Biosystem, USA). A 25 µL reaction mix, composed of 22 µL PCR mix (MyTaq HS Red Mix, Bioline, UK), 2.0 µL (10 µM) primer forward and reverse, and 1 µL (10× diluted containing ca. 10 ng DNA) template. The amplified DNA fragments were then separated by 2% agarose gel with 1X TBE buffer solution, stained with a DNA dye (FluoroVue, SMOBio Technology, Taiwan), and observed by UV transilluminator. The successful amplified DNA was then sent to 1st Base Ltd., Malaysia, for purification and sequencing bidirectionally using the Sanger method. All sequences were deposited in GenBank with accession numbers shown in Table 1.

**Genetic diversity and phylogenetic analyses**

Sequences were analyzed, edited and assembled using the MEGA-X software (Kumar et al. 2018). The genetic diversity was determined using the nucleotide diversity index (\(\pi\)) method (Nei and Li 1979). Meanwhile, the level of genetic diversity was referred to Nei (1987) category, where 0.1 to 0.4 is low, 0.5 to 0.7 is the medium, and 0.8-2.00 is high. For phylogenetic analysis, multiple sequence alignments of sequences were performed with Clustal Omega (Sievers & Higgins 2018) and edited manually using a similar software used previously to obtain an unambiguous sequence alignment. Interspecific genetic divergences were calculated using Kimura 2-Parameter (K2) distances in MEGA-X following the instruction of the CBOL for distance calculations (Kumar et al. 2018). Three phylogenetic analyses, namely Maximum Likelihood (ML), Maximum Parsimony (MP), and Neighbor-Joining (NJ) were also carried out in MEGA-X. The bootstrap analysis with 1000 replicates was applied for evaluated the topological robustness of the phylogram (Lemey et al. 2009).

**Materials and Methods**

**Plant materials**

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Table 1. List of Amorphophallus samples collected from the Meratus Mountains, South Kalimantan, Indonesia.

| Species           | Origin                                      | Nucleotide length (bp) | Accession number |
|-------------------|---------------------------------------------|------------------------|------------------|
| *A. paeoniifolius* | Lower Bajuin, Tanah Laut, South Kalimantan  | 606                    | MT818202         |
| *A. paeoniifolius* | Upper Bajuin, Tanah Laut, South Kalimantan  | 606                    | MT818203         |
| *A. paeoniifolius* | Pani, Tapin, South Kalimantan               | 606                    | MT818204         |
| *A. muelleri*     | Lower Bajuin, Tanah Laut, South Kalimantan  | 606                    | MT818205         |
| *A. muelleri*     | Upper Bajuin, Tanah Laut, South Kalimantan  | 606                    | MT818206         |
| *A. borneensis*   | Pani, Tapin, South Kalimantan               | 543                    | MT818211         |

Table 2. List of Amorphophallus obtained from GenBank database and its length sequences of the *rbcL*.

| Species          | Nucleotide length (bp) | Accession number |
|------------------|------------------------|------------------|
| *A. abyssinicus* | 1454 AF497060.1        |                  |
| *A. amygdaloides*| 1433 DQ012482.1        |                  |
| *A. angolensis*  | 1470 AF497061.1        |                  |
| *A. ankarana*    | 1455 AF497062.1        |                  |
| *A. baumannii*   | 1482 AF497063.1        |                  |
| *A. beccarii*    | 1488 AF497064.1        |                  |
| *A. borneensis*  | 1453 DQ012484.1        |                  |
| *A. brevispathus*| 1458 AF497065.1        |                  |
| *A. baco*        | 1381 KT94021.1         |                  |
| *A. canaliculatus*| 1479 AF497066.1        |                  |
| *A. cirrifer*    | 1484 AF497067.1        |                  |
| *A. coueaneus*   | 1450 AF497068.1        |                  |
| *A. commutatus*  | 1460 AF497069.1        |                  |
| *A. corrugatus*  | 1459 AF497070.1        |                  |
| *A. dactylifer*  | 1456 DQ012485.1        |                  |
| *A. declinatus*  | 1448 DQ012486.1        |                  |
| *A. decus-silvae*| 1454 AF497071.1        |                  |
| *A. dracoides*   | 1460 AF497072.1        |                  |
| *A. ebarrus*     | 1459 AF497073.1        |                  |
| *A. eichleri*    | 1460 AF497074.1        |                  |
| *A. galbra*      | 1458 AF497075.1        |                  |
| *A. glossophyllus*| 1459 DQ012489.1        |                  |
| *A. henry*       | 1491 AF497076.1        |                  |
| *A. hewitii*     | 1432 DQ012490.1        |                  |
| *A. hirsutus*    | 1482 AF497077.1        |                  |
| *A. hirtus*      | 1458 AF497078.1        |                  |
| *A. hohenackeri* | 1430 DQ012491.1        |                  |
| *A. hotta*       | 1391 AM05785.1         |                  |
| *A. johnsonii*   | 1459 DQ012494.1        |                  |
| *A. konjac*      | 1460 AF497080.1        |                  |
| *A. konkanensis* | 1454 DQ012495.1        |                  |
| *A. koratensis*  | 1363 KT94052.1         |                  |
| *A. krausei*     | 1478 AF497081.1        |                  |
| *A. lambii*      | 1473 AF497082.1        |                  |
| *A. lanuginosus* | 1451 DQ012496.1        |                  |
| *A. laoticus*    | 1458 DQ012497.1        |                  |
| *A. levalliei*   | 1486 AF497083.1        |                  |
| *A. longiconnectivus*| 1454 DQ012498.1        |                  |
| *A. longituberosus*| 1466 AF497084.1        |                  |
| *A. margarifer*  | 1480 AF497085.1        |                  |
| *A. maxwellii*   | 1458 AF497086.1        |                  |
| *A. mossambicensis*| 1448 DQ012499.1        |                  |
| *A. muelleri*    | 1441 AF497087.1        |                  |
| *A. napalensis*  | 1460 AF497088.1        |                  |

| Parameter | rbcL |
|-----------|------|
| Range of sequence length (bp) | 543-1491 |
| Number of polymorphic sites (S) | 126 |
| Bayesian Information Criterion (BIC) | 8904.75 |
| Akaike Information Criterion (AICc) | 7386.04 |
| Maximum Likelihood Value (lnL) | -3534.79 |
| Transition/Transversion (Ti/Tv) bias value (R) | 2.06 |
| GC content (%) | 42.91 |
| Nucleotide diversity (π) | 0.63 |

Note: 1 Based on Kimura 2-parameter model.
Table 4. Polymorphic information for the rbcL region of *Amorphophallus* from South Kalimantan, Indonesia.

| Nucleotide position | Consensus | A. paeoniifolius var. Sylvestris (MT818202) | A. paeoniifolius var. sylvestris (MT818203) | A. muelleri (MT818204) | A. muelleri (MT818205) | A. paeoniifolius var. hortensis (MT818206) | A. borneensis (MT818211) |
|---------------------|-----------|------------------------------------------|------------------------------------------|-----------------------|-----------------------|------------------------------------------|------------------------|
| 43a                 | T         | -                                        | -                                        | .                     | .                     | C                                        | .                      |
| 86a                 | T         | -                                        | -                                        | G                     | G                     | .                                        | .                      |
| 155a                | T         | -                                        | -                                        | .                     | .                     | C                                        | .                      |
| 164a                | A         | -                                        | -                                        | .                     | .                     | G                                        | .                      |
| 191a                | C         | T                                        | T                                        | T                     | T                     | T                                        | T                      |
| 254a                | A         | -                                        | -                                        | .                     | .                     | G                                        | .                      |
| 266b                | C         | -                                        | -                                        | T                     | T                     | G                                        | .                      |
| 270ab               | G         | T                                        | T                                        | .                     | .                     | T                                        | C                      |
| 281a                | G         | A                                        | A                                        | .                     | .                     | A                                        | .                      |
| 341a                | T         | -                                        | -                                        | C                     | C                     | .                                        | .                      |
| 470a                | C         | T                                        | T                                        | -                     | .                     | T                                        | .                      |
| 497a                | G         | -                                        | -                                        | A                     | A                     | .                                        | .                      |
| 560a                | C         | -                                        | -                                        | T                     | T                     | .                                        | .                      |
| 571a                | G         | -                                        | -                                        | .                     | .                     | T                                        | .                      |
| 594bc               | A         | G                                        | G                                        | .                     | .                     | T                                        | .                      |
| 605ac               | C         | A                                        | A                                        | A                     | A                     | A                                        | .                      |

Note: a: transversion, b: transition, c: deletion

Figure 1. Phylogenetic position of *Amorphophallus* native to the Meratus Mountains of South Kalimantan, Indonesia (red highlight) based on Neighbor-Joining (NJ). The numbers above branches indicate bootstrap values inferred from 1000 replicates.
Interestingly, *A. borneensis* (MT818211), in this case, although it has a close relationship with *A. Tinekeae* (DQ012505.1) in NJ and ML analyses, MP have generated and joined this species with a similar *A. Borneensis* (DQ012484.1). However, a bootstrap analysis showed the lowest value (only 1%) for the last approach (Figure 3), so it is not significant. Moreover, phylogenetic trees generated by NJ and ML have a bootstrap significance of 80% and 78%, respectively (Figure 1 and 2).

**Discussion**

In this study, *Amorphophallus* has a moderate level of diversity, \( p = 0.63 \) (Table 3). According to Govindaraj et al. (2015), genetic diversity is one factor in forming a baseline population for natural selection and the evolutionary process. In other words, it has a fundamental role in the future evolutionary trajectory or a prerequisite for future adaptive change of a species. Hence, genetic diversity has profound implications for species conservation and breeding (Lloyd et al. 2016). In conservation practices, understanding genetic diversity is essential in increasing effectiveness and efficiency, especially for rare species. Because some aspects of conservation biology, such as loss of genetic diversity, only addressed by detailed population genetic studies (Luan et al. 2006).

For plant breeding, genetic diversity becomes more urgent in the context of climate change (Govindaraj et al. 2015). Plant breeders utilize this aspect in plant genetic resources to develop new and improved cultivars with desirable traits, both associated with different biotic and abiotic stress tolerance and farmer-preferred (Swarup et al. 2021). It is also fundamental in generating many essential agricultural phenomena, like heterosis and transgressive segregation. Diverse lines are required for defect correction of commercial varieties and the development of new ones. Thus, identification of various cultivars (if available), creation of diversity (if not exist or limited), and their subsequent utilization are the main objectives of the crop improvement program (Bhandari et al. 2017).
Compared to other studies with similar germplasm, there are differences in the value of genetic diversity. *Amorphophallus* in the study has a higher genetic diversity than reported by, for example, Gao et al. (2017a) in wild *A. paeoniifolius* population from Western China (p = 0.23-0.36) but lower than similar germplasm in Asia with p = 0.80 (Santoso et al. 2017). Referred to Gao et al. (2017a), these differences might be due to the continuous selection had reduced effective population size and increased genetic drift and hitchhiking during domestication. During this process, inbreeding and intensive selection, which narrow the germplasm genetic base, tend to reduce the genetic diversity (Gao et al. 2017a). Further, reduced genetic diversity has been shown to decrease disease resistance and resilience to environmental disturbance and extreme conditions (Lloyd et al. 2016).

According to Lloyd et al. (2016), only as present-day populations need a high genetic diversity to rapidly adapt, future generations will need equally as much genetic diversity to adapt to future changes. Although the genetic diversity is currently high, the rapid rate of evolutionary change could outpace the rate of adaptation of this species. Consequently, future studies are necessary to understand how the loss of genetic diversity will impact the ability of future generations to continue to cope with environmental change in the population (Lloyd et al. 2016). It is because the low level of diversity may result from a founder effect, genetic isolation, population decline, or natural selection (Gao et al. 2017b).

Molecularly, the level of genetic diversity is affected by polymorphic or mutation events. In this case, the rbcL sequence of this germplasm has generated many polymorphic sites (126 loci) with a Transition/Transversion (Ti/Tv) bias value is recorded of 2.06 (Table 3). It means that transition is dominant to transversion and other mutations. Some researchers claim that the transition is more frequently encountered in sequences than transversions, as it can provide easy tolerance from selection pressure (Aloqalaa et al. 2019). In other words, a pattern in which nucleotide transitions are favored several times over transversions is commonly in molecular evolution (Stoltzfus and Norris 2015). It is due to the
biased mutational processes within plant genomes, e.g., cytosine deamination (Lewis et al. 2016). In *Amorphophallus* and others, this case might be a loss of evolutionary potential (Gao et al. 2017a).

Information on the phylogenetic relationship is also urgent and has implications for species conservation and breeding (Flint-Garcia 2013). In this study, *Amorphophallus* revealed complex genetic relationships (Figure 1-3). Specifically, for native germplasm from South Kalimantan, Indonesia, is grouping with similar species in GenBank (Figure 1-3, red highlight). According to Fernández-García (2017), phylogenetic studies can apply in inferring species and their evolutionary history, including helping analyze species delimitation, gene flow, and genetic differentiation. Furthermore, the use of phylogenetic relationship is of current interest given its objective metrics for conservation in the past evolution history, the present genetic status of species, and management for future ones (Fernández-García 2017).

In plant breeding program, information on this relationship can use in predicting the genetic diversity of the offspring when individuals cross (Acquaah 2012). Conceptually, crossing individuals with distant relationships, the offspring may have high genetic diversity. Conversely, if the individual is a closely related cross, then the genetic is low (Acquaah 2012, Turner-Hissong et al. 2020). Hence, crossing the parent with a close relationship tends to avoid, due to the inbreeding, except in developing a new homozygous or pure-line hybrid (de Los Reyes 2019).

In conclusion, while *Amorphophallus* has a moderate level of genetic diversity, this germplasm revealed complex genetic relationships. Thus, this information is valuable in supporting the conservation and breeding programs of this germplasm, both locally and globally.

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