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Genetic Diversity of Orchids for Sustainable Floriculture: A Narrative Literature Review

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ABSTRACT

Orchids represent one of the most diverse and economically important groups of ornamental plants, with thousands of species cultivated worldwide. Their aesthetic appeal, coupled with unique genetic variation, makes them central to the floriculture industry. This study applies a Narrative Literature Review (NLR) approach to explore the genetic diversity of orchids, particularly in Indonesia, which is recognized as a center of orchid megadiversity. Literature was collected from databases such as Scopus, Lens, and Publish or Perish, focusing on genetic research relevant to ornamental development. Findings highlight the role of genes such as POH1, MADS-box, and MYB in regulating bud development, floral morphogenesis, pigmentation, and somatic embryogenesis. Advanced techniques, including CRISPR/Cas9, polyploidization, and RNA interference, enhance breeding programs and support the creation of novel hybrids with improved traits. The review concludes that orchid genetic diversity offers vast potential for sustainable floriculture, conservation, and economic growth in the global ornamental plant industry.

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1. INTRODUCTION

Orchids are one of the most popular groups of ornamental plants, with thousands of species spread all over the world. The beauty, variety of shapes, and colors of orchid flowers make it a highly sought-after plant for hobbyists and commercial customers. The diversity of orchids in Indonesia is so diverse that it is known as the world's orchid megadiversity (see **Figure 1**). This diversity is not only seen in terms of morphology but also genetics, which creates great potential for innovation in horticulture and plant breeding. As a country with the genetic diversity of several orchid species, Indonesia has the potential to be a leader in producing new varieties of cut flower orchids, such as *Dendrobium*, *Vanda*, *Arachnis*, and *Renanthera*, as well as pot plants, such as *Phalaenopsis* and *Paphiopedilum*. Currently, some orchid populations are threatened with extinction due to natural disasters and the conversion of forest areas, especially in Java, into settlements or plantations. However, due to the uneven distribution of orchids in Indonesia, orchid enthusiasts have begun to look for places that are centers of their distribution (Widiastoety *et al.,* 2010).

Technological advances have led to several solutions to overcome these problems. One of them is the utilization of the genetic diversity of orchid plants. Around the world, there is a lot of research on the genetic diversity of orchid plants, the results of which can be developed and used for profit. It takes genetic engineering with altered DNA to create transgenic plants with improved traits over their parent line (Saputro *et al.,* 2018).

Genetic variety is highly valued, particularly in orchid breeding and development, which not only increases the diversity and beauty of the species but also promotes sustainable agricultural practices and economic growth. The floricultural sector plays a significant role in agriculture by satisfying consumer demand for attractive products, creating jobs and revenue, and facilitating international trade. These are very good for orchid enthusiasts to increase economic value (Khairul-Anuar *et al.,* 2019).

Figure 1. Types of Orchids in Sleman, Yogyakarta (Source: taken by research team on 28 June 2024)

This paper reviews the genetic diversity of orchids for ornamental plant development in Sleman, Yogyakarta, Indonesia, which can be seen from several aspects, starting from the opportunities and potential of orchids, especially in Sleman, Yogyakarta. It is expected to add insight to the reader. Hence, the purpose of this review is to find out more about the genetic diversity of orchids for the development of ornamental plants in Sleman, Yogyakarta. Also, for the development of ornamental plants and where they grow, the types of orchids developed for ornamental plants, the benefits offered for crossing between orchids, and the genetic diversity benefit floriculture.

2. METHODS

This study employed a Narrative Literature Review (NLR) approach, which synthesizes research findings to provide a comprehensive understanding of orchid genetic diversity and its relevance to floriculture. The review process began with the identification of relevant keywords, including *orchid*, *genetic diversity*, *floriculture*, *breeding*, and *conservation*. Literature searches were conducted across multiple databases, such as Scopus, Lens, and Publish or Perish, complemented by open-access journal sources and subscriptions available through the National Research and Innovation Agency (BRIN).

The selection of literature followed two criteria: (i) relevance to orchid genetics and ornamental plant development, and (ii) availability of full-text articles in English or Indonesian. Reference management software (Mendeley) was used to organize and screen the retrieved documents. Each study was then analyzed narratively, focusing on genetic mechanisms, breeding methods, conservation practices, and biotechnological applications. This approach allowed the integration of diverse findings into a cohesive perspective on the role of orchid genetic diversity in supporting sustainable floriculture. We also compared with the current literature (Latip *et al*., 2023).

3. RESULTS AND DISCUSSION

Based on the data obtained from the search results about the genetic diversity of orchids for the development of ornamental plants in Sleman, then to find out more about the genetic diversity of orchids for the development of ornamental plants in Sleman Yogyakarta, Indonesia, how orchids for the development of ornamental plants and where they grow, what types of orchids are developed for ornamental plants, what benefits are offered for crosses between orchids and how genetic diversity can be useful for floriculture, it will be described in **Table 1**.

Orchids, especially in Sleman, Yogyakarta, Indonesia, play an important role in ornamental plant development. Genetic diversity in orchids is essential to improve the quality and quantity of these ornamental plants. Research has identified genes such as Phalaenopsis Orchid Homeobox1 (POH1) involved in plant development, emphasizing the importance of genetic understanding (Battistus *et al.,* 2014; Zeng *et al.,* 2020). Polyploidization has been used to improve ornamental traits in orchids, resulting in larger flowers, sturdier stems, and increased ornamental value (Takamiya *et al.,* 2014). Furthermore, genetic studies have revealed the complexity of orchid lineages, such as the genus *Dendrobium*, highlighting the challenges in establishing a consistent classification system due to morphological diversification (Rasjid *et al.,* 2023). These genetic insights are crucial for the biotechnological improvement of orchids, contributing to their significance in the floriculture industry.

Genetic research on orchids revealed various genes that have important roles in plant development, including bud development, floral morphogenesis, and somatic embryogenesis. Some of the important genes identified are *Phalaenopsis Orchid Homeobox1* (POH1), which functions in bud development and acts as a transcription factor, and DOH1 from *Dendrobium* orchids, which has a similar function (Rasjid *et al.,* 2023). Modern techniques such as CRISPR/Cas9 are used for genetic manipulation, such as inactivating the GAI gene for early flowering (Suputri *et al.,* 2024). Phylogenetic analysis was used to understand the evolutionary relationships between orchid species, and plastome analysis aided in the understanding of genetic conservation (Chen *et al.,* 2023).

The MADS-box gene family was identified as a major controller in flower development, and the ABCDE model was validated in *Phalaenopsis equestris*, showing how gene expression affects floral organs (Himani *et al.,* 2019). Genetic studies also include morphological analysis and characterization of transgenic plants for stability.

Table 1. Genetic diversity of orchids for ornamental plant development in Sleman, Yogyakarta, Indonesia.

No.	Orchid Genetics Found	Location	Orchid Latin Name	Ref.
1.	- Phalaenopsis Orchid Homeobox1 (POH1) gene identified for shoot development. - The POH1 gene aligns with a conserved domain region for the role of transcription factors. - POH1 gene modeling was performed using ColabFold and SWISS-MODEL web servers. - Phylogenetic analysis of the POH1 gene showed similarity to DOH1 from Dendrobium orchids. - Homeobox genes regulate plant development by enhancing or repressing specific genes.	- This study focuses on the in-silico analysis of the POH1 gene. - Research location/findings not mentioned.	- Orchid Phalaenopsis Homeobox1 (POH1) is the Latin name for orchids.	(Rasjid *et al.,* 2023)
2.	- The dhMyB1 gene affects flower cell shape in Dendrobium hybrida. - Direct application of dsRNA alters flower cell phenotype in orchids. - MYB genes regulate floral pigmentation and morphogenesis in orchids.	- This study focuses on the cell shape of the floral epidermis in orchids. - Direct application of dsRNA changes the phenotype of flower cells.	- Dendrobium hybrida is the Latin name for the orchid.	(Lau *et al.,* 2015)
3.	- The integration of the AtRKD4 gene in the Phalaenopsis amabilis genome is stable. - The gene promotes zygote extension and induces somatic embryogenesis. - Orchid transformants carrying the AtRKD4 gene grow normally with no change in phenotype. - The RKD4 gene is a member of the protein family RWP-RK.	- The research was conducted at the Orchid Research Team, Faculty of Biology, UGM. - Research location/findings are in Yogyakarta	- *Phalaenopsis amabilis* (L.) Blume is the Latin name for orchids.	(Perdana *et al.,* 2021)
4.	- CRISPR/Cas9 was used to inactivate the GAI gene for early flowering. - Phylogenetic clustering with related orchid species for protein structure analysis.	- CRISPR/Cas9 genome editing for early flowering in *Phalaenopsis amabilis*. - Research location/findings not specified	- *Phalaenopsis amabilis* is the Latin name for orchids.	(Suputri *et al.,* 2024)

Table 1 (continue). Genetic diversity of orchids for ornamental plant development in Sleman, Yogyakarta, Indonesia.

No.	Orchid Genetics Found	Location	Orchid Latin Name	Ref.
5.	- The KNAT1 gene is integrated into the Phalaenopsis amabilis genome for multishoot formation. - Transgenic plants produced a 45.8 kDa protein equivalent to the KNAT1 protein. - PCR analysis confirmed the transgenic plants contained the KNAT1 gene and the NPTII gene.	- This study focuses on phenotypic and molecular characterization of transgenic *Phalaenopsis amabilis.* - Research location/ findings not mentioned	- *Phalaenopsis amabilis* (L.) Blume is the Latin name for orchids.	(Saputro *et al.,* 2018)
6.	- The MADS-box gene family controls orchid flower development. - The ABCDE model was validated in *Phalaenopsis equestris* through gene characterization. - MADS-box Type I & II genes regulate different flower whorls	- This research focuses on the validation of the ABCDE model in orchids. - It explores the role of the MADS-box gene family in flower development. - Research location/findings not mentione	- *Phalaenopsis equestris* is the Latin name for orchids.	(Himani *et al.,* 2019)
7.	- Genetic transformation in orchids was achieved through the CRISPR/Cas9 system.	- Research location/findings not mentioned	- *Phalaenopsis amabilis*	(Semiarti *et al.,* 2020)
8.	- The *Aerides plastome* has 120 genes, including protein-coding, tRNA, and rRNA genes. - *Aerides plastome* size ranges from 147,244 bp to 148,391 bp. - *Aerides plastomes* show high similarity to conserved gene sequences.	- This study focuses on the phylogenetic analysis of Aerides orchids. - Research site/findings not mentioned	- Aerides Lour. is the Latin name for orchids.	(Chen *et al.,* 2023)
9.	- Molecular phylogenetics analyzed 210 Dendrobium taxa using DNA sequences. - Morphological characters in Dendrobium section revealed paraphyly and polyphily.	- This study focuses on the molecular phylogenetics of Dendrobium section. - Research location/findings not mentioned.	- Dendrobium is the common Latin name for orchids.	(Takamiya *et al.,* 2014)

Table 1 (continue). Genetic diversity of orchids for ornamental plant development in Sleman, Yogyakarta, Indonesia.

No.	Orchid Genetics Found	Location	Orchid Latin Name	Ref.
10.	- The Phalaenopsis Orchid Homeobox1 (POH1) gene was identified for shoot development. - The POH1 gene functions as a transcription factor in plant development. - The POH1 gene affects bud formation in Phalaenopsis orchids at an early stage.	Research location/findings not mentioned.	- Orchid Phalaenopsis Homeobox1 (POH1) is the Latin name for orchids.	
11.	- High-quality RNA was isolated from richly pigmented Dendrobium flowers for genetic studies. - An improved CTAB method yielded intact RNA suitable for genetic analysis.	- This study focuses on the isolation of high-quality RNA from pigment-rich Dendrobium flowers. - The improved method yielded a large amount of intact RNA suitable for downstream processing. - Not mentioned location/findings not mentioned	- Dendrobium Rubi Burma x Dendrobium Mae-Klong River. - Dendrobium Burana Jade x (Dendrobium Bertha Chong x Dendrobium Imelda Romualdez). - Dendrobium Trudy Brandt x Dendrobium Udom Blue Angel. - Dendrobium Aridang x Dendrobium Burana Sundae.	(Khairul-Anuar *et al.,* 2019)

The research site of several RKD4 gene is a member of the RWP-RK protein family. The research was conducted at the Orchid Research Team, Faculty of Biology, UGM. The research location of findings is in Yogyakarta (Perdana *et al.,* 2021). The Orchid Germplasm Collection in Boa Vista has 137 accessions. The genera *Epidendrum* and *Catasetum* are the most representative in the collection. The Brazilian Agricultural Research Corporation (Embrapa) preserves collections of ornamental plants. Embrapa has six ex-situ collections of ornamental plants. The Tropical Floral Germplasm Collection focuses on valuable native species. Brazilian Research locations of findings (de Castro *et al.,* 2022).

Phalaenopsis, Cattleya, and *Dendrobium* are popular orchid species developed for ornamental plants and the floriculture trade (Hsing *et al.,* 2016; Zeng *et al.,* 2020). *Phalaenopsis* orchids, known for their elegant appearance, are widely cultivated as ornamental plants (Saidah *et al.,* 2022). *Cattleya* orchids such as Lisa annex Lucky Strike, and Temanggung Beauty Brasco Pacto are also preferred varieties (Rasjid *et al.,* 2023). In addition, *Dendrobium* species and hybrids, such as *Dendrobium burmese* Ruby x *Dendrobium* Mae-klong River, *Dendrobium* Burana Jade x *Dendrobium* Bertha Chong x *Dendrobium* Imelda Romualdez, *Dendrobium* Trudy Brandt x *Dendrobium* Udom Blue Angel, and *Dendrobium* Aridang x *Dendrobium* Burana Sundae, are popular choices for houseplant enthusiasts (Khairul-Anuar *et al.,* 2019). These orchids offer a wide array of colors, shapes, and long-lasting flowers, making them ideal for indoor cultivation (Axiotis *et al.,* 2022).

Major genera such as *Dendrobium*, *Phalaenopsis, Cattleya*, and *Oncidium* play an important role in floriculture for their bright and attractive flowers. *Dendrobiums*, in particular, offer significant morphological diversity with species such as *D. lasianthera* and *D. antennatum*. *Oncidium* hybrids with yellow and brown flower colors and *Ionopsis* with rose flower colors add to the richness of the color palette in this group (Chang *et al.,* 2011). Breeding and research continue to develop new varieties with unique characteristics to meet consumer desires, using genetic techniques such as RNA interference (RNAi) to modify pigment and flower shape. The R2R3-MYB gene, for example, plays a role in the regulation of flower morphogenesis and pigmentation, causing variations in different flower colors and shapes. This genetic diversity not only enriches ornamental plant collections but also offers opportunities for the development of new varieties with desirable flower characteristics (Lau *et al.,* 2015).

Phalaenopsis, Cymbidium, and Golden Rain Orchid hybrids stand out for their beautiful and long-lasting flowers, each providing great economic value in the floriculture industry (Saidah *et al.,* 2022). Techniques such as polyploidization have been used to develop hybrids with improved flower and growth characteristics, showing further potential for innovation in orchid breeding. Orchid species such as *Cymbidium aloifolium* and *Dendrobium sylvanum* are also studied for their potential in ornamental plant development, with techniques such as gamma irradiation and tissue culture used to induce genetic diversity and create new varieties. Overall, the wealth of genetic diversity within *Orchidaceae* offers tremendous opportunities for the discovery and development of new varieties, increasing the attractiveness of ornamental plants in global markets and enriching ornamental plant biodiversity (Lestari *et al.,* 2018; Zeng *et al.,* 2020).

Orchids are a group of ornamental plants that have very high species diversity and are interesting to develop. Some orchid species mentioned in the data, such as *Phalaenopsis* Orchid, *Cymbidium ensifolium*, *C. goeringii, C. sinense*, *Oncidium, Dendrobium, Phalaenopsis*, and *Cattleya*, showed wide variations in terms of habitat, flower shape, color, and fragrance, which make them highly sought after by ornamental plant enthusiasts and can enhance the aesthetic value of the environment (Hsiao *et al.,* 2011; Ahmad *et al.,* 2022).

There are some orchid species for ornamental plants, there are *Cymbidium* and *Phalaenopsis*. They are very popular species due to the beauty of their flowers and ease of maintenance. Next are *Dendrobiums*, including hybrids such as Burma Ruby and Mae-Klong River, which offer charming and diverse flowers (Khairul-Anuar *et al.,* 2019). *Paphiopedilum,* known for the lady's slipper orchid and *Vanda* are also highly prized for cultivation due to the uniqueness and beauty of their flowers (Chang *et al.,* 2011). *Oncidium* 'Gower Ramsey' is one example of a valuable commercial orchid, famous in Taiwan, and Aerides were developed for ornamental purposes, having beautiful flower shapes and colors (Lee *et al.,* 2011).

Orchids developed for ornamentals include Lucky Strike attachment *Cattleya* Lisa, Temanggung Beauty Brasco Pacto *Cattleya, Phalaenopsis, Doritaenopsis*, and *Meltonia* sp. (Battistus *et al.,* 2014). In addition, the genus *Oncidium*, along with the hybrid groups *Dendrobium, Phalaenopsis*, and *Cattleya*, is important in the flower market, with a variety of species and interspecific hybrids used for pot and cut flower production (Takamiya *et al.,* 2014). 'Golden Rain Orchid' and 'Brown Orchid' of the Oncidium Hybrid Group are notable for their large inflorescences with canary yellow flowers and red-brown flowers, respectively (Saidah *et al.,* 2022). In addition, *Ionopsis*, a genus of the Oncidiinae subtribe, is known for its rose-colored flowers and large inflorescences, contributing to the breeding program of new orchid varieties (Ahmad *et al.,* 2022).

The use of genetic techniques such as RNAi and the R2R3-MYB gene has enabled researchers to develop new varieties with unique characteristics, expanding the range of orchid varieties available (Lau *et al.,* 2015). Genetic research, particularly the MADS-box gene family, has provided valuable insights into the genetic diversity and development potential of ornamental plants (Himani *et al.,* 2019.

The genetic diversity of orchids has also contributed to the development of polyploid species, which exhibit traits such as larger flowers and more compact growth forms, increasing their ornamental value (Zeng *et al.,* 2020). In addition, research into orchids such as *Dendrobium sylvanum* through gamma irradiation shows the potential for innovation in orchid cultivation, resulting in new varieties with desirable characteristics (Lestari *et al.,* 2017).

The development of ornamental plants through genetic modification techniques such as CRISPR/Cas9 opens up opportunities to create orchid varieties with altered flowering times and other unique characteristics. The ornamental orchid industry continues to grow with ongoing research and innovation, promising the development of orchid varieties. (Semiarti *et al*., 2020).

Orchid research and conservation sites are diverse, including nurseries, laboratories, greenhouses, and in vivo and in vitro conservation sites. These studies are conducted in various parts of the world, including Taiwan, Indonesia, Brazil, and Nepal, and cover topics such as phytochemical analysis, biotechnology, conservation, genetics, and ornamental plant development (de Castro *et al.,* 2022; Hsing *et al.,* 2016; Pradhan *et al.,* 2016).

As explained above, orchids are not only ornamental plants but also the subject of extensive scientific research, including genetic aspects, conservation, and technological applications such as tissue culture for maintenance and reproduction. The diverse geographical locations emphasize the adaptation of orchids in various environmental conditions and the importance of conservation in native habitats as well as in laboratories. These activities demonstrate the importance of orchids in various aspects, ranging from commercial and aesthetic interests to conservation and scientific research. This research also emphasizes the importance of techniques such as tissue culture and molecular analysis for further understanding and development of orchids and other species (Saputro *et al.,* 2018).

Crossing between orchids offers several benefits, including the creation of new hybrids with desirable traits, such as unique color, shape, and fragrance, which are highly sought after in the floriculture industry (Hsing *et al.,* 2016). In addition, hybridization can lead to the development of plants with increased tolerance to environmental stresses, larger and stronger organs, and increased ornamental value (Zeng *et al.,* 2020). Through hybridization, genetic diversity can be increased, resulting in improved growth characteristics and flower quality, making orchids more attractive to consumers (Takamiya *et al.,* 2014).

Furthermore, crosses between orchids allow exploration of genetic relationships among different species, aiding in the understanding of phylogenetic distances and genomic affinities (Lee *et al.,* 2011). The benefits are offered by crosses between species or varieties of plants, particularly orchids. Some of the major benefits identified include improving flower quality and flowering ability, which suggests that crosses can produce flowers with higher aesthetic quality and better flowering ability, hybridization results in a wide array of flower colors, meaning crosses can create new varieties with a broad color palette, offering greater visual diversity to hobbyists and cultivators, and orchid crosses offer significant genetic diversity, indicating the potential to develop varieties with new and unique traits, be it for improved disease resistance, environmental adaptation, or other desirable traits (Axiotis *et al.,* 2022; Battistus *et al.,* 2014; DaSilva, 1998).

This explains the value and potential of crosses in improving the quality, genetic diversity, and aesthetics of plants, with a particular focus on improving orchid varieties. Intergeneric crosses in orchids, which involve breeding between different genera, play an important role in developing new varieties that offer a wide array of benefits for both horticultural and commercial purposes (Battistus *et al.,* 2014). Here are some of the main benefits offered by intergeneric crosses in orchids: first is increased genetic diversity in orchids, which is vital for developing disease resistance, increasing adaptability to varying environmental conditions, and creating unique characteristics never seen before. Second, a combination of desired traits from two or more species can be combined to produce hybrids with characteristics such as unique flower color, attractive shape, pleasant scent, and enhanced vigor or resistance. Third, the creation of new varieties with enhanced aesthetic features, such as larger flower size, brighter colors, and more complex patterns, which increase commercial value and appeal to consumers. Fourth, improved resistance to diseases and pests, which reduces the need for chemical interventions in cultivation and maintains environmental sustainability (Diantina *et al.,* 2020; Hsiao *et al.,* 2011; Saidah *et al.,* 2022).

Next is the expansion of the ecological range of environmental conditions, expanding the range in which orchids can grow and thrive, both in greenhouse and outdoor settings. Sixth, innovation in the horticulture industry, creating new opportunities for orchid breeding, cultivation, and marketing. Seventh, conservation and preservation, by creating hybrids that carry genes from rare or endangered orchid species, aiding in biodiversity preservation efforts. Last, increased market attractiveness (Indraloka, 2020).

Through intergeneric crosses, breeders and scientists can continue to explore the vast genetic potential of orchids, push the boundaries of innovation in plant breeding, and enrich the world with the stunning beauty of diverse ornamental plants (Cardoso, 2017).

Orchid genetic diversity plays an important role in benefiting floriculture by offering a wide array of traits that can be utilized to breed new varieties with desirable characteristics. The diverse genetic makeup of orchids allows the development of hybrids with new colors, shapes, and fragrances, meeting the high demand in the floral industry (Takamiya *et al.,* 2014). In addition, genetic diversity enables the selection of traits such as pest and disease resistance, rapid growth, and high-quality, long-lasting flowers, improving the economic viability and competitiveness of orchids in the market (Khairul-Anuar *et al.,* 2019). Through controlled hybridization and selection of superior offspring, orchid breeders can create new cultivars that are not only visually appealing but also exhibit traits such as compact size, season-independent flowering, and resistance to environmental stressors (Ahmad *et al.,* 2022).

Genetic diversity in floriculture, particularly in orchid variety development, offers a range of important benefits that enhance the aesthetic value, hardiness, and adaptability of plants. By harnessing genetic diversity, breeders can produce orchids with more attractive aesthetic traits, including unique and novel flower colors, shapes, and patterns (Saputro *et al.,* 2018).

Polyploidization, which is one method of increasing genetic diversity, can produce plants with improved traits such as larger organ size, increased tolerance to environmental stress, and improved ornamental properties (Takamiya *et al.,* 2014).

This process expands the range of genetic diversity available for breeding, allowing the creation of new hybrids with desirable traits such as disease resistance, environmental adaptability, and attractive floral characteristics (Zeng *et al.,* 2020). The use of genetic transformation techniques, as illustrated in the development of transgenic Phalaenopsis, opens up the opportunity to incorporate desired traits directly into the plant genome, thus accelerating the breeding process and expanding the possibility of developing new varieties with desired traits (Hsing *et al.*, 2016).

Genetic diversity plays a crucial role in supporting innovation and sustainability in the floriculture industry, enabling the development of ornamental plants that are not only aesthetically appealing but also more robust and durable. Through careful breeding and the application of genetic technologies, genetic diversity provides an important tool to meet future challenges and opportunities in floriculture, enriching the diversity of ornamental plants available to consumers and contributing to biodiversity conservation (Puspitaningtyas & Handini, 2021).

Also, genetic diversity plays a crucial role in improving plant quality and resistance to diseases and unfavorable environmental conditions also contributes to improvements in flower aesthetics and quality, such as color, size, and flowering duration. Specialized genes, such as the homeobox gene POH1, play an important role in plant growth and development, including in floriculture. Genetic analysis of these genes helps in understanding their specific functions. This enables the development of new cultivars that are more attractive and have high economic value. In addition, characteristics such as rapid flowering and longer inflorescences can be improved through the utilization of genetic diversity, which is important for commercial production and meeting market demands of ornamental plants (Rasjid *et al.,* 2023).

Genetic diversity plays an important role in the development of floriculture, especially in orchid breeding. Its advantages include improved quality and quantity, disease resistance, new cultivar development, and contribution to plant breeding (Ahmad *et al.,* 2022).

Genetic diversity has significant value in the floriculture sector, especially in orchid breeding and development, which not only enhances species beauty and diversity but also supports sustainable agricultural practices and economic development (Khairul-Anuar *et al.,* 2019).

Orchids contribute greatly to the ornamental plant industry by adding value through their uniqueness and beauty. This opens up opportunities for researchers and developers to further explore the potential of orchids in creating new varieties that can appeal to the ornamental plant market. Thus, orchids become a key element in the development of ornamental plants, not only enriching biological diversity but also providing significant economic contributions to industry players (Zanello *et al.,* 2022).

Orchids play an important role in many aspects, from genetic diversity, conservation to innovations in floriculture and plant breeding. Orchids, with their extraordinary species diversity and adaptability, not only decorate the environment but also become important research subjects to develop more effective breeding and conservation techniques.

Indonesia, with its great diversity, is known as one of the world's centers of orchid megadiversity, offering opportunities as a leader in the production of new varieties of orchids, both for commercial and conservation purposes. Conservation efforts, including the registration of local plant genetic resources such as those carried out in Sleman, Yogyakarta, are important steps to protect this genetic wealth from biopiracy and ensure its continued use.

Recognition of local genetic resources, such as the initiative in Sleman, Yogyakarta, demonstrates the importance of conserving and responsibly utilizing plant genetic resources. Cooperation between research institutions, governments, and local communities in registering and protecting local varieties is an important step in controlling biopiracy and ensuring that the benefits of using these genetic resources return to the community.

Advances in orchid genetic research, including the identification of genes involved in plant development and techniques such as CRISPR/Cas9, are opening new avenues for the development of improved orchid varieties, including varieties with higher disease resistance, increased aesthetic beauty, and wider environmental adaptation. This not only contributes to the ornamental plant industry but also provides opportunities for orchid conservation, especially for endangered species.

The genetic diversity of orchids provides great potential not only in commercial and aesthetic aspects but also in conservation and sustainable development. Crosses between orchids, both intra- and intergeneric, show how genetic innovation can produce new varieties that enrich biological diversity and meet market demands. The genetic diversity of orchids not only enriches ornamental plant collections but also provides opportunities for the development of new varieties that increase global market appeal and enrich biodiversity. Intergeneric crosses, for example, show the potential to create hybrids with desirable traits, paving the way for innovation and improvement in the floriculture sector.

Orchids are an outstanding example of a natural treasure that, when managed wisely, can provide ecological, economic, and aesthetic benefits. Continued research, breeding, and conservation efforts will ensure that orchids continue to play an important role in global floriculture and biodiversity conservation.

Genetic research has paved the way for an in-depth understanding of the genetic regulation of orchid development, leading to the possibility of genetic manipulation for the development of desirable plant traits. These include disease resistance, better environmental adaptation, and improved aesthetic traits. Modern techniques such as CRISPR/Cas9 promise to revolutionize orchid breeding, enabling the creation of new varieties that can meet diverse market demands and enhance conservation efforts.

Overall, orchids symbolize a natural wonder that, when supported by ongoing research and innovation, has great potential to advance the ornamental plant industry, support biodiversity conservation, and make significant economic contributions to society. Cooperative efforts between researchers, governments, and communities are key to ensuring that these natural treasures can be enjoyed by future generations.

4. CONCLUSION

Orchid genetic diversity provides a foundation for innovation in floriculture, enabling the development of cultivars with improved beauty, resilience, and adaptability. Indonesia, as a center of orchid megadiversity, holds significant potential to lead in sustainable breeding and conservation efforts. Advances in biotechnology, including CRISPR/Cas9 and polyploidization, open opportunities for creating superior varieties while supporting biodiversity preservation.

By combining scientific research with conservation initiatives, orchids can continue to enrich global markets, strengthen local economies, and contribute to sustainable agricultural practices.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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