Technical risk control system of sustainable vanilli cultivation in Indonesia

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Abstract. Vanilla is a high-value spice product and is used as a flavoring ingredient for food and beverages, pharmaceuticals and cosmetics. Indonesia is a major producer of vanilla in the world, however the production has declined since 2017, due to the high risk in vanilla cultivation, like economic risks (fluctuations of vanilla prices), technical risks (high attack of vanilla stem rot disease) and social risks (threats of vanilla fruit theft). Hence, vanilla cultivation has a low level of sustainability. This review aims to analyze risk control systems in vanilla cultivation to improve the sustainability of vanilla production. Given that the main risk in vanilla cultivation is the risk of attacks of vanilla stem rot disease, the risk control system uses it as a reference factor, while other factors as supporting factors. The hierarchy of risk control in the vanilla cultivation system when connected with its sustainability level follows reverse pyramids of vanilla cultivation systems in open land, shade houses and greenhouses. In its implementation, to increase the continued cultivation of vanilla in Indonesia is required cultivation with the highest risk control system, although there are consequences of increased investment costs but the opportunity to achieve high productivity will be better.

1 Introduction

Vanilla is a spice that is widely used as a flavor and aroma of food and beverages such as cakes, breads, and ice cream both in the industry and household as well as ingredients in the pharmaceutical and perfume industries. According to information from [1], vanilla prices in the European market in the period 2013-2015 ranged from US$42-48, and prices in 2016-2018 ranged from US$ 195-272 per kg. The price increase occurred partly because of the increasing demand for natural vanilla due to the transition from the use of synthetic vanilla. Vanilla demand has changed significantly due to three trend changes, namely (1) the growth of demand for super premium quality ice cream containing high fat so that it requires a lot of flavoring, (2) the shifting tendency of understanding that the use of natural ingredients is better than synthetic, especially in Europe and the United States, and (3) food and beverage marketers see that globalization will continue and the many well-known global brands include vanilla extract in their product labels [2]. However, due to limited

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vanilla production, the use of natural vanilla is still very limited, estimated to be less than 1% [3].

The main producers of vanilla today are Madagascar, Indonesia, and China which according to FAO Statistics production is 3,227 tons, 2,402 tons and 662 tons per year respectively [4]. Other producing countries are Mexico, Uganda, Comoros, Papua New Guinea, Turkey, Tonga and several Asian countries such as India, Thailand and Malaysia [5]. The development of world vanilla production tends to be slow, because vanilla productivity in major producer countries such as Madagascar only reaches 150 kg / ha and is sometimes hit by cyclones so that the increase in acreage is also slow, in addition to very high price volatility [5]. In Indonesia both acreage and production tend to fluctuate [6], with a productivity of 0.38-0.77 kg/tree or an average of 0.58 kg/green pod tree with an effective population of about 2,000 trees (polyculture), the vanilla productivity is about 464 kg/ha of dry pods, although the potential can reach more than 2 tons/ha [7]. In addition, the slow development of world vanilla production is also due to the presence of root and stem rot endemic to almost all producing countries caused by fusarium oxysporum sp fungus. This fungus is in the ground making it difficult to control [8].

The increasing demand for natural vanilla that cannot be responded to by increased production shows that vanilla production faces a problem that has not been fully solved. Even experience shows that due to the increasing demand for natural vanilla there is very little that can be responded to, then the price of natural vanilla that increases again down because consumers again meet their needs with synthetic vanilla [5]. Such conditions indicate that vanilla production has not been sustainable, in the sense that production is unstable either caused by environmental factors such as disease attacks, economic factors such as price instability or other disruption factors.

The increase in vanilla price is an attraction for planters and investors in Indonesia to work on vanilla. However, vanilla businesses have very high risks, not only technical risks but also financial risks, so a strategy is needed to mitigate those risks. Prominent risks of vanilla business investment are attacks of vanilla stem rot, theft of vanilla fruit, and price fluctuations [9]. Proper handling and management of these risks is key to achieving sustainable vanilla production. Handling technical risks such as the occurrence of attacks of vanilla stem rot can be handled by the application of appropriate vanilla cultivation systems and security risks due to theft handled with security systems through cooperation and policies. Handling the risk of price fluctuations can be handled by managing the supply chain of produced vanilla products [10]. In addition, the quality of Indonesian vanilla is lower than bourbon-type vanilla so the price is about 20% lower [5].

Based on the risks inherent in vanilla business, the sustainable vanilla cultivation is more focused on cultivation that can control the attack of rotting vanilla stems that are environmentally friendly and can still achieve high productivity so that the products produced remain competitive. The choice of vanilla cultivation that can be considered is the cultivation of vanilla with a low, medium or high level of control, which is the higher the level of control in its cultivation, then the opportunity to be able to control the emergence of risk is higher as well. The consequence of cultivation with a high level of control is a high investment cost, so that by taking into account the rate of return on investment can be determined cultivation with the optimal level of control.

Handling safety risks is important in the vanilla business, especially when vanilla pods have reached six months until harvest, because it can encourage planters who are unable to handle this security disturbance (theft) to harvest vanilla pods prematurely, so that the quality of vanilla is low. What stimulates the occurrence of theft is the high price of green pods. The approach used in security that can be done is the security system of individuals, groups and social as well as a combination of the three. The consequences of individual security costs are generally highest followed by group and social. In addition, the local

government policy approach also allows to be applied especially in vanilla production areas, through the provision of certificates of origin of vanilla pods.

The most difficult to control is the economic risk of price fluctuations, since vanilla products are currently traded on international markets especially in the United States and Europe as commodities, thus facing many obstacles in market entry, high market risk, high transaction costs and low bargaining positions in sales [11]. Efforts can be made to build synergy with certification bodies of vanilla products that meet the requirements as sustainable vanilla products as well as the development of trade directly with consumers or through the options market [12].

This study aims to study the sustainable vanilla cultivation and processing system at various levels of environmental control, especially in order to control the rotting disease of vanilla stems and theft disorders of vanilla pods, which can be developed in Indonesia, as well as analyze various possible marketing systems to anticipate the occurrence of fluctuations in vanilla prices that have been the main factors that affect the sustainability of vanilla production in Indonesia.

2 Hierarchy of risk control

Vanilla (Vanilla planifolia) belongs to plants in the orchid family that propagate on trees or climbing poles using tendrils and generally grow in open areas in tropical areas (sub), although it also grows well in shaded areas, so that more controlled cultivation can be applied [13]. Sustainable vanilla cultivation can produce vanilla with high productivity and quality through the application of innovations that are environmentally friendly, efficient in the use of resources and energy and can improve social welfare [14]. As has been conveyed that the main problem faced in the cultivation of vanilla is the high risk of attacks of root rot or vanilla stem disease caused by fusarium sp fungus. which is spreading very quickly and can result in high losses. Without neglecting other factors, to realize sustainable vanilla cultivation, the control factor against root rot and vanilla stem is used as a leading factor, while other factors become supporting factors.

Hierarchically risk control in sustainable vanilla cultivation consists of cultivation with high, medium and low control where the level of sustainability is equivalent to the level of control (Figure 1). In general, vanilla planters still apply cultivation with a low level of control, so it is very prone to attacks of rotting diseases of roots and vanilla stems and the level of sustainability is also low. The application of innovation is indispensable to improve the level of control and sustainability. Innovations with moderate control levels can be applied with the use of screenhouses and high levels of control with greenhouses.

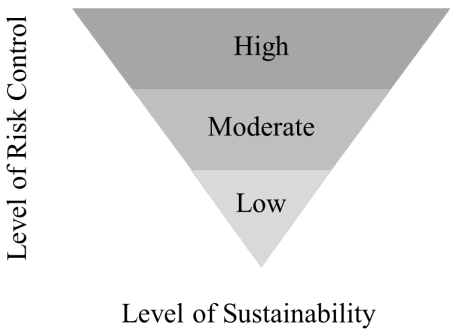

Fig. 1. Hierarchy of Risk Control for Vanilla Cultivation and Level of Sustainability

3 Implementation of technical risk control

Risk control is carried out at each stage of vanilla cultivation, which consists of three main stages, namely planting, maintenance and harvesting (Figure 2). For the implementation of risk control of each stage is used the basis of ecophysiology of vanilla plants or interaction between the biotic and abiotic environment with vanilla plants [15]. Risk control is carried out by influencing biotic and abiotic environmental conditions to make the best environmental conditions for plants to grow and develop. One of the biotic environments that are known to be the main inhibitors of the growth and development of vanilla plants is the attack of rotting diseases of roots and vanilla stems caused by fusarium sp mushrooms, so that risk control is implemented by controlling the biotic and abiotic environment in the hope that the development of fungi can be suppressed less than the adverse economic threshold [16].

The path of photosynthesis (carbon fixation) used by vanilla is CAM (crassulacean acid metabolism) where during the day the stomata closes mainly to defend itself when there is a water shortage [13]. In general vanilla in Indonesia can grow well in lowlands up to 700 m above sea level, with rainfall of 1500-2500 mm, with 3-5 dry months and gooddrainase land [7]. To produce vanilla pods with the largest levels of vanilla, the optimal humidity is less than 75% with a light of 50-55%. This means that it is necessary to adjust the light with living shade (tree) or other shade materials such as paranets to obtain the best conditions for plants. For example light settings to achieve high productivity and vanilla quality in addition to the regulation of humidity to prevent the appearance of pathogenic fungi.

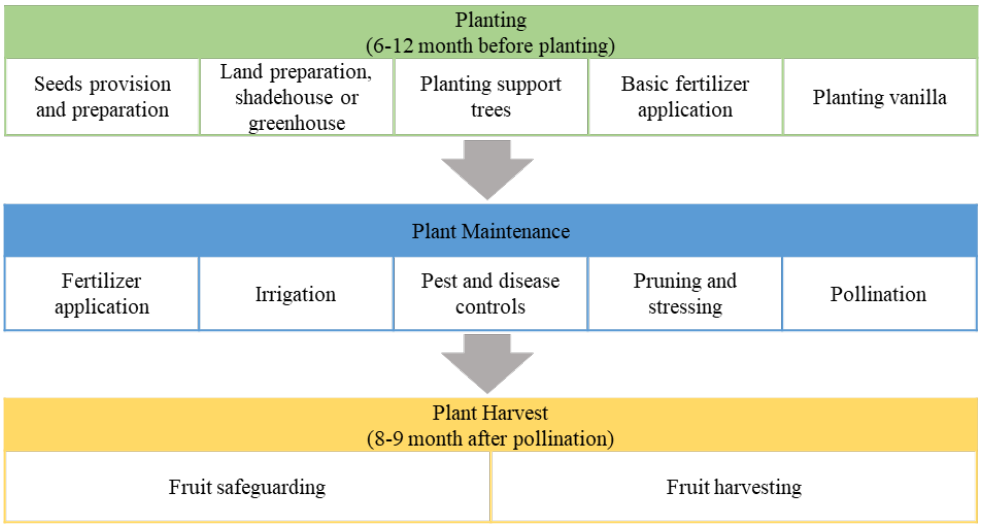

Fig. 2. Stage in Vanilla Cultivation

3.1 Planting

Vanilla planting is the initial activity of vanilla cultivation, which starts from the provision of seeds and preparation of vanilla planting sites that can be in the form of land preparation, the creation of a shade house, or the construction of greenhouses. The provision of seeds in accordance with seed quality standards (certified) becomes an important factor to achieve success in vanilla cultivation whose chances of disease attack are high. According to SNI 01-7156-2006, the quality requirement of vanilla seed is to have purity and health of 100% seed with the number of segments 5-7 derived minimun fourth segment of shoots. Given

that often the availability of ready-to-plant vanilla seeds (seeds 5-7 segments) is limited, then seed propagation should be done with available plant materials, namely the enlargement of cuttings 1-3 segments to a minimum of 5 segments [17]. The enlargement takes 6-8 months so it needs to be taken into account the time of readiness of planting time. Plant material comes from varieties that are in accordance with the planting environment to obtain maximum production and quality. For example Vania 1 and Vania 2 are suitable for development in areas with 3-4 months of firm dryness, which can produce 2.1 tons/ha and 1.8 tons/ha of dry pods with vanillin levels of 2.808% and 2.983% respectively. In addition Vania 2 is more tolerant of rotten vanilla rods [7].

Vanilla cultivation in open land is the cultivation with the highest risk, because environmental control is relatively limited that can be done, so the possibility of attacks of rotting diseases of roots and vanilla stems is relatively large. The use of shade houses can control the intensity of light that impacts the temperature and humidity of the environment, which affects the development of fungi causing rotting diseases of roots and vanilla stems. Greenhouses with available installations can be used to carry out environmental control, so the risk of pathogen attack can be suppressed.

3.1.1 Open field system

Preparation of open field system begins with soil processing that applies soil and water resource conservation technology, so that soil and water productivity can be maintained sustainably by preventing soil damage due to erosion that occurs naturally or because of treatment in cultivation [18]. Methods that can be used for soil and water conservation are vegetative (plant use) and mechanical methods (mechanical manipulation of soil and soil surface) [19]. The use of vegetative methods is very suitable, because vanilla planting requires trees as shelters and vines, while mechanical methods as a support especially for drought-sized land to suppress erosion. Soil processing is necessary to make the soil as a medium of growing and growing vanilla plants. Given that vanilla plants need loose soil with good drainage, the manufacture of mound and drainage channels is necessary on relatively flat land. On dry land it is necessary to make rorak according to the contour of the soil to reduce the flow of water so that the erosion rate can be suppressed, and minimum soil processing is required for the soil to become loose.

Vanilla is a hemi-epiphytic orchid that need tree or climbing pole to provide physical support in cultivation with a height of about 200 cm with consideration to facilitate the implementation of flowers pollination. For planting in open land is commonly used gamal tree (*Gliricidia* sp.) as a support tree, which at the same time serves as a shading plant. The use of climbing pole such as wood pole is also possible although the cost is much more expensive and can't be used as a shade for vanilla. Planting support tree began to be done in 3-6 months before planting vanilla using cuttings gamal tree with a diameter of about 3 cm [7] and height 150 cm, in order to quickly grow and able to support the vanilla plant that will be attached. If the available gamal tree cuttings are less than that size then planting should be done longer before planting vanilla.

The position of planting support trees against vanilla plants ranges is about 30 cm, the longer the segment of tendrils of the vanilla seed used the more stretched the distance of the base of the seed with their support tree. Support trees planting distance is adjusted to the desired vanilla population, which is related to the density of plants, humidity and light intensity of microclimate wich affect the possibility of vanilla stem rot disease, also the availability of labor to conduct the polynation when vanilla plant has reached the production age. The common population of vanilla is 5,000-8,000 plants per ha, the higher the population of plants the more frecuent pruning of support tree should be done especially to achieve optimal humidity and light intensity.

Basic fertilization is given to planting holes that become planting media to support the growth and development of vanilla plants and maintain support trees. Organic fertilizer needs to be given mainly to improve the physical properties of the soil such as increasing the capacity to hold water and water, in addition to increasing the availability of soil nutrients, which vanilla plants need. Organic fertilizer in principle is better when given in sufficient quantities (effective and efficient), or at least 5 kg per planting hole, given 1-2 weeks before vanilla planting.

Vanilla planting is best to use seeds with 5-7 internodes and 3 interdnodes of the base planted slightly tilted towards the support tree so that 2-4 internodes of the tip attached to the support tree. The distance between plants in row is about 75-100 cm and the distance between rows is about 150-200 cm, until obtained the desired population. Plant distance and pruning of support tree in open land is a method that can be used to adjust humidity and light intensity despite its low accuracy.

3.1.2 Shadehouse

Shade house is a simple or semi-permanent plant cultivation house construction on a field that use artificial shade to substitude natural shade, which is accompanied by a control system against internal environmental factors in a very limited manner, to adjust to certain environmental conditions that are most needed plants in order to grow and develop optimally. Simple shade house construction is a construction that uses a skeleton of bamboo or wood, while a semi-permanent one uses a lightweight steel frame, using a patron from a paranet.

Environmental factors that can be controlled in shade houses are the level of lighting and airflow, which are also determinants of air temperature and humidity. The level of exposure and airflow is controlled by adjusting the exposure level of the paranet used. Vanilla planting in shade houses is an effort to provide optimal lighting (according to the needs of plants) as well as temperature and humidity settings to reduce the risk of growing fusarium sp mushrooms, which are the cause of vanilla stem rot.

Vanilla planting in a simple shade house generally uses a support tree or pole (wood or other materials) with an individual support tree system (one support tree for one plant), but because support tree can be a patron then the wooden pole is better. In semi-permanent shade houses generally apply line support system with wall encroachment of woven wire filled with coconut fiber, in addition to can also be used wood pole (individual system). When using individual systems either support tree or pole then land preparation such as on open field using mound and drainage on flat land and the use of individual rorak for sloping land. When using a jajar system, the use of planting media made based on plant needs can be given on each line with the addition of drainage to avoid puddles. The density of vanilla plants in shade houses covering an area of 200 m^2 ranges from 150-210 stems, with a minimum line distance of 125 cm and in rows of 75 cm for those who use support tree, and those who use pole, the distance in rows can be reduced to 50 cm, so that the density of plants between 210-320 stems.

3.1.3 Greenhouse

Greenhouse is a semi-permanent or permanent plant cultivation house construction on a common plot of land with an area of about 100-300 m2 accompanied by a control system against environmental factors in a particular greenhouse on a limited basis to create an environment that suits the needs of plants in order to grow and develop optimally. Roof coverings on greenhouses can be used glass, UV plastic or other transparent cover materials. Controllable environmental factors such as lighting intensity, airflow,

temperature, humidity, groundwater flow, and soil moisture. Through the regulation of more environmental factors than shade houses, it is expected that the use of greenhouses can create a more optimal growing and developing environment of vanilla plants, especially can further reduce the risk of attacks fusarium sp mushrooms and other diseases.

Automation of greenhouse environmental control systems can be installed to obtain an optimal plant growing environment in a more precise manner. In addition, it can be equipped with a system of monitoring environmental changes that occur continuously. Fully automated and efficient control systems can be installed using Internet of Things (IoT) innovations, where control systems in agriculture can be grouped into three categories namely farm monitoring, automated irrigation systems, and pest monitoring systems [20].

Artificial support tree in the greenhouse can use poles (individual systems) or walls that can be used as a place for vanilla to propagate. In general, poles or walls are wrapped or coated with coconut fiber or palm oil with a wire webbing binder, with a height of about 200 cm and on the top is installed a place to polish the vanilla rod. The density of plants for greenhouses with an area of 100 m^2 ranges from 150-200 stems, with a minimum line distance of 100 cm and in rows of 50 cm.

3.2 Plant maintenance

Maintenance of vanilla plants consists of the maintenance of immature plants for about two years after planting, and the maintenance of productive plants carried out in the third and following years. In general, the maintenance activities of immature and productive plants are the same, with addition of flower pollination on productive plant phase and maintenance activities that follo with the plant development. However, maintenance activities can be different depending on the cultivation sistem used, such as open field system with low level risk control, moderate level risk control on shade house and high level risk control on greenhouse cultivation system.

Fertilization is done with the principle of fulfilling the needs of nutrients as much as possible by adding nutrients that are already available in the soil so that the use of fertilizer is effective and efficient. The need for plant nutrients in general increases in line with the development of plants. In addition fertilization on open field and shade houses system will be less eficiensy than fertilization on the greenhouses, that will lead to sustainability production of vanilla on greenhouse because there is no loss nutrient to environment [13].

Vanilla plants can grow and develop well on well-drainated soils, and are less resistant to dry conditions. Control of water availability on open land and shade houses can be done by creating drainage channels to channel excess water during rain and watering during the dry season, especially during the development of vanilla fruit that occurs in the dry season. The availability of water and the water loss on the greenhouse system can be minimize to zero loss of water because of the system that can be controlled [13].

Pest and disease controls on vanilla production is one of the maintenance activities that will affect the success in vanilla cultivation. One of the disease that have the high risk in the production of vanilla is stem rot disease [9]. Open field and shade house system that mostly depends in natural resources and climatic condition have the highest risk of stem rot disease attack, because there is a minimum control on enviromental like humidity and light intensity. Environmental conditions especially temperature and humidity are the determining factors for the growth and development of pathogens, especially fungi [8]. Although on the shade house system environmental conditions such as humidity and light intensity can be controlled with the use of artificial shade, the control is still very limited.

In contrary vanilla production in a greenhouse allows the control of resource and many enviromental conditions, such as temperature, humidity, CO_2 and light intensity [13]. Fully

control of climatic conditions and resource (fertilization) can lead to optimize the vanilla production and quality.

3.3 Harvesting

Harvesting process is an important stage that will affect the quality of production [21]. In vanilla cultivation, harvesting can be done after the fruit is formed from flower pollination with a time span of 8 to 9 months [22]. The quality of vanilla fruit is very dependent on the age of harvest [7]. When the vanilla fruit colour is dark green and a little yellow at the tip is a characteristic of the fruit and the best time to harvest [23].

Harvesting can be done by cutting a series of vanilla fruit on each segment using hand shears, and placing the fruit that has been harvested in a sterile place and stored in a shady place with good air circulation. The shoots that have produced can be pruned, because in general these shoots will not produce again on the internodes that have produced flowers unless the buds are maintained [22].

In vanilla production, one of the highest risk is the vanilla fruit theft [9], mainly towards harvesting process. Farmers that use open field and shade houses system have the highest risk due to vanilla fruit theft because of the limitited resources (funding and labor) to minimal the risk, so risk control for open field and shade houses system is still relatively low. The risk of vanilla fruit theft can lead to decrease quality of the vanilla, because one of the solutions to minimal the risk, farmers harvest vanilla fruit early. Vanilla fruit that harvested prematurly can reduce the aroma produced (quality) [23].

Vanilla cultivation that use greenhouse system have the lowest risk from vanilla fruit theft. Besides being used to create optimal environmental conditions for vanilla plant, greenhouse can maintain risk from vanilla fruit theft because it is building with closed space that usually in small area. That conditions can create a better security system with minimal security personnel. The use of greenhouse is one of the highest risk controls to minimize the risk caused by the vanilla fruit theft, so as to increase the level of sustainability of vanilla cultivation.

4 Conclusions

Vanilla is a high-value spice product and is used as a flavoring ingredient for food and beverages, pharmaceuticals and cosmetics. Indonesia is a major producer of vanilla in the world besides Madagascar and China, although Indonesia's vanilla production has declined since 2017. This is due to the high risk in vanilla cultivation, both economic risks due to fluctuations in high vanilla prices, technical risks due to the high attack of vanilla stem rot disease and social risks due to the many threats of vanilla fruit theft. The high risk resulted in vanilla cultivation has a low level of sustainability.

The level of sustainability of vanilla cultivation seen from the hierarchy of risk control will be related to the risk control system in vanilla cultivation. The higher the risk control system implemented, the higher the level of sustainability of vanilla cultivation itself. The vanilla cultivation system in the greenhouse is a form of high-level risk control system, which will increase sustainability of vanilla cultivation. Practically, to increase the sustainability of vanilla cultivation in Indonesia, the high-level risk control system is needed, Although it requires a high investment, but the opportunity to optimize the production and quality of vanilla will be better.

References

1. FAO, (2020).
2. R. J. Brownell, *Handbook of Vanilla Science and Technology*. **223** (2019).
3. N. J. Gallage and B. L. Møller, *Biotechnology of Natural Products.* **3** (2017).
4. C. Watteyn *et al.*, *Ecosphere*. **11**, 1 (2020).
5. K. M. Menz and E. M. Fleming, Economic prospects for vanilla in the South Pacific, (Canberra :Australian Centre for International Agricultural Research (1989).
6. O. Chandra Dewi, Brawijaya (2016).
7. A. Kartikawati and R. Rosman, *Sirkuler Inf. Teknol. Tanam. Rempah dan Obat* (2018).
8. J. Hernández-Hernández, *Handbook of Vanilla Science and Technology*. **27** (2019).
9. S. Wulandari, in *E3S Web of Conferences*. **232** (2021).
10. C. S. Tang, *Int. J. Prod. Econ.* **103**, 451 (2006).
11. V. Borbolla-Pérez, L. G. Iglesias-Andreu, M. Luna-Rodríguez, and P. Octavio-Aguilar, *Environ. Dev. Sustain.* **19**, 2421 (2017).
12. M. Rusnáková, *Agric. Econ. (Czech Republic)*. **61**, 149 (2015).
13. F. Van Noort, *Handbook of Vanilla Science and Technology*. 157, (2019).
14. R. Guo *et al.*, *Resour. Conserv. Recycl.* **153**, 104580 (2020).
15. M. N. V Prasad, *Plant Ecophysiology* (1996).
16. M. Arifin, *Ipt. Tan. Pang.* 98 (2012).
17. P. N. Supardi and S. Seda, *AGRICA*. **3**, 86 (2010).
18. Karyati and S. Sarminah, *Teknologi Konservasi Tanah dan Air* (2018).
19. A. A. Idjudin, *J. Sumberd. Lahan*. **5**, 103 (2017).
20. N. P. Mohanty, D. Singh, A. Hota, and S. Kumar, in *International Conference on Communication and Signal Processing*, 235 (2019).
21. C. C. de Guzman and J. S. Siemonsma, *Plant Resources of South-East Asia* (1999).
22. J. Hernández-Hernández, *Handbook of Vanilla Science and Technology* (2019).
23. J. T. G. Straver, *Plant Resources of South-East Asia* (1999).