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# Candlenut (*Aleurites moluccana*) Seed Export Treatment Using Nanotechnology with Microbial Antagonist Secondary Metabolites as a Preventive Drug: A Review

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**ABSTRACT**

Candlenut seed quality is an important aspect of plantation commodities used to export from Indonesia. But, this commodities have many problems with export processing, such as infection and destruction by pest microorganisms, especially caused by quarantined pest microorganisms. To enhance germination, beneficial microbes that produce secondary metabolites produce biostimulants, such as plant growth enhancement, increased nutrient uptake, and improved plant resilience to pest stress. This review highlights the most viable alternative to seed treatment for preventive quarantine using nanotechnology, such as nanomaterials based on secondary metabolites of candlenut seeds. Secondary metabolites from microbial antagonists are beneficial for increasing plant productivity and production, but seed production is still not widely known and performed. In addition, nanoparticles can be used to absorb nutrients from secondary metabolites that must be protected before export inspection by a quarantine agency. The results are generally positive, but more scientific information needs to be acquired for candlenut crops and under variable quarantine export inspection to understand the effects of seed treatments.

## INTRODUCTION

Indonesia is a country with suitable environment for candlenut cultivation (Susilowati et al., 2020). Candlenut growing conditions are at an altitude of 0-700 meters above sea level with rainfall between 640 and 4290 mm. In addition, the age and productivity of this tree can reach 60 years and produce 80-kg seeds per tree. This is why candlenut trees can grow and develop quickly under various soil textures. The Ministry of Environment and Forestry also nominates candlenut as a community forest plant (Shintawati et al., 2021). Based on their habitat, candlenut plants are distributed throughout Indonesia, including East Nusa Tenggara (NTT), South Sulawesi, Aceh, North Sumatra, and Gorontalo (Putri and Jamilah, 2020), with the largest production being in the Sulawesi and Sumatra provinces. It is proven that there are 7 sub-districts, namely Monoglot, Timbang, Tantalite, Tompobulu, Camba, Cerana, and Mallawa sub-districts, and there are 3 sub-districts with the highest candlenut production, namely Cerana, Camba, and Mal-

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lawa sub-districts. In addition, candlenuts are critical for several industries and have many benefits that can be exploited by some people (Samsu et al., 2022).

Candlenut (*Aleurites moluccana* L.) is a functional plant and has many benefits. The function of this plant by the people of Indonesia is used as a seasoning in traditional food recipes (Tarigan et al., 2024), as a traditional medicinal ingredient that is effective for health, and as a raw material for biofuel production (Wonggo et al., 2023). Based on this information, many Indonesians use candlenut seeds as a seasoning, but the amount of domestic production is still relatively low compared to national and international market demand. This condition causes price fluctuations when production is hampered, which can be harmful to farmers. In some cases, the price of candlenut seeds fluctuates between IDR 19,000/kg and Rp 25,000/kg because farmers cannot ensure price stability during marketing (Moruk et al., 2021). In addition, a decrease in candlenut production will also have an impact on the sustainability of exports or can harm the country's foreign exchange (Putri and Jamilah, 2020).

Agricultural export commodities that are profitable for foreign exchange are plantation crop products. However, plantation products have not significantly increased economic value. This is because plantation products are either unprocessed or middle-level products. Based on this, concrete evidence can be found from the production of plantation products such as oil palm and rubber. (Dahiri, 2022). In addition, candlenut is also a plantation product that has been exported although it still has some shortcomings in its production process. This commodity has been exported to several countries, such as Saudi Arabia (Khalish, 2023), Singapore, Hong Kong, and Europe (Parwati and Suparno, 2017). In practice, this commodity has several problems that become barriers, one of which is plant pests organisms (Junaid and Gokce, 2024).

Plant growth practices are grown from seeds up to 90% and are a vital input for sustainable agriculture in terms of productivity and production (Pereira et al., 2021). Healthy agroseed industries must produce healthier, more viable, and vigours seedlings, and contributing. However, seed quality is reduced by seed-borne pathogens or broken by insect pests and other pests (Kumar and Gupta, 2020). This can lead to abnormal seed dormancy, non-viability, and impaired water absorbedness (Shelar et al., 2023). In addition, These problems can lead to damage generally caused by pests and plant pathogens (Kumar and Rathor, 2020), which makes the export process more difficult (Sathyanarayana and Latha, 2016). Therefore, agricultural commodities to be exported must go through an inspection process by a quarantine agency before being shipped or received by an importer (Octoraningtyas, 2024).

Plant quarantine in each country has various regulations for inspection and preventive treatment to protect food safety. Quarantine is also a regulator that seeks to prevent the introduction of pests into other areas where they do not exist through import and export controls. This means that agricultural commodities such as plants, seeds and planting materials must be quarantined to prevent the spread of diseases and pests. Quarantine safeguards the country's borders and to make decisions on product entry permits, such as export and import activities. Another purpose of quarantine is to completely block the movement of biological materials. The government also has regulations to destroy plants that are detected to be harmful, such as pests or pathogens (both introduced and native) that are prohibited from being distributed throughout the country (Kumar and Vishwakarma, 2018). In several cases, agricultural commodities to be exported do not have an approval entry permit from the quarantine regency because they are proven to be carriers of pathogens and pests. Another example in this case is papaya rings spot potyvirus (PRSVP) on papaya plants, which have a distribution area in North Sumatra, has been reported and categorized as an A2 quarantine pest (Ministry of Agriculture, 2020; Tasrif et al., 2021). Meanwhile, chemical seed protection is the best solution because it can have a negative impact on the environment. In addition, losses for farmers remain high because they are expensive, harmful to health, and can increase resistance to seed pathogens (Vojvodić and Bažok, 2021). An ecofriendly alternative is to use organic compounds from secondary metab-

olites of microbial antagonists (Calvo et al., 2020).

Secondary metabolites are the metabolic products of microorganisms that are formed by abiotic stress (Ullah et al., 2020) or compounds that serve as defense against pathogen infection (Pawar et al., 2023). In addition, secondary metabolites of microbial antagonists contain bioactive compounds that can be preventive materials against insecticide entomopathogenic production (Maharana et al., 2022). Although the advantages of secondary metabolites to protect plants are numerous, their use requires support to deliver nutrients to plants from other compounds, one of which is by using nanomaterials (Pulizzi, 2019).

Nanotechnology has made various products more efficient than before. This approach has been applied to agriculture systems to improve the efficacy of various materials such as pesticides, fertilizers, and nutrient uptake to plant derivatives (Kah et al., 2019). In other areas, such as increased penetration and coverage of the target market in agriculture (Li et al., 2021). This nanomaterials was applicate to seed treatment and provide a good effect on germination and seedlings growth (Ratnikova et al., 2015). Therefore, crop protection using nanomaterials for seed treatment, including of candlenut seeds, is necessary to improve the supported export quality of candlenut crops in Indonesia, and this will be discussed in this review.

## CANDLENUT-SEED QUARANTINE

### *Quarantine Procedural for the Treatment of Candlenut Seeds*

Candlenut plant quarantine conducted in Indonesia is similar to plant quarantine activities in general. Before that, this scope is about the pre-export quarantine process of candlenut seeds. In general, exporters must conduct several processes to cultivate candlenut before obtaining a license certificate for export from the quarantine agency. It maintains the quality of agricultural products and plant health. A process carried out is sanitation and phytosanitary (SPS) measures. These measures are based on scientific principles and risk assessment to protect the agricultural industry from pest threats (Tasrif et al., 2021). In terms of the steps before candlenut seed exported such as (Mishra and Singh, 2023):

1. Field inspection: Plant seeds are regularly checked for disease-infected plants, weeding, and other weeding practices. Plant must meet the requirements of the importing country.
2. Inspection of seed lots: Seed lots are thoroughly inspected for the presence of microorganisms and properly cleaned before export. Samples must meet the requirements of the importing country.
3. Seed treatment: The seed must have been treated for the presence or absence of pathogens and well cleared before export. Seed samples should meet the requirements of the importing country.
4. Phytosanitary certificate: Certification of phytosanitary issued by the exporting country for plant health materials are transported along with the seeds based on the international plant protection convention.

### *Quarantine Plant Pests and Pathogens on Candlenut Plant*

The Indonesian Ministry of Agriculture has been published about 830 species that have detected and classified as quarantine pests. That quarantined pests such as insects, fungi, nematodes, bacteria, mollicutes, viruses, weeds, mites, slugs, and snails that potentially could destroy and spread out to Indonesian territory. The percentage of this plant risk is 33% for insects, 18.8% for fungi, and 9% for nematodes, and the lowest is 2% for mollicutes (Tasrif et al., 2021). The data of quarantined pests that are potentially spread throughout Indonesia are shown in Table 1.

Based on the Decree of Indonesian Ministry of Agriculture No. 51/Permentan/KR.010/9/2015 of 2015, describes types of Pest Quarantine (PQ) categories in several classes, such as A1 class and II and categories A2 class I and II at Host, Carrier Medium, and distribution area of the pest quarantine. That class is the mean where A1 categories on PQ are species that have not yet been found in Indonesia territory, and A2 is categorized if PQ

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Table 1. List of pests that should be alerted to in Indonesia

| Quarantine Pest Group | Number of Species *) | Total Percentage (%) |
|---|---|---|
| Insects | 274 | 33.0 |
| Fungi | 155 | 18.8 |
| Virus | 143 | 17.2 |
| Bacteria | 68 | 11.0 |
| Nematodes | 76 | 9.0 |
| Weeds | 41 | 6.0 |
| Mites | 30 | 5.0 |
| Snails and Slugs | 31 | 4.0 |
| Mollicutes | 12 | 2.0 |
| Total | 830 | 100.0 |

Note: *) According to data from the Indonesian Ministry of Agriculture (Decree Number 25 of 2020).

already exists in Indonesia but the amount of them is limited to a certain area. Then, classes of this category such as class I and II mean that class I is a type that can not be eliminated by treatment, and class II is a type that can be eliminated by treatment while the pest is already exist in Indonesia (Ministry of Agriculture, 2015).

According to the data, candlenut plants are also under several pest quarantine that can inhibit the exporting process. Several quarantine pests were found that broke the candlenut seed and damaged it. Pests quarantined such as *Bactrocera psidii* (Frogg.) were categorized as group II and found in fruit and planting media from New Caledonia, *Pseudocercospora aleuritis* (I. Miyake) Deighton, which have two sex types were categorized as groups I and II (I: if medium not processed and II: if medium is processed) and found in leaves from Asia, that is, China and Oceania, such as Tonga, Cook Islands, and New Zealand (Ministry of Agriculture, 2015). In other cases, the insect

Candlenut seed export products are potentially found under an insect quarantine on post-harvest pest categories caused by imported products. Previous reports have described *Oryzaephylus surrinamenensis* and *Carphophilus dimidiatus*. Pests found in imported commodities from Timor-Leste passed to the agricultural quarantine agency of the Mota'ain District of Belt. In this case, the plant insect pest is already existence in Indonesia, especially on Java Island, for *C. dimidiatus* and *O. surrinamenensis* is not already but it is a cosmopolitan insect, especially on stored products (Handayani et al., 2019).

In addition to insect pests, candlenut is also potentially infected by seed pathogens. This is because candlenut seeds are damaged during the production process, especially during the post-harvest process. Because of that, the candlenut seed will crack or break, and they are easily infected by fungal pathogens. In addition, climate factors have the potential to increase fungi infection. That fungal pathogens included *Aspergillus flavus*, *A. niger*, *A. wentii*, *A. tamarii*, *A. rubrum*, *A. chevallieri*, and *P. citrinum* (Putri and Jamilah, 2020). However, to decree of the Indonesia Ministry of Agriculture that is not categorized as a pest quarantine or not found as new pathogens (Ministry of Agriculture, 2015). The distribution of fungal pathogens can be seen on Figure 1.

## MICROBIAL ANTAGONIST SECONDARY METABOLITES FOR SEED TREATMENT

Microorganisms have various metabolic processes that are produced by their metabolism. That metabolic such as primary metabolites and secondary metabolites. Secondary metabolites are produced during microbial metabolism based on primary metabolism and are channeled through systematic metabolic pathways for synthesis (Maharana et al., 2022). Microorganisms possessing secondary metabolites are commonly used as biological control agents to reduce pathogen infections and pest attacks in plants. Secondary metabolites have

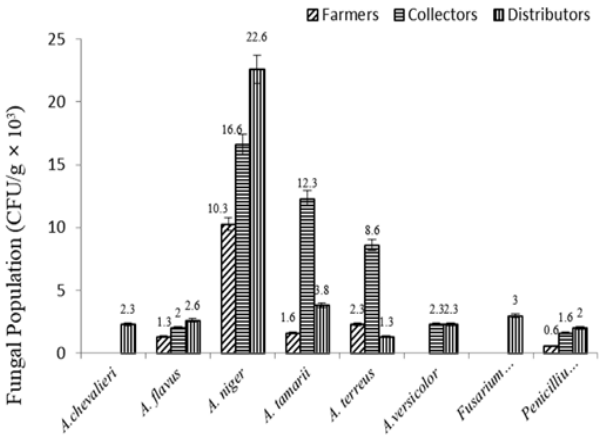


Figure 1. Fungal population found in candlenut in the distribution chain

been proven to be able to control plant diseases, such as in a study that tested two secondary metabolites of *Trichoderma harzianum* isolates toward vascular spot disease in cocoa seedlings, which was significantly more resistant to this pathogen compared to control and fungicides. In addition, the raw secondary metabolites can form phenolic compounds on cacao seedlings, which is beneficial for plant resistance (Soesanto et al., 2019).

Accordingly, potential secondary metabolites are also utilized for seed treatment to support sustainable agriculture and trading needs (Pereira et al., 2021). Generally, seed treatment involves two techniques: seed coating and seed priming. However, in various studies conducted by microorganisms to seed treatment on pre-sowing but that do not induce any changes within the seed, and active materials provide advantages for seed germination and seedlings growth. On the other hand, this treatment can also have a biostimulatory effect by influencing germination and seedlings growth several crops (Cardarelli et al., 2022). It is different from seed coating, which involves water coating or special treatment that can help the imbibition process to activate DNA repair and antioxidant activity (Waskow et al., 2021). In this case, secondary metabolites were categorized by hormonal, biological, and matrix priming during seed treatment before export to various countries (Pawar and Laware, 2018).

The seed treatment for candlenut seeds is matrix priming based on secondary metabolites. This is caused by seed characteristics that have a hard shell that can inhibit $O_2$ and water from inhibiting seed germination. In several studies, abnormal seed growth and low vigor were observed during the germination process. Low vigor is caused by several factors, such as physiological, cytological, and microbial infection, during storage (Susilowati et al., 2020). According to seed characteristics, secondary metabolites must be delivered by nanomaterials that can increase germination.

## NANO TECHNOLOGY IN SEED TREATMENTS

Nanotechnology is beneficial to agricultural production, such as in seed treatment, to increase export changes. This can deliver several materials to plant cells and affect the efficacy and efficiency of the product. In this case, nanomaterials can be a new technology for seed treatment, especially for seed priming, or can be called seed nano-priming. This benefit to be a seed priming material is that it can employ substances like nutrients, hormones, or biopolymers that are adsorbed on the seed. The nanomaterial that was demonstrated was carbon nanotubes that can be taken up by tomato seeds. Many materials that can be used for this nano-seeding include silver, iron oxide, iron, zinc oxide, silicon, zinc, titanium, chitosan, gold, manganese(III) oxide, iron(II) sulfide aqua, copper, carbon tubes, platinum, chitosan guar, turmeric, multi-walled carbon, molybdenum, lignin, biochar, cobalt, nano-pyrite, and mesoporous silica nanoparticles (Pereira et al., 2021).

The potential of nanoparticles applied to seeds will be considered in two groups: active nanoparticles and sustained release nanocarrier systems. Active nanoparticles that have a causal such a biological effect act as stimulants and provide extended release of this compound over time (Camara et al., 2019; Kumar et al., 2020; Shakiba et al., 2020). Polymer nanoparticles have other potential as an active system for seed nanopriming. These systems can be sustained with substances including pesticides, fertilizers, biological compounds, and even nanoparticles. Many products that use nanoparticles to seed priming can be loaded into nanocarrier systems, including biological activities (Pereira et al., 2021).

## CONCLUSION

Since candlenut seeds use seed treatment in other processes before export, inspections can be completely inspections caused not to infections by pathogens. The based materials can be used for seed priming on candlenut seed is antagonist microbial secondary metaolites for supporting their seed growth and germination. In addition, nanomaterials can also be delivery materials or carriers that take bioactive compounds from secondary metabolites to inside of the candle seeds.

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