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Identification of Different Host Plants in Commercially Grown Sandal Wood (*Santalum album*) Plantations in Sri Lanka

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Sandalwood (Santalum album) is an obligatory parasite plant that needs an adequate host to survive. Primary inpot hosts, intermediate hosts, and long-term (secondary) hosts are the three stages of parasitism which have so far been recognized. The success of the establishment and survival of sandalwood plants in the field depends entirely on the other woody plants that could serve as hosts. Through root associations known as haustoria, which are vascular connections between the roots of sandalwood and its host plant, sandalwood obtains certain supplements from its host plant. Trees contribute to its growth. Thus, this study was conducted to identify intermediate and long-term (secondary) host plants in eight different commercial sandalwood plantations, which belong to Sadaharitha Plantations, representing five districts in Sri Lanka. Identification of host plants was made by carefully observing the presence of nodule-like haustoria in the root system and the physical connection between host roots and sandalwood roots. A total of 21 host plant species, namely: Sesbenia grandiflora (Kathurumurunga), Acacia acuminate (Acacia), Clitoria ternatea (Katarolu), Lantana camara (Gadapana), Leucaena leucocephala (Ipil ipil), Azadirachta indica (Neem), Crotalaria juncea (Sunn hemp), Imperata cylindrica (Iluk), Achyranthes aspera (Karal sabo), Tectona grandis (Teak), Coccos nucifera (Coconut), Vernoina zeylanica (Pupula), Tithonia diversifolian (Wild sun flower), Vigna unguiculata (Cowpea), Camonea umbellate (Madu wel), Ipomoea pestigridis (Diwi pahuru), Musa spp (Banana), Gliricidia sepium (Gliricidia), Passiflora foetida (Pada), Grewia orientalis (Wel Keliya) were identified as intermediate or long-term host plants. Long-term further studies are needed to evaluate their comparative effeteness as host plants before recommending them as host plants for commercial-scale sandalwood plantations.

Keywords: Sandalwood, haustoria, host plants, Sri Lanka

Sandalwood (*Santalum album*) is an evergreen semi-parasitic plant associated with old Indian culture and tradition, which has high economic worth due to its aromatic heartwood (Brown et al., 2022). According to

Flora and Fauna Act (1964), as amended by the Fauna and Flora Protection Amendment Act No. 22, 2009, sandalwood is a protected species in Sri Lanka (Konasinghe, Seethawaka, 2021). Around 18 different varieties of sandalSHORT COMMUNICATIONS

wood is a protected species in Sri Lanka (Konasinghe, Seethawaka, 2021). Around 18 different varieties of sandalwood are found in the genus *Santalum*, including S. *freycinetianum*, S. haleakalae, S. ellipticum, S. peniculatum, S. pyrularium, S. involutum, S. boninese, S. insulare, S. austrocaledonicum, S. yasi, S. macgregorii, S. accuminatum, S. murrayanum, S. obtusifolium, S. lanceolatum, S. fernandezianum, S. salicifolium and S. spicatum (Subasinghe et al., 2013).

Sandalwood is native to Southeast Asia and Southern India. Between 30 degrees N and 40 degrees S, from Indonesia in the west to Juan Fernandez Island in the north to New Zealand in the south, is where the sandal family is found worldwide (Choudhary, Chaudhary, 2021). Since 2010, commercial-scale sandalwood cultivation has gained popularity in Sri Lanka in several climatic zones (Nakandalage et al., 2021). Sandalwood prices are relatively high because of the enormous disparity between supply and demand. However, the area under sandalwood trees is rapidly shrinking due to threats from illegal harvesters and difficulties in cultivating in new locations. Therefore Accordingly, the private sector plantation companies are paying more attention to commercial-scale cultivation, particularly in countries like, and there has been a recent trend in the creation of sandalwood plantations in Australia, India, Sri Lanka, China, and Fiji (Bapat, 2021).

This species can grow up to 12 to 15 m in height and is a partial root parasite.

Sandalwood is an obligatory parasite plant that needs adequate hosts for survival. Forthe successful establishment of S. album plantations, three stages of parasitism have been recognized. These are primary in-pot hosts, inserted into a pot containing a seedling during nursery propagation; intermediate hosts, which link the nursery and the field; and long-term (secondary) hosts. The success of the establishment and survival of sandalwood plants in the field is entirely dependent on the host of other woody plants, which could serve as host plants as they. Sandalwood plant obtains certain supplements from its host plant through root associations (Subasinghe, 2022).

All the sandalwood species are identified as obligate wood hemi-parasites which mean they absorb certain nutrients such as phosphates and nitrates from the host trees via root connections called haustoria (Subasinghe, 2022). Known as haustoria, which are vascular connections between the roots of sandalwood. It has been reported that seedlings grow seedlings growing with host plants have better plant water status than the others, and Sandalwood tree with the host has shown a significant reduction in water potential after the removal of the host plant. Therefore, it is apparent that, according to the studies, host plants impact the absorption of water and mineral nutrients by sandalwood plants and tree seedlings (Rocha, Santhoshkumar, 2022). According to D. Srikantaprasad study, host plants provide the N, P, and K that sandalwood trees need through haustorial linkages. One of the things

that makes a host more suited is its decreased cation exchange capacity. The haustoria formed by sandalwood on the roots of different hosts were poorly correlated with host quality (Srikantaprasad et al., 2022). Sandalwood grows with various associated, and possibly host, species. Associated species include Acacia sp., Casuarina sp., and Calophyllum sp (Nakandalage et al., 2021). The Heartwood of the sandalwood is recorded as the most valuable which vields part, fragrant sandalwood oil. In India, sandalwood and its oil were among the first items traded, along with spices and silk, to Middle Eastern and other countries (Gao et al., 2021).

Sandalwood plantations should be kept clean by complete slashing. To prevent the host from overshadowing the sandalwood plant, it should be kept in reasonable condition through pruning. It is advised to use 50% of the host's crown (Sundararaj et al., 2019). Most sandalwood tree-host interaction studies have been done in the seedling stage. Only a few research studies have been conducted for long-term (secondary) and intermediate hosts (bridging nursery and field) in fieldgrown conditions. Thus, this study was conducted to identify intermediate host eight different commercial plants in sandalwood plantations in Sri Lanka.

MATERIALS AND METHODS

The study was carried out during the South-west monsoon from July to September 2022 in commercially grown sandalwood plantations which belong to Sadaharitha Plantations (Pvt) Ltd. The study was conducted in five districts covering a total land area of about 400 ac with approximately 80000 plants.

Plantation experimental sites of the sandalwood

1. Tangalle plantation.

Tangalle plantation is located in the Hambantota district, Southern province, and the land area of the plantation is 106 acres. The elevation is 29 m in the low country intermediate zone (IL1b). The annual temperature is 31°C, and the annual rainfall is 1 410 mm.

2. Godigamuwa plantation.

Godigamuwa plantation is located in the Hambantota district, Southern province, and the land area of the plantation is 30 acres. These sandalwood trees were planted in 2013 and 2016.

3. Moratuwawala plantation. Moratuwawala plantation is located in the Hambantota district, Southern Province. The land area of the plantation is 50 acres. These sandalwood trees have been planted in 2011, 2012 and 2016.

4. Beragala plantation. Beragala plantation is located in Badulla district, Uva province, and the land area of the plantation is 39 acres. Sandalwood trees were planted in the year 2010 year. The annual temperature is 21.3°C, and the annual rainfall is 1 652 mm. The elevation is 1 037 m in the upcountry intermediate zone (IU3c). 5. Diyaluma plantation.

Diyaluma plantation is located in Badulla district, Uva province. The land area of the plantation is 15 acres. Sandalwood trees were planted in the 2010 year.

6. Belihuloya plantation. Belihuloya plantation is located in Ratnapura district, Sabaragamuwa province, and the land area of the plantation is 26 acres. These Sandalwood trees were planted in 2011 year. The elevation is 598 m.

7. Matale state.

Sandalwood trees were planted in 2013, 2014 and 2016 years. The land area of the plantation is 63 acres. The elevation is 358 m in the mid-country wet zone (WM3b). The annual temperature is 24.10°C, and the annual rainfall is 1 868 mm.

8. Mahao plantation.

Mahao plantation is located in Kurunegala district, Northwestern province, and the land area of the plantation is 32 acres. The elevation is 93 m. These Sandalwood trees were planted in 2011 and 2012 years.

The entire land of each plantation was observed for the identification of host plant species. Identification of host plants was made by carefully following the nodule-like haustoria in the root system. Possible host plants present at the base of the sandalwood within 1.5 m radius was recorded, and the roots zone was exposed 15 to 145 cm away from the base of the sandalwood respective trees. The physical connection between host and sandalwood roots was carefully observed for nodule-like haustoria formation.

RESULTS AND DISCUSSION

A total of 21 host plant species were identified and most of the observed host plants were trees or large shrubs. However, some short-lived annuals were also observed. Total 21 plants are Acacia асиminata (Acacia), Achyranthes aspera (karal sabo), *Azadirachta* indica (Neem), *Camonea umbellate* (Madu wel), Clitoria *ternatea* (Katarolu), Coccos nucifera (Coconut), Crotalaria juncea (Sun hemp), Gliricidia (Gliricidia), Grewia sepium orientalis (Wel Keliya), Imperata cylindrical (Iluk), Ipomoea pestigridis (Diwi pahuru), Lantana *camara* (Gadapana), Leucaena leucocephala (Ipil ipil), Musa spp (Banana), foetida Passiflora (Pada), Sesbenia (Kathurumurunga), grandiflora Tectona grandis (Teak), Tithonia diversifolia (Wild Sun flower), Vernoina zeylanica (Pupula), Vigna mungo (Mun) and Vigna (Cowpea). Distribution unguiculata of the plants in the selected plantation are given in the table 1.

A study conducted by J. Tefnai et al. (2021) on the influence of host plants on the growth of sandalwood seedlings has proven that *Acacia nilotica, Tectona grandis, Azadirachta indica, Leucena leucocephala* and *Acacia auriculiformis* could be used as suitable primary host plants (Tefnai et al., 2021).

According to a study conducted in India, Sandalwood grown with Sesbania recorded the highest biometric observations, chlorophyll and transpiration rate (Balasubramanian et al., 2021). A study conducted in Australia has proven that *A. saligna* and *A. acuminate* as the best host plants among other Acacia species (Lu et al., 2020). However, the species should be

further researched under Sri Lankan conditions to determine their suitability under different climatic regions.

Table 1. Plant distribution in the selected plantation with respect to Sandalwood plant

Species	Godigamuwa plantation	Tangalle plantation	Beragala plantation	Moratuwawala plantation	Diyaluma plantation	Belihulhoya plantation	Matale plantation	Mahao plantation
Acacia acuminata (Acacia)		X	X	Х	X	X	X	X
Achyranthes aspera (karal sabo)				Х				
Azadirachta indica (Neem)				Х	Х			
Camonea umbellate (Madu wel)	Х	Х	Х	Х				
Clitoria ternatea (Katarolu)				X				
Coccos nucifera (Coconut)				X			X	X
Crotalaria juncea (Sun hemp)		X	X	Х	Х	X		X
Gliricidia sepium (Gliricidia)	X	X		Х				
Grewia orientalis (Wel Keliya)	Х							
Imperata cylindrical (Iluk)		Х	X	Х	Х	X		
Ipomoea pestigridis (Diwi pahuru)				X				
Lantana camara (Gadapana)		Х	X	Х	Х			
Leucaena leucocephala (Ipil ipil)	Х	Х	Х	X	Х	Х	X	X
Musa spp (Banana)	Х	Х	X	X	X	X	X	X
Passiflora foetida (Pada)	X	X						
Sesbenia grandiflora (Kathurumurunga)		Х	X	Х	X	X	Х	X
Tectona grandis (Teak)	Х	Х	X	Х	Х			X
Tithonia diversifolia (Wild sun flower)	Х	X	Х		X		X	X
Vernoina zeylanica (Pupula)				Х				
Vigna mungo (Mun)								X
Vigna unguiculata (Cowpea)	Х	Х	Х		Х	X	Х	X



Figure 1. Plants root association with Sandalwood

A) Acacia acuminata pant; A¹) Acacia acuminata haustorial connection; B) Achyranthes aspera plant, B^1) Achyranthes aspera root is represented by the whitish root and Sandalwood root is represented by blackish redroot; C) Sandalwood plant near Azadirachta indica; C¹) Nodule like haustaria structure of Leucaena leucocephala; D) Camonea umbellata plant; D¹) Nodule like haustaria structures on Camonea *umbellata* roots; **E**) *Clitoria ternatea* vine near sandalwood plant; **F**) Coconut plant in sandalwood cultivation, **F**¹) Sandalwood root is represented by the brownish root and coconut root is represented by reddish root; G) Sunn hemp pant; G¹) Narrow pink sandalwood root with haustoria formation; **H**) *Gliricidia sepium*, **H**¹) *Gliricidia sepium* haustorial, I) Grewia orientalis plant, I¹) Nodule like haustaria structures on Grewia orientalis root; J) Imperata cylindrica roots and plant, J¹) Nodule like haustaria structures on Imperata cylindrica roots; K) Ipomoea pes-tigridis plant, K¹) Sandalwood root is represented by red narrow root and Host plant is represented by light brown one; L) Lantana camara plant with flowers, L¹) Nodule like haustaria structure of Lantana camara; M) Sandalwood plant grown near ipil plant, M¹) Nodule like haustaria structure of Leucaena leucocephala; N) Banana plant N¹) Sandalwood root is represented by brown narrow root and the haustorial structure connects them and enables sandalwood to draw nutrients and water from its host; **0**) Passiflora foetida plant, **0**¹) Nodule like haustoria formation on Passiflora foetida roots; **P**) Sesbenia grandiflora plant cultivated near sandalwood plant P¹) The host species is represented by the narrow yellow root ad sandalwood by the wider reddish brown root; **Q**) Teak plant grown with sandalwood plants; Q^1) Teak root is represented by the brownish root and Sandalwood root is represented by blackish red root; R) Sun flower plant grown with sandalwood wood; \mathbf{R}^1) Nodule like haustaria structures on *Tithonia diversifolia* roots; **S**) Vernoina zeylanica plant; **S**¹) Nodule like haustaria structures on Vernoina zeylanica roots; T) Vigna unquiculata plant, T^1) Nodule like haustaria structures on Vigna unguiculata.

Another research conducted by N. Nakandalage et al. (2021) confirmed that Vigna species could function as superior host species for sandalwood plants, and sandalwood plants grown with legume pot hosts such as *Pongamia pinnata* and *Vigna unguiculata* reported increased quality index and shoot-root ratio (Nakandalage et al., 2021). S. M. C. U. P. Subasinghe (2022) states that D. triflorum, M. pudica, and C. ternatea were the best host species for S. album under the nursery stage. He noted that containers maintained without host species resulted in nominal growth. Lantana camara has been identified as a potential secondary host for natural populations of S. album in the Foothills of the Himalayas (Krishna, 2019). A study conducted on suitable host species has shown variable results and has been reported on the performance of different host species in other localities. However, the most commonly identified suitable hosts recorded by them were *Pongamina pinata*, *Casuarina* equestifolia, and Sesbania grandiflora have been identified as suitable hosts (Lee et al., 2020). K. U. Tennakoon and D. D. Cameron (2006) investigated the morphology and anatomy of haustoria formed by S. album attached to Tithonia diversifolia. It confirmed that the sunflower plant is a good host plant with sandalwood (Tennakoon, Cameron, 2006). Weeding should be given considerable attention concerning hostplant relationship management, and Intercropping can be linked with successful host-plant management. The host plants should be selected considering the size, shade nature. economic value. and contribution to sandalwood.

CONCLUSION

Sesbenia grandiflora, Acacia acuminata, Clitoria ternatea, Lantana camara, Leucaena leucocephala, Azadirachta indica, Crotalaria juncea, Imperata cylindrica, Achyranthes aspera, Tectona grandis, Coccos nucifera, Vernoina zeylanica, Tithonia diversifolian, Vigna unguiculata, Camonea umbellata, Ipomoea pestigridis, Musa spp, Glidiciria sepium, Passiflora foetida, Grewia orientalis were the identified host plants recorded commercially in grown sandalwood plantations in Sri Lanka. Further studies are needed to evaluate their degree of success as host plants and adaptability to a wide range of soil and environmental conditions.

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