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Identification of pollinators for good quality seed productions in sandal wood (*Santalum album* L.)

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Abstract
The pollination biology of *Santalum album* was carried out in five different flowering seasons during the period between 2014 and 2016. The study identified and confirmed that *Santalum album* is predominantly a cross pollinating species and the pollination was facilitated by *Monomorium destructor*, *Camponotus sp.* and *Apis cerana indica.* This study clearly conclude that the identification of pollinators and pollination biology is very important for obtaining good quality seed productions.

Keywords: Reproductive biology, pollinators, flowering seasons, insect biology, seed production

1. Introduction
Sandalwood belongs to the family Santalaceae and it is one of the high valuable trees in the world. It is distributed around 17,432 ha in predominantly to the eleven states of India (Pallavi, 2015) [1]. In with Indian culture and heritage sandalwood is associated as most precious and valuable among Indian forest trees (Manoj Kumar, 1994) [7]. The sandal is known for its oil which is pronounced as the most famous East Indian sandal wood oil which is produced from the heartwood of sandal on distillation mainly for perfumery industries and pharmaceutical industries (Shankaranarayana *et al.*, 1998) [11]. The demand for sandal is increasing, but the supply from forests has almost been stopped which resulting in wider gap between demand and supply. Due to this wider gap between the actual availability and the growing demand, the prices of sandal wood and the associated value added product have gone out steeply (Jeremy Luedi, 2017) [4]. Because of its demand and high value, live sandal tree in their natural habitats are ruthlessly felled and removed by smugglers (Manonmani, 1997) [8]. Due to its status (vulnerability) and availability, this species is under threat and need to conserve. For conservation as well as large scale afforestation of this species, quality seed production is the important criteria. In case, obtaining good quality seed production the reproductive biology need to be known. Hence, there is an urgent need to identify the pollinators in *Santalum album*, this study has designed for identification of effective pollinators and the pollinators biology for obtaining good quality seeds.

2. Materials and Methods
The pollination biology was carried out in the sandalwood plantation at Forest College and Research Institute, Mettupalayam, Tamil Nadu, India. Five predominant trees were marked in the sandal plantations and the insect behavior was studied using the modified methods of Ghazoul (1997) [4] with following parameters.

2.1 Insect visits
The insects visiting were observed starting from 06.00 A.M to 7.00 P.M at the time of flowering and the photograph was used to identification of each insect (Ghazoul. 1997) [4].

2.2 Insect visiting time
The Insect visiting time was recorded at 06.00 A.M to 7.00 P.M and it mentioned in Morning, Day, Evening and Night (Talwar and Bhatnagar. 2014) [15].

2.3 Insect time spent on flower
The Insect time spent on flower was recorded based on average time spent by an insect on the flower was recorded with the help of stopwatch (Talwar and Bhatnagar., 2014) [15].

2.4 Insect stigma touch

The insect stigma touch was recorded based on the insect average touch the stigma of the flower and classified as detailed below.

+++	**Good**
++	Intermediate
+	Poor
-	Absent

2.5 Insect frequency of visit

The frequency of insect visit was observed and classified as very low, low, intermediate and high.

3. Results and Discussion

Sandalwood is an endangered species characterized by IUCN 2009 (Krishnakumar *et al.,* 2017) [6]. Beacause of this status it is under thread, which is essential to develop effective conservation strategies for exploitation of the economic potential of the species. For conservation of this species the reproductive biology is very essential. In the reproductive biology of this species was predominantly out crossing with insects (Tamla *et al.,* 2012) [16]. In this paper discussed on the insects attraction and the insect behaviour on sandal wood in different flowering seasons with following parameters.

3.1 Insect visits

Pollination of *Santalum album* flowers through insect and the insects are identified as pollinators are furnished in the table 1. The identified pollinators are
Monomorium destructor, Camponotus sp., Apis cerana indica, Calliphora vomitoria and *Vanessa cardui*.

Table 1: Details of floral visitors (Pollinators)

S. No	Common name	Scientific name	Family	Order
1.	House ant/ Red ant	*Monomorium destructor*	Formicidae	Hymenoptera
2.	Black tree ant	*Camponotus sp.*	Formicidae	Hymenoptera
3.	Indian honey bee	*Apis cerana indica*	Apidae	Hymenoptera
4.	Blue bottle fly	*Calliphora vomitoria*	Calliphoridae	Diptera
5.	Painted Lady butterfly	*Vanessa cardui*	Nymphalidae	Lepidoptera

3.2 Insect visiting time

Among the different flowering seasons, the insect visiting time was varied with pollinators. The pollinators *viz., Monomorium destructor, Camponotus sp, Apis cerana indica* and *Calliphora vomitoria* visited the flowers only in day time and *Vanessa cardui* visited only in evening time. The detailed insect visiting time is furnished in the table 2.

Table 2: Variation for insect visiting time in *Santalum album* at different period of flowering

S. No	Insect	Insect visiting time				
		2014 (II)	2015 (I)	2015 (II)	2016 (I)	2016 (II)
1.	*Monomorium destructor*	Day	Day	Day	Day	Day
2.	*Camponotus sp.*	Day	Day	Day	Day	Day
3.	*Apis cerana indica*	Day	Day	Day	Day	Day
4.	*Calliphora vomitoria*	-	-	-	Day	-
5.	*Vanessa cardui*	-	-	Evening	-	-

3.3 Insect time spend on flower

The observation during different flowering season in *Santalum album,* indicated that time spended by the insect on the flower is ranged between 5-10 seconds and 35 - 50 seconds. The *Monomorium destructor* spends more time on flower compared to all other pollinators. The *Calliphora vomitoria* and *Vanessa cardui* have spend only least time on flower. The flowering season wise insect time spend / flower has furnished in table 3.

Table 3: Variation for insect time spend / flower in *Santalum album* at different period of flowering

S. No	Insect	Insect time spend / flower (Seconds)				
		2014 (II)	2015 (I)	2015 (II)	2016 (I)	2016 (II)
1.	*Monomorium destructor*	35 - 50	20 - 40	20 - 50	20 - 45	30 - 50
2.	*Camponotus sp.*	5 - 20	10 - 15	10 - 20	10 - 15	5 - 20
3.	*Apis cerana indica*	10 - 30	15 - 20	5 - 20	10 - 25	5 - 30
4.	*Calliphora vomitoria*	-	-	-	5 - 10	-
5.	*Vanessa cardui*	-	-	0 - 10	-	-

3.4 Insect stigma touch

The stigma is one of the important parts of the flower in terms of reproductive biology. The stigma touch of insect *viz., Monomorium destructor* and *Apis cerana indica* was good among different flowering seasons; whereas *Camponotus sp* recorded only intermediate touch in all the flowering seasons. *Calliphora vomitoria* and *Vanessa cardui* observed poor stigma touch and also observed only in 1st Season of 2016 and 2nd season of 2015 respectively. The detailed stigma touch has furnished in the table 4.

Table 4: Variation for insect stigma touch in *Santalum album* at different period of flowering

S. No	Insect	Insect stigma touch				
		2014 (II)	2015 (I)	2015 (II)	2016 (I)	2016 (II)
1.	*Monomorium destructor*	+++	+++	+++	+++	+++
2.	*Camponotus sp.*	++	++	++	++	++
3.	*Apis cerana indica*	+++	+++	+++	+++	+++
4.	*Calliphora vomitoria*	-	-	-	+	-
5.	*Vanessa cardui*	-	-	+	-	-
+++ Good; ++ Intermediate; + Poor; - Absent						

3.5 Frequency of insect visit

Monomorium destructor and *Apis cerana indica* are identified as frequent visitors among different flowering seasons studied, Incase of *Camponotus sp* recorded only intermediate frequency of visit among different flowering seasons. The *Vanessa cardui* observed very low frequency of visit. The complete insect frequency visits among different flower seasons has furnished in the table 5.

Table 5: Variation for insect frequency of visit in *Santalum album* at different period of flowering

S. No	Insect	Insect frequency of visit				
		2014 (II)	2015 (I)	2015 (II)	2016 (I)	2016 (II)
1.	*Monomorium destructor*	High	High	High	High	High
2.	*Camponotus sp.*	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
3.	*Apis cerana indica*	High	High	High	High	High
4.	*Calliphora vomitoria*	-	-	-	Intermediate	-
5.	*Vanessa cardui*	-	-	Very Low	-	-

For obtaining good quality seedling production the reproductive biology of the species is very essential (Sindhuveerendra and Sujatha, 1989) [12]. Reproductive biology is an important interdisciplinary area of plant sciences, which is essential to understand the evolution and survival of the species, to develop effective conservation strategies for exploitation of the economic potential of this species (Smitha and Thondaiman. 2016) [14]. In the recent years, studies on reproductive biology of endangered tree species have gained importance in order to make proper management and conservation strategies (Ramasubbu and Irudhyaraj, 2016) [9]. The seed production as well as pollination of this species was strongly controlled by insects. Freshly opened flowers were bright white in color and it attracts the insects. In sandal, most common pollinators are bees, ants, flies, beetles, wasps and butterflies (Tamla *et al.*, 2012) [16]. In the current study both bees (*Apis cerana indica*) and ants (*Monomorium destructor* and *Camponotus* sp.) were commonly observed on the flower during different flowering seasons. Gaint asian honey bee (*Apis dorsata*) was the most common visitors among the insects in *Saraca asoca* (Smitha and Thondaiman, 2016) [14] and *Apis cerana indica* and *Lasioglossum sp*. are the main pollinator in *Feronia limonia* (Chauhan, 2015) [2] which lend support to the results of current findings. The pollination of above mentioned species are similar to *Santalum album* due to the pollinators viz., bees and ants are the major pollinators in that species. Present findings are also supported by those of *Syzygium caryophyllatum* (Geethika and Sabu, 2017) [3]; *Abrus precatorius* (Sandip Choudhury *et al.*, 2017) [10]; *Saraca asoca* (Smitha and Thondaiman, 2016) [14]; *Elaeocarpus blascoi* (Ramasubbu and Irudhyaraj, 2016) [9]; *Feronia limonia* (Chauhan, 2015) [2]; *Terminalia chebula* (Talwar and Bhatnagar, 2014) [15] and *Aegle marmelos* (Singhal *et al.*, 2011) [13] due to similar pollination like *Santalum album*. The Pollination and insect behaviour could be helpful in setting up the conservation strategies as well as formulating measures for crop improvement and sustainable cultivation of this species.

4. Conclusion

Sandal wood is predominantly cross pollination species. Considering the pollinator's studies *viz.*, insect visits, insect visiting time, insect time spend on flower, insect stigma touch and frequency of insect visit, it is observed that *Monomorium destructor*, *Camponotus sp.* and *Apis cerana indica* were the good pollinators for *Santalum album* to obtain good quality seed production.

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