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Flowering Phenology and Seed Production of *Santalum album* L.

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A B S T R A C T

Santalum album L. occupies a prime position in Indian forestry and has been rated as the most precious and valuable tree. For successful cultivation and conservation of Sandal plants a detailed knowledge of their reproductive biology is required. The observations were undertaken during flowering season of *Santalum album* in the year 2015 with objectives to determine bud, flower, fruit and seed morphology for quality and quantity of seed production. The sandal plantation at Forest College and Research Institute, Mettupalayam, Tamil Nadu commenced to first flower on July and second flower commenced on December. The total number of days taken for flowering biology is varied between the season's first and second, 93.92 and 111.32 days respectively. In this population, the seed setting (35.01 %) and seed germination percentage (60.40%) is more on second season compared to the first season of flowering (Seed setting - 20.52 % and Seed germination percentage - 51.84 %). This bud, flower, fruit and seed morphology is directly contributed in seed setting and seed germination percentage. It indicated that the good quality seedling production through the seeds collected from second season of flowering.

Introduction

Sandal (*Santalum album* L.) is one of the most primitive precious useful plants since ancient times. This plant was domesticated due to its multifarious usefulness. Through, it has the natural regeneration capability, but it needs further experiment towards artificial propagation through seed. It has observed that there is lot of problems on seed germination. This can be accomplished by raising quality planting stock using known and superior seed source material as well as good quality of seed production (Das and Tah, 2013). Sandal occupies a pre-eminent place among the forest crops which are of great economic value (Sundararaj, 2008).

It is a source of East Indian sandal oil which underpins Indian culture. The oil extracted from the heart wood of sandal tree has over 2000 years of uninterrupted history in the perfumery trade. An earlier study indicates that sandal is a polymorphic species (Srimathi *et al.,* 1995). Natural impediments apart, the wanton destruction of tree by unscrupulous elements has been so devastating that this tree which underpins Indian culture is facing extinction and listed as an endangered species. There is therefore an imperative need to save the species from total annihilation and enrich the debilitated population with superior and economically viable seedlings. Its high

economic value provides sufficient incentives to farmers and land holders to cultivate the tree for commerce and the development of superior variety in sandal wood helps the farmers to get high revenue besides growing this species. For this purposes the reproductive biology of this species is essential.

Knowledge in reproductive biology is fundamental for systematic, evolutionary and conservation studies (Ornduff, 1969; Holsinger, 1991; Anderson, 1995). The study of reproductive biology of species, along with the analysis of its genetic variation provides data critical to their conservation and improvement efforts. This is especially true for endangered species when there is limited population available to supply propagules for future generation. Knowledge of reproductive biology is a prerequisite for both evolutionary and conservation studies (Anderson, 1995). Ideas that concern about species conservation and recovery will remain ineffective without adequate knowledge on breeding system and pollination mechanisms. Reproductive biology studies help in estimating the genetic variation (Costich, 1995) and also they reveal about the quality and quantity of seeds produced by a species (Nagrajan *et al*., 1996). Observation of features such as floral morphology and phenology as well as pollination studies provide inferences into tree breeding systems (Nagrajan *et al.,* 1998; Gituru *et al.,* 2002). Studies on breeding system and floral morphology in turn give an idea about genetic variation and genetic structure that exist both within and among populations (Loveless and Hamrick, 1984).

Materials and Methods

The present investigation was carried out in the sandalwood plantation at Forest College and Research Institute, Mettupalayam, Tamil Nadu at 11˚18'N latitude and 76˚59'E longitude during the period from 2015. Five trees were marked in the sandal plantations and every tree 6 inflorescences were tagged for flowering biology study in *Santalum album*. Observation on flowering and seed production was conducted during the year 2015 flowering periods following modified methods of Owens *et al.,* (2001) and Ghazoul (1997).

Bud and inflorescence morphology

The number of buds, number of rachis per inflorescence and number of flowers per Inflorescence was counted and the mean value was arrived at numbers. The bud length, bud width, inflorescence length, inflorescence width was measured and expressed in cm. The sequence (ascending or descending) of flowering in a tree and the direction in which flowering begins were observed and recorded. This bud and inflorescence morphology was registered following the procedure of Dafni (1992).

Flower morphology

Flower morphology of randomly tagged flowering branches was following the method described by Gill *et al*., (1998). The flower length and flower width was measured and expressed in mm. The anther length, anther width, style length, ovary length, ovary width and pollen perimeter was measured using the image analyzer and expressed in mm.

Fruit and seed morphology

The number of fruits was counted and the mean value was arrived at numbers. The fruit length and fruit width was measured and expressed in cm. The fresh fruit weight and dry fruit weight also measured and expressed in g. The seed setting percentage and seed germination percentage were observed and calculated adopting the following formulae described by Bonnett (1938):

$$1.\ \text{Seed Setting Percentage} = \left(\frac{\text{Number of seeds formed}}{\text{Total Number of Flowers per Inflorescence}}\right) X100$$

$$2.\ \text{Seed Germination Percentage} = \left(\frac{\text{Number of seeds Germinated}}{\text{Total Number of Seeds Sown}}\right) X100$$

Duration of flowering biology

Bud initiation stage was calculated as the period taken from initiation to opening of flower. Flower duration was calculated as the period taken from bud primordial to anthesis. Flower color changing was calculated as the period taken from white color flower to reddish brown color. Fruit duration was calculated as the period taken from the fruit development to mature fruit drop. This flowering biology duration is followed by Ratnaningrum and Indrioko (2014).

Results and Discussion

The present investigation was carried out in the sandalwood plantation at Forest College and Research Institute, Mettupalayam, Tamil Nadu at 11˚18'N latitude and 76˚59'E longitude during the period from 2015. Over 1 year study, flowering season of sandalwood occurred two times July – October and December to march. Five trees were marked and every tree 6 inflorescences were tagged for flowering biology study in *Santalum album*. The results of all the observation are recorded and present here under.

Bud and inflorescence morphology

The number of buds is no variation in both the seasons. In that the first season recorded in an average of 54.00 buds and second season recorded 54.08 buds. The length and width of the buds are nearly on par each other and recorded (0.72 cm, 0.32 cm) and (0.73 cm, 0.31 cm) respectively. Sequence of flowering in all the observed trees, flowering proceeded from the top to bottom. And the inflorescence of identified all sandalwood trees are cyme. The inflorescence length and width of first and second season (6.93 cm, 2.97 cm and 7.10 cm, 3.03 cm) respectively. Number of rachis per inflorescence and number of flowers per inflorescence are not that much varied between the seasons. The range between Number of rachis per inflorescence and Number of flowers per inflorescence are 7.12, 48.24 in first season and 6.48, 44.20 in second seasons respectively (Table 1).

Flowering proceeded top to bottom. It commenced first on the Southern and South Eastern sides of the crown. Ratnaningrum and Indrioko (2014) and Ratnaningrum *et al.*, (2016) have reported such Sequence of flowering on plant characteristics and flowering phenology, exclusively in bud and inflorescence in *Santalum album.*

Flower morphology

Compared to both the first and second season, there is not variation in flower morphology. The flower length and width registered 0.44 cm and 0.84 cm in first season and 0.40 cm and 0.91 cm in second season of flowering. The range between anther length and width recorded 0.38 mm to 0.51 mm and 0.64 mm to 0.76 mm respectively. The ovary length and width of first and second season (1.35 mm, 0.69 mm) and (1.30 mm, 0.35 mm) respectively.

At December to March flowering, the style length is long as 0.73 mm and short in July to October flowering as 0.71 mm. The pollen perimeter registered as 0.35 mm in first season and second season (Table 2).

This Pollen perimeter anther length, anther breadth, ovary length, ovary breadth, style length are indirectly indicate the seed setting percentage, seed quality of the trees. Seed setting percentage is based on the anther, pollen length and breadth. Floral traits can also have a significant impact on pollination success. Early closure of the stigma (Fetscher and Kohn, 1999) can limit the pollen received by flowers. Reductions in petal size frequently reduce pollinator visitation, thereby increasing pollination limitation in plants with flowers of smaller size than is usual for the species (Kudon and Wighain, 1998).

Fruit morphology

The number of fruits is recorded highest in December to March (14.08) flowering season and low in July to October (8.56) in flowering season. The range between length and width of fruit is 11.10 mm to 12.44 mm and 7.82 mm to 9.34 mm respectively. The fresh and dry fruit weight of first and second season (1.36 g, 0.17 g and 1.39 g, 0.15 g) respectively. Based on the flowering parameter and fruiting parameters, the seed setting percentage is calculated. The seed setting percentage is high in second season (35.01 %) and low in first season (20.52%). After the fruit is developed the mature fruit is dropped in the ground. The dropped fruits are collected and the seeds are tested for germination studies. The germination percentage is higher in December to March (60.40 %) season and low in July to October (51.84 %) season of flowering in sandal tree. Based on seed setting and seed germination percentage indicates that the production of good quality seedling through the second season (December to March) is evident (Table 3).

The seed setting percentage is also based on the length of inflorescence, number of rachis per inflorescence. The high length of inflorescence gives more number of flower production, the inflorescence length also a reason for high seed production (Bonnet, 1938).

Duration of flowering biology

The development of buds, bud initiation to development of buds in full inflorescence. The number of days taken for bud development in December to March season (16.36 days) of flowering registered highest compared to the July to October season (14.20 days) of flowering. Number of days taken for bud into flower, the first and second season recorded 19.56 and 23.12 days respectively. The open flowers are whitish in color. It changed into reddish brown in color. 3.64 days to changing the color of the flower in both the season. The flower is developed into fruits in after color changing.

Second season (39.68 days) registered more number of days taken for fruit development compared to first season (33.08 days). The fruit is matured and drop into the ground. The mature fruits collected in short period in first season as 23.44 days and long period in second season as 28.52 days. The sandal tree flowering biology, the total number of days taken from bud initiation to mature fruit is 93.92 and 111.32 days in first and second season respectively (Table 4; Figure 1).

Similar results were observed in *Santalum album*s which thus lend support to the current findings (Sindhu Veerendra and Anantha Padmanabha, 1996). Timing is a very important strategy in plants, more so during reproduction. This will ensure that the plats flower on time and produce viable seed when the environmental conditions are favorable and there are sufficient resources to sustain the processes. Poor timing of the reproduction season may lead to poor seed production due to lack of sufficient time for maturation. Proper timing of these environmental cues and how the plant responds to them permits the plant to initiate reproductive phase when the conditions are favorable.

Table.1 Variation for morphology of bud and inflorescence at flowering periods in *Santalum album*

Season	Experimental Trees	No. of buds	Bud Length (cm)	Bud Width (cm)	Sequencing of Flowers	Inflorescence Length (cm)	Inflorescence Width (cm)	No of Rachis/ Inflorescence	No of Flowers/ Inflorescence
July to October (First Season)	Tree 1	56.20	0.74	0.35	Top to Bottom	6.80	3.12	7.60	49.60
	Tree 2	53.60	0.79	0.28		6.96	3.00	6.20	49.80
	Tree 3	63.80	0.64	0.31		6.36	2.72	7.20	48.80
	Tree 4	51.40	0.70	0.31		7.38	2.90	7.80	49.40
	Tree 5	45.00	0.71	0.37		7.14	3.12	6.80	43.60
	Mean	**54.00**	**0.72**	**0.32**		**6.93**	**2.97**	**7.12**	**48.24**
December to March (Second Season)	Tree 1	51.20	0.72	0.32	Top to Bottom	6.54	3.22	6.60	49.20
	Tree 2	56.60	0.72	0.27		6.86	3.20	6.40	41.00
	Tree 3	63.60	0.72	0.31		8.06	3.14	6.80	51.40
	Tree 4	46.80	0.74	0.31		6.98	2.90	6.00	43.60
	Tree 5	52.20	0.73	0.33		7.08	2.68	6.60	35.80
	Mean	**54.08**	**0.73**	**0.31**		**7.10**	**3.03**	**6.48**	**44.20**

Table.2 Variation for morphology of flowers at flowering periods in *Santalum album*

Season	Experimental Trees	Flower Length (cm)	Flower Width (cm)	Anther Length (mm)	Anther Width (mm)	Style Length (mm)	Ovary Length (mm)	Ovary Width (mm)	Pollen Perimeter (mm)
July to October (First Season)	Tree 1	0.47	0.88	0.43	0.72	0.70	1.30	0.66	0.34
	Tree 2	0.43	0.87	0.46	0.67	0.74	1.36	0.72	0.33
	Tree 3	0.42	0.87	0.38	0.72	0.71	1.35	0.64	0.39
	Tree 4	0.45	0.75	0.43	0.69	0.69	1.37	0.69	0.36
	Tree 5	0.45	0.84	0.50	0.76	0.72	1.37	0.74	0.36
	Mean	**0.44**	**0.84**	**0.44**	**0.71**	**0.71**	**1.35**	**0.69**	**0.35**
December to March (Second Season)	Tree 1	0.42	0.88	0.49	0.70	0.71	1.15	0.68	0.35
	Tree 2	0.44	0.93	0.51	0.70	0.73	1.34	0.74	0.33
	Tree 3	0.48	0.88	0.41	0.64	0.78	1.33	0.75	0.35
	Tree 4	0.32	0.94	0.49	0.75	0.72	1.31	0.73	0.36
	Tree 5	0.32	0.95	0.44	0.67	0.69	1.38	0.72	0.35
	Mean	**0.40**	**0.91**	**0.47**	**0.69**	**0.73**	**1.30**	**0.72**	**0.35**

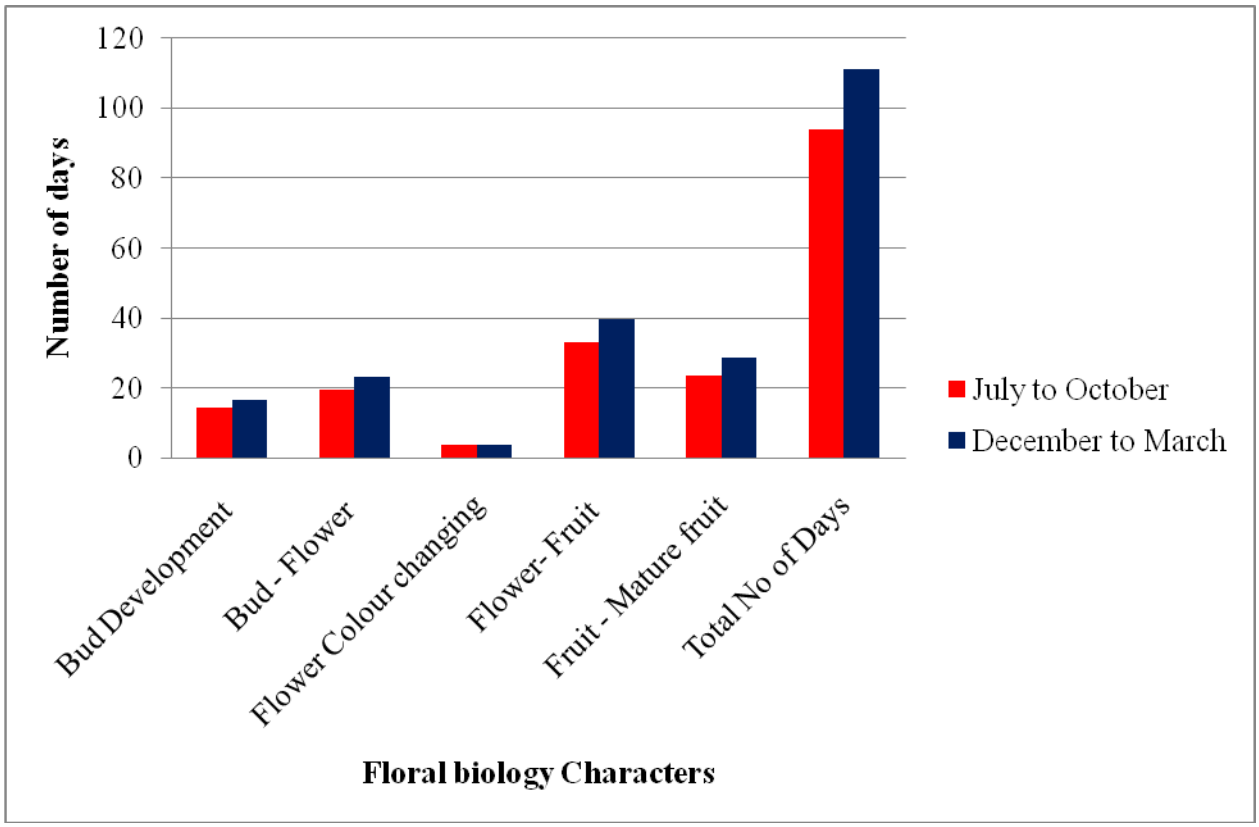
Table.3 Variation for morphology of fruit and seed at flowering periods in *Santalum album*

Season	Experimental Trees	No.of Fruits	Fruit Length (mm)	Fruit Width (mm)	Fresh fruit Weight (g)	Dry fruit Weight (g)	Seed setting Percentage (%)	Seed germination Percentage (%)
July to October (First Season)	Tree 1	8.60	11.10	8.04	1.35	0.19	18.80	53.40
	Tree 2	7.60	11.16	7.82	1.40	0.16	17.06	50.60
	Tree 3	9.40	11.24	8.10	1.29	0.14	25.31	50.60
	Tree 4	9.80	11.46	8.06	1.45	0.18	22.00	53.40
	Tree 5	7.40	11.42	8.00	1.30	0.16	19.44	51.20
	Mean	**8.56**	**11.28**	**8.00**	**1.36**	**0.17**	**20.52**	**51.84**
December to March (Second Season)	Tree 1	16.60	12.28	9.18	1.37	0.15	37.78	59.40
	Tree 2	13.00	12.44	9.34	1.44	0.16	32.19	62.20
	Tree 3	13.20	11.90	9.12	1.17	0.15	28.27	63.20
	Tree 4	13.60	11.62	9.16	1.59	0.16	36.05	61.20
	Tree 5	14.00	12.14	9.42	1.41	0.17	40.78	56.00
	Mean	**14.08**	**12.08**	**9.24**	**1.39**	**0.15**	**35.01**	**60.40**

Table.4 Variation for number of days to taken from bud initiation to fruit development at different flowering periods in *Santalum album*

Season	Experimental Trees	Bud Development	Bud - Flower	Flower Colour changing	Flower- Fruit	Fruit - Mature fruit	Total No of Days
July to October (First Season)	Tree 1	13.80	20.00	3.80	32.80	23.20	93.60
	Tree 2	13.80	20.00	3.60	32.40	23.40	93.20
	Tree 3	14.60	19.40	3.40	33.40	24.60	95.40
	Tree 4	14.20	19.00	3.80	33.60	22.80	93.40
	Tree 5	14.60	19.40	3.60	33.20	23.20	94.00
	Mean	**14.20**	**19.56**	**3.64**	**33.08**	**23.44**	**93.92**
December to March (Second Season)	Tree 1	16.00	22.80	3.60	39.00	28.40	109.80
	Tree 2	16.60	23.00	3.40	39.40	28.00	110.40
	Tree 3	16.60	23.60	3.80	39.80	29.20	113.00
	Tree 4	16.60	23.40	3.80	39.60	28.40	111.80
	Tree 5	16.00	22.80	3.60	40.60	28.60	111.60
	Mean	**16.36**	**23.12**	**3.64**	**39.68**	**28.52**	**111.32**

Fig.1 Number of days to taken from bud initiation to fruit development at different flowering periods in *Santalum album*



In that case, availability of resources and suitable environmental conditions exert selective force on phenological responses.

The duration of flowering biology in the *Santalum album* is 94 to 112 days. Croat (1969) opined that flowering duration within population ranged from a single day to the entire year for different species. The variation in the flowering duration could possibly be due to physiological condition, health and vigor of the trees concerned and changes in local climatic condition. Rathacke and Lacey (1985) Flowering may prolong in a species if favorable environmental conditions persist and may cease if adverse environmental conditions set in. This lends support to the variation in the duration of flowering in *Santalum album*.

A superfluity of workers reported the existence of significant differences in flowering biology in various tree species like *Faidherbia albida* (Gassama Dia *et al.*, 2003), *Butea monosperma* (Rajesh Tandon, 2003), *Acacia saligna* (George *et al.*, 2009), *Terminalia pallid* (Solomon Raju *et al.*, 2012), *Pittosporum dasycaulon* (Gopalakrishnan and Thomas, 2014), *Syzygium alternifolium* (Solomon Raju *et al.*, 2014), *Cinnamomum sulphuratum* (Shivaprasad *et al.*, 2015), *Pterospermum reticulatum* (Keshavanarayan *et al.*, 2015), *Saraca asoca* (Smitha and Thondaiman, 2016), *Santalum album* (Ratnaningrum *et al.*, 2016) and *Croton scabiosus* (Nagireddy, 2016) which thus lend support to the current findings in *Santalum album*.

In conclusion, the sandal plantation at Forest College and Research Institute, Mettupalayam, Tamil Nadu commenced to first flower on July and second flower commenced on December. In this population, the seed setting as well as seed germination percentage is more on second season. This bud, flower, fruit and seed morphology is directly contributed in seed setting and seed germination percentage. It indicated that the good quality seedling production through the seeds collected from second season of flowering in *Santalum album.* Our study presents a detailed account on reproductive biology of this tree which may help in the conservation and genetic improvement of this particular species.

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