STANDARDIZATION OF GERMINATION PROTOCOL IN SANDALWOOD SEED (*Santalum album* L.)

by

Miss. Mendhe Pratiksha Ramraoji
Reg. No. 016/069

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA

in partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL BOTANY
(SEED SCIENCE AND TECHNOLOGY)

DEPARTMENT OF AGRICULTURAL BOTANY

POST GRADUATE INSTITUTE,
MAHATMA PHULE KRISHI VIDYAPEETH,
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2018

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institute
for a Degree or
Diploma

Place : MPKV, Rahuri (P.R. Mendhe)

Dated : / /2018

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Maharashtra (INDIA)

CERTIFICATE

This is to certify that the thesis entitled **"STANDARDIZATION OF GERMINATION PROTOCOL IN SANDALWOOD SEED (*Santalum album* L.)",** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra (India), in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRICULTURAL BOTANY (SEED SCIENCE AND TECHNOLOGY),** embodies results of piece of bonafide research work carried out by **Miss. MENDHE PRATIKSHA RAMRAOJI,** under my guidance and supervision and that no part of the thesis has been submitted to any other degree or diploma.

Place : MPKV, Rahuri
Date : / /2018

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Place : MPKV, Rahuri

Date : / /2018 (R.S. Patil)

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Place : MPKV, Rahuri (P.R. Mendhe)

Date : / /2018

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LIST OF ABBREVIATIONS

%	:	Per cent
/	:	Per
@	:	At the rate
^{0}C	:	Degree Celsius
A.D.	:	Anno Domini (After Christ)
B.C.	:	Before Christ
C.D.	:	Critical differences
cm	:	centimeter
DMC	:	Dry matter content
et al.	:	And other (et alli)
GP	:	Germination Percentage
Hrs	:	Hours
i.e.	:	That is (id est)
Mg	:	Milligrams
NS	:	Non-Significant
ppm	:	Parts per million
SE	:	Standard error
Viz.,	:	Namely (videlicent)

ABSTRACT

STANDARDIZATION OF GERMINATION PROTOCOL IN SANDALWOOD SEED (*Santalum album* L.)

by

Miss. Mendhe Pratiksha Ramraoji

A candidate for the degree
of
MASTER OF SCIENCE (AGRICULTURE)

2018

Research Guide	**: Dr. S.K. Ransing**
Department	**: Agricultural Botany**
Major discipline	**: Seed Science and Technology**

The present investigation was undertaken to "standardize the germination protocol in sandalwood seed (*Santalum album* L.)". The experiment was conducted during 2016-2017. The fresh and fully matured seeds of sandalwood were collected from Medicinal and Aromatic Plants Project, M.P.K.V. Rahuri. The experiment was conducted at Seed Technology Research Unit (STRU), M.P.K.V., Rahuri. The experiment was conducted in Factorial Completely Randomized Design (FCRD) with three replications to assess the suitable method, temperature and treatments for germination.

The seeds of sandalwood were treated with various chemical treatments *viz*., Hydro-priming for 24 hrs. (T_1), priming with GA_3 @ 100 ppm for 24 hrs. (T_2), priming with 2% KNO_3 solution for 24 hrs. (T_3) and priming with 3 % KNO_3 solution for 24 hrs. (T_4). For standardization of seed germination protocol three germination methods *viz*., between paper method (M_1), top of paper method(M_2) and sand method (M_3) and temperatures viz., 20 ± 2^0C (C_1), 25 ± 2^0C (C_2) and 30 ± 2^0C (C_3) were used. The seed quality parameters *viz*., germination (%), seedling length (cm), dry matter content of seedling (g), vigour index-I and vigour index-II were recorded.

Among the various seed treatments the seeds primed with GA_3 @ 100 ppm for 24 hrs. has recorded significantly higher germination (25.55 %) as compared to other treatments. The root- shoot length was significantly increased (17.33cm) when treated with GA3 @ 100 ppm solution for 24 hrs. as compared with others.

Significantly higher dry matter content (0.92 g) was also obtained when seed primed with GA_3 @ 100 ppm solution for 24 hrs. also increase in vigour index I (476) and II (25) was observed.

Among the various seed germination methods the germination (26 %), seedling length (19.20 cm), seedling dry matter content (1.00 g), vigour index I (535) and vigour index II (28) were observed highest in sand method.

Among the various temperature 30 ± 2^0C was found suitable as the germination (16.75 %), seedling length (14.98 cm), seedling dry matter content (0.80 g), vigour index I (276) and vigour index II (14) were observed highest at this temperature.

The germination was significantly highest (46.66 %) when seeds were primed with GA_3 @ 100 ppm solution for 24 hrs. and kept in sand at 30 ± 2^0C for germination. The seedling length (24.23 cm), seedling dry weight (1.37 g) and vigour index I (1131) and vigour index II (64) were also highest when seeds were primed with GA_3 @ 100 ppm for 24 hrs. in the sand method at 30 ± 2^0C. Hence the seed primed with GA_3 @ 100 ppm for 24 hrs. in the sand method at 30 ± 2^0C ($M_3C_3T_2$) is better treatment combination.

1. INTRODUCTION

Sandalwood is a commercially and culturally important plant species belonging to the family Santalaceae and the genus *Santalum*. Sandalwood oil extracted from the heartwood has been used for perfumery, medicinal, religious and cultural purposes over centuries of years. In addition to oil, the wood and its powder are used for religious, cultural and medicinal purposes especially in the Asian and Arab regions. There are around 18 sandalwood species belonging to the genus Santalum. All the sandalwood species are identified as obligate wood hemi-parasites which means they absorb certain nutrients such as phosphates and nitrates from the host trees via root connections called haustoria.

The global distribution of the sandal family is between 30 degrees N and 40 degrees S from Indonesia in West to Juan Fernandez Island in the north to New Zealand in the South. These species are mainly found in India, Indonesia, Australia, Timor, Hawaii etc. The main reason for the economic and cultural value of sandalwood is the oil contained in the sandalwood timber, mainly in the heartwood. Heartwood oil content varies largely between species and even within species. S. album known as Indian sandalwood is renowned for its oil, which is highly rated for its sweet, fragrant, persistent aroma and the fixative property which is highly demanded by the perfume industry. Jain et al (2003) reported that heartwood of S. album was priced at 12 lakhs of Indian rupees per tonne and oil was priced at 22,000 Indian rupees per kg. However, the prices are highly depended on the quality. Due to the high value of oil and timber, *S. album* has been central among all sandalwood species in the aspect of research. Currently most of the world demand of sandalwood is supplied from Australia using *S. spicatum* known as Australian sandalwood. Due to the high value and the demand, there is a growing attention at present in establishing sandalwood, especially *S. album* plantations in the tropical region including Sri Lanka over the most demanding other forest plantation species, i.e., teak, mahogany etc. by the private sector plantation companies, due to the large domestic demand and the existing high demand. In accordance with that, there is a trend in sandalwood

plantation establishment in Australia, India, Sri Lanka, China, and Fiji since recently. However, the plantation sector lacks the information on establishing sandalwood plantations, which is identified as a great risk when considering their profit maximizing goal. Without the information such as nursery techniques, host suitability, plantation establishment, growth rates and oil characteristics, managers of sandalwood plantations might therefore face difficulties in achieving the expected outcomes.

Santalum album is small evergreen tree that grows to 4 m in Australia but in India it is much larger and can grow to a height of 20 m, girth of 2.4 m with slender drooping branches. Bark is tight, dark brown, reddish, dark grey or nearly black, smooth in young trees. Flower panicles appear from March to April in India, and fruits ripe in the cold season. The species is spread rapidly through seed dispersal by birds, which feed on the outer fleshy pericarp. Viable seed production occurs when the tree is 5 year old.

The main distribution is in the drier tropical regions of India and the Indonesian islands of Timor and Sumba. The principal sandal tracts are most parts of Karnataka and adjoining districts of Maharashtra, Tamil Nadu and Andhra Pradesh in India. Total cultivated area of sandalwood in India is around 9034 km^2 and sandalwood production is around 2000 tonnes. The species is mostly found in dry deciduous and scrub forest region. It also grows in the low lateritic cliffs above the beach. It is a partial parasite that attaches to the roots of other trees, it needs nurse species in the area of planting out. Host plants that fix nitrogen and provide light shade are preferred. *Senna seamea* is best for this, and a most probable *Drypetis lasiogyna*, observed to be the most prolific species in the vicinity of S. album. It does not tolerate frost or water logging, but is drought-hardy and is a light demander in sapling and later stages.

Many workers have attempted to study the presence of seed dormancy, its duration, its mechanism, method to overcome and standardize the germination methods of many plant species. They indicated the presence of inhibitory substances which causes dormancy in the sandal seeds (Srimathi and Rao, 1969). The standard

seed testing procedures including laboratory germination tests have also been prescribed in International Rules for seed testing for most of agricultural, horticultural crops and forest trees. It has been concluded that vegetative propagation has not been successful for sandalwood (Uniyal *et al.*, 1985). Propagation of Sandalwood is commonly done by propagating seeds in nurseries or directly sowing them in the field (Dayal, 1986 and Fox, 1989). However, for the most forest trees the germination methods are to be understood. So this study is one of the attempts to standardize the germination protocol for Sandalwood seed.

In India cultivation of sandalwood by the individual is permitted from 2002. After permission around 2800 ha area came under sandalwood cultivation and about 600 ha area increases every year. Nowadays Indian farmers are interested to cultivate sandalwood on extensive scales as they can get better remuneration but seed germination and availability of seedlings in required quantities at proper times is the main constraint. So in view of these problems an experiment was designed with available literature relevant to the present investigations entitled “Standardization of germination protocol in sandalwood seed (*Santalum album* L.) has been undertaken with following objectives

1. To standardize germination method for sandalwood seed.
2. To find out optimum temperature for germination of sandalwood seed in the laboratory.

2. REVIEW OF LITERATURE

2.1 Effect of seed treatments

Burns and Coggnies (1969) found that the germination of Sweet orange seeds was significantly hastened when seed soaked for 24 hours in GA_3 1000 ppm solution. The growth and uniformity of seedlings were also enhanced by seed treated with GA_3 at 1000 ppm.

Srimathi and Rao (1969) reported early and quick germination in short time 15 days by breaking the false seed coat and they indicated the presence of inhibitory principles in the seed coat in sandal seeds.

Shanmugavelu (1970) concluded from his experiment that Gibberelic acid at various doses improved the seed germination and shoot growth of 15 tropical tree species including cashew, tamarind, Acacia spp., *Albizzia lebbek*, *Artocarpus heterophyllus, Eugenia jambolana* (*Syzygium cumini*), *Leucaena glauca* [*Leucaena leucocephala*] and *Zizyphus jujuba*.

Khaltakar and Bhargava (1981) reported that the growth regulators viz., GA_3, NAA and IAA behaved indifferently for germination of seeds of *Cassia angustifolia*. They also reported that seeds treated with 50 ppm GA_3, 50 ppm NAA and 50 ppm IAA for 18 hrs at $26\,^0$C were significantly improved the seed germination.

Choudhary and Chakrawar (1982) studied the effect of soaking the seed of Rangpur lime for 6 and 12 h in solution of GA_3 10, 20 and 40 ppm; NAA 10, 20, 40 ppm and thiourea 2 %. The maximum value of seedling height, number of leaves, stem girth and fresh and dry shoot weight were obtained when seed treatment with GA_3 at 40 ppm for 12 h followed by same concentration of NAA.

Uniyal *et al.* (1985) concluded from his germination studies of sandalwood that the vegetative propagation has not been successful for sandalwood.

Norton (1986) reported that treated the *Rhus typhina* seeds with 100 ppm GA_3 gave more germination percentage as compared to control.

Mahdi (1986) studied that most scarification or soaking treatment in Gibberelic acid gives higher germination in Sandal seeds.

Bahuguna *et al.* (1987) reported that the highest germination in champa (*Michellia champaca*) was obtained from 500 ppm GA_3 treatment but germination value was highest in 1000 ppm and it was slightly greater 24 hours of soaking of seeds than 48 hours.

Pitel and Wang (1988) treated the seeds of brasswood (*Tillia americana*) with conc. H_2SO_4 and GA_3. The rate and germination percentage were increased after 15-20 min soaking in conc. H_2SO_4 followed by washing with tap water and then imbibed for 24 hrs in 500 ppm GA_3 which gave germination upto 90 percent and concluded that GA_3 helps to enhance the germination.

Reddy(1988) reported that the seeds of *Cassia renigera* treated with GA_3 (50 ppm) improved the seed germination in *Cassia renigera.*

Ananthapadmanabha *et al.* (1988) have reported that treatments with dilute Sodium hydroxide or dilute hydrochloric acid or gibberellic acid can remove the dormancy principle from the seed.

Dayal (1986) and Fox (1989) studied that propagation of sandalwood is commonly done by propagating seeds in nurseries or directly sowing them in the field.

Radhakrishnan *et al.* (1989) reported that seeds treated with KNO_3 promoted the germination of positively photoblastic seeds in *Cassia sericed*.

Singh and Motilal (1990) reported that *Rauvolfia serpentina* seeds gave significantly increased germination percentage from 1.5 to 4.8 per cent to 45.2 per cent when treated with GA_3 (500 mg/l) in laboratory condition and concluded that GA_3 is effective in increasing the germination (%).

Srinivasan *et al.* (1992) concluded from sandalwood germination studies that In Santalum album germination is sporadic and takes 4-12 weeks time to complete germination.

Effendi and Surata (1993) worked on germination studies of sandalwood seeds and concluded that viability of sandalwood seeds varies between individual trees.

Brand (1993) and Susila *et al.* (1995) reported in their sandalwood seed germination studies that the viability of sandalwood seed varies between population.

Hore and Sen (1995) reported the role of pre-sowing seed treatment on germination, seedling growth and longevity of ber (*Zizyphus mauritiana* Lam.) seeds. Seeds of ber cv. Gola were stored for 1 and 17 months in a polyethylene bag and then treated with a range of chemicals for 24 hrs. The highest germination percentage after 1 and 17 months was obtained from seeds treated with 200 ppm GA_3 (98.76 and 77.82 %, respectively). Days to first germination were lowest with 1.0 % thiourea treatment, while the shortest span of germination was recorded under concentration of 1000-2000 ppm Cycocel (chlormequat).

Khedkar (1996) observed that seeds *of Santalum album* soaked in water for 24 hrs. and followed by treatment 500 ppm GA_3 for 24 hrs. gave 63.41 per cent mean germination at 30 ^{O}C temperature.

Pawshe *et al.* (1997) conducted an experiment to determine the effect of pre-germination seed treatment on germination and vigour of aonla (*E. officinalis*) seeds. Treatments included gibberellic acid (GA_3) at 50 and 100 ppm, soaking in water for 24 h and hot water soaking at 60^0C for 5 min. They reported that GA_3 at 50 and 100 ppm increased the percentage seed germination. Further the tallest plants were observed when seed treated with 100 ppm GA_3 and soaking for 24 h.

Wagh *et al.* (1998) conducted an experiment on effect of seed treatment on germination of seed and initial growth of Aonla seedling in polybag. Seeds were soaked for 12 hrs.in 100-400 ppm gibberellic acid (GA_3), water and dry (control). They reported that 400 ppm GA_3 resulted in higher percentage germination as well as seedling development (plant height, number of leaves/plant and root development).

Nagaveni and Srimathi (1981) reported that sandal seeds have been found to germinate fast when the seed coat is completely removed or seeds are soaked in 0.05 % Gibberelic acid for 12-16 hrs.

Kalalbandi *et al.* (2003) conducted a field experiment to investigate the effect of GA_3 (40, 60 and 80 ppm); NAA (40, 60 and 80 ppm) and KNO_3 (1%) on the germination and growth of kagzi lime. They observed that the seed soaked in GA_3 and NAA for 12 hrs resulted in high germination and shoot length. Further they observed that GA_3 concentration of 80 ppm was the most effective for improving germination, seedling height and number of leaves.

Meena *et al.* (2003) reported that pre-sowing seed treatment with four concentration of GA_3 (25, 50,100 and 200 ppm) and control without any treatment. The maximum percentage of germination and percent survival was noted under 100 ppm GA_3. Further they reported that the GA_3 significantly affected the germination percentage, days required for completion of germination and survival percentage in all the cultivars of papaya.

Ratan and Reddy (2003) studied the influence of potassium nitrate on germination and subsequent seedling growth of custard apple (*Annona squamosa*). Seeds of *A. squamosa* were soaked in 0.5 or 1 % potassium nitrate for 12 or 24 hrs. before sowing in raised beds. Seed germination was highest with seed soaking at 1 % potassium nitrate for 24 h.

Ratan and Reddy (2004) reported that when the seeds of custard apple (*Annona squamosa*) cv. Balanagar were soaked in 200, 400, 600 ppm GA_3 for 12 and 24 h to determine their effect on seed germination and seedling growth. Seed soaked with 400 ppm GA_3 gave the highest seed germination percentage (69.00), plant height (25.33 cm), root length (12.23 cm), and dry weight of stems (0.245 g) and roots (0.175 g). Further they observed that seed soaked with 600 ppm GA_3 for 12 h gave the earliest days for initiation of germination (16.00), which was at par with 600 ppm GA_3 for 24 h and leaf dry weight (0.795) whereas The highest stem diameter (2.86 cm) was obtained with 200 ppm GA_3 for 24 h.

Kucera *et al.* (2005) concluded from his experiments that gibberellins counteract ABA effects and promote seed germination.

Rao and Reddy (2005) reported that soaking of mango stones for 12 hrs. in gibberellic acid (GA_3; 100, 200 and 300 ppm), potassium nitrate (1, 2 and 3 %)

and water increased the germination percentage and enhanced the rate of germination of mango stones. GA_3 at 200 ppm for 12 h was the best treatment which recorded the maximum germination percentage (85.5 %) as compared to other treatments. further GA3 at 200 ppm recorded the maximum seedling growth compared to other treatments.

Som Dutt and Verma (2005) observed percentage and germination energy in *Santalum album* due to GA_3 (0.05%) treatment. In their study they stated that the higher dose (0.1%) of Gibberelic acid gave comparatively less germination (%) and germination energy. Higher dose may have resulted in hormonal imbalance affecting adversely the germination.

Lavania *et al.* (2006) reported that the seed germination of *Pinus wallichiana* was maximum with the application of 300 ppm GA_3 for 24 hrs. followed by 200 ppm GA_3 for 36 h. These results indicate that increasing the soaking period or concentration of GA_3 leads to maximum germination.

Radhakrishnan and Renganayaki (2008) reported that the seeds surface sterilized with 0.1 % mercuric chloride for 30 minutes and washed and subsequently the seeds were soaked in IAA, IBA, GA_3 @ 200 and 400 ppm for 24 hrs in Simaru baglauca. They recorded higher and earlier germination as compared to other treatments. The commencement of germination was early in case of seed treated with 200 ppm IAA and GA_3.

Munde and Gajbhiye (2010) studied the effect of plant growth regulators on seedling growth of mango stone. They observed that the plant growth regulator GA_3 at 200 ppm applied to mango stone produced maximum height and more number of leaves. Further plant growth regulator IAA at 500 ppm applied to mango stone produced maximum girth and leaf area. GA_3 at 200 ppm and IAA at 500 ppm applied to mango stones induced more growth of mango seedlings.

Gharge *et al.* (2011) studied the effect of various concentration of GA_3 and soaking period on seed germination of custard apple. The maximum germination percentage was recorded when seed soaked with GA_3 at 400 ppm, with regard to the period of soaking, soaking of seeds for 24 to 48 hrs. gave early and maximum

germination percentage of the seedlings. In respect of interaction effect of GA_3 concentration and soaking period, it was observed that soaking of seeds in GA_3 400 ppm for 12 hrs. gave maximum germination percentage and seedling height.

Msaakpa and Obasi (2013) stated that treating castor (*Ricinus cummunis* L) seeds with either coconut milk or KNO_3 produced higher final germination count and germination speed and lower total mortality of seeds.

Dasand and Tah (2013) revealed from their research that soaking the seeds in 0.05 % GA_3 for 16 to 24 hrs. gives good germination of sandalwood seeds.

Billah *et al.* (2015) concluded from their experiment that pre-sowing treatment is obviously better than sowing the seeds of *Tectona grandis* without treatment.

Dileepa *et al.* (2015) studied that increased germination with GA_3 indicated a physiological component to dormancy.

Dhiman *et al.* (2015) conducted an experiment to find out the effect of soaking conditions with growth regulators and nutrient solutions on germination behaviour of Ratela : a fuel wood species of Shiwalik hills. The seeds were soaked at different periods viz., no soaking, 6 hrs. and 12 hrs. with different growth regulators-IAA, IBA, NAA, GA_3, KIN, and Ethrel and salt solutions ($MgSO_4$ and KNO_3). The results revealed that treatment with GA_3 without soaking gave higher germination percentage (41.67 %) though the interaction effect was non-significant. The seeds took minimum days of 4.67 in water soaked seeds for initiation of germination.

2.2 Effect of germination methods

Bhagat *et al.* (1992 a) reported that seeds of *Ephedra gerandiana* sown in sand medium recorded maximum germination with shortest period than those sown in soil and on filter paper.

Bhagat *et al.* (1992 b) reported the sand medium as good for germination when they observed the maximum germination of 97 per cent in *Woodfordia fruiticosa* when seeds sown in sand medium compared to brick media and soil, which registered 58 and 43 per cent, respectively.

Kalavathi (1996) reported that sand method was best for conducting the germination test in *Cassia angustifolia and Carthamus roseus* and between paper method for *Hibiscus sabdariffa.*

Miyan (1997) reported that maximum germination per cent was observed in *Acacia auriculiformis* at 35^0C in TP/BP/ vermiculite media. In *Acacia catechu* at 25^0C temperatures in TP method gives better germination. Whereas, in *Cassia fistula* gave maximum germination at 25 both in TP and BP method.

Venudevan *et al.* (2013) studies were conducted on standardization of media and methodologies for germination test under room conditions in line with ISTA for Bael seeds. The results revealed that, either river sand or paper media should be used for obtaining reproducible and complete expression of germination of seed. In river sand, in- sand method and in paper, between paper method had better expression for germination.

2.3 Effect of temperature

Adarshkumar and Bhatnagar (1976) reported that fresh and one year old seed lots of *Dalbergia sissoo,* germinated faster and gave maximum germination at 30 ^{0}C in between paper method within 9 days. The alternate temperature of 20 and 30 ^{0}C, 25 and 30 ^{0}C, 30and 40 ^{0}C were also equally effective but high temperatures of 40 and 35 to 40 ^{0}C were not favourable.

Thomson and Wilt (1987) suggested that a constant temperature of 30 ^{0}C or alternating temperature regime of 20/30 ^{0}C for maximum germination in Physalis species and *Solanum ptycanthum*.

Ganigara *et al.* (1995a) reported that *Dalbergia latifolia* gave maximum germination at constant temperature 25^0C with between paper method. The first count of germination can be taken on fourth day and second count on seventh day.

Ganigara *et al.* (1995b) reported that the constant temperature of either 25 or 30^0C and sand medium was better for germination test of seeds of *Tamarindus indica*. In *Acaciani lotica* constant temperature of 30 ^{0}C and between paper as substratum and first count on third day and final count on seventh day were found to be optimum.

3. MATERIAL AND METHODS

The present investigation entitled, "Standardization of germination protocol in Sandalwood seed (*Santalum album* L.)," was conducted during 2016-17 at Seed Technology Research Unit (STRU) Laboratory, M.P.K.V., Rahuri, (Maharashtra state). The details of the material used and methods adopted for the investigation are described under various sub headings in this chapter.

3.1 Experimental Material

The fresh seeds of Sandalwood (*Santalum album*) were collected from Medicinal and Aromatic Plant Project, M.P.K.V., Rahuri during 2016-2017 from their natural stand.

3.2 Treatment details

To standardize the suitable germination protocol, treated seeds were kept for germination by different method at different temperature and recorded the normal seedling percentage.

3.2.1 Treatments

To assess the effect of different treatments on seed germination and growth, the seed are treated as detailed given below.

T_1 : Hydro-priming (Soaking in water) for 24 hrs. The seeds were soaked in tap water for 24 hrs.

T_2 : Priming with GA_3 @ 100 ppm for 24 hrs. The 100 ppm GA_3 solution was prepared and the seed were treated for 24 hrs.

T_3 : Priming with 2% KNO_3 Solution for 24 hrs. The dilute solution of 2 % KNO_3 was freshly prepared and the seed were treated with the solution 24 hrs.

T_4 : Priming with 3% KNO_3 Solution for 24 hrs.

The dilute solution of 3 % KNO_3 was freshly prepared and the seed were treated with the solution for 24 hrs. After the treatment and washing the seeds were dried under shade.

3.2.2 Germination Methods

M_1 : Between paper method (BP)

M_2 : Top of paper method (TP)

M_3 : Sand method (SM)

3.2.3 Temperatures

C_1 : $20 \pm 2\ ^0C$

C_2 : $25 \pm 2\ ^0C$

C_3 : $30 \pm 2\ ^0C$

3.2.4 Relative Humidity

RH: 85 $\pm$ 5 %

3.2.5 Treatments combinations: M×C×T= 36

Combinations		Combination details
$M_1C_1T_1$	:	Between paper x 20 ± 2^0C x Hydro-priming for 24 hrs.
$M_1C_1T_2$	:	Between paper x 20 ± 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_1C_1T_3$	:	Between paper x 20 ± 2^0C x 2% KNO_3 24 hrs.
$M_1C_1T_4$	:	Between paper x 20 ± 2^0C x 3% KNO_3 24 hrs.
$M_1C_2T_1$	:	Between paper x 25 ± 2^0C x Hydro-priming for 24 hrs.
$M_1C_2T_2$	:	Between paper x 25 ± 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_1C_2T_3$	:	Between paper x 25 ± 2^0C x 2% KNO_3 24 hrs.
$M_1C_2T_4$	:	Between paper x 25 ± 2^0C x 3% KNO_3 24 hrs.
$M_1C_3T_1$	:	Between paper x 30 ± 2^0C x Hydro-priming for24 hrs.
$M_1C_3T_2$	:	Between paper x 30 ± 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_1C_3T_3$	:	Between paper x 30 ± 2^0C x 2 % KNO_3 24 hrs.
$M_1C_3T_4$	:	Between paper x 30 ± 2^0C x 3 % KNO_3 24 hrs.
$M_2C_1T_1$	:	Top of paper x 20 ± 2^0C x Hydro-priming for 24 hrs.
$M_2C_1T_2$	:	Top of paper x 20 ± 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_2C_1T_3$	:	Top of paper x 20 ± 2^0C x 2% KNO_3 24 hrs.
$M_2C_1T_4$	:	Top of paper x 20 ± 2^0C x 3% KNO_3 24 hrs.
$M_2C_2T_1$	:	Top of paper x 25 ± 2^0C x Hydro-priming for 24 hrs.

$M_2C_2T_2$	:	Top of paper x 25 $\pm$ 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_2C_2T_3$	:	Top of paper x 25 $\pm$ 2^0C x 2% KNO_3 24 hrs.
$M_2C_2T_4$	:	Top of paper x 25 $\pm$ 2^0C x 3% KNO_3 24 hrs.
$M_2C_3T_1$	:	Top of paper x 30 $\pm$ 2^0C x Hydro-priming for24 hrs.
$M_2C_3T_2$	:	Top of paper x 30 $\pm$ 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_2C_3T_3$	:	Top of paper x 30 $\pm$ 2^0C x 2% KNO_3 24 hrs.
$M_2C_3T_4$	:	Top of paper x 30 $\pm$ 2^0C x 3% KNO_3 24 hrs.
$M_3C_1T_1$	:	Sand method x 20 $\pm$ 2^0C x Hydro-priming for 24 hrs.
$M_3C_1T_2$	:	Sand method x 20 $\pm$ 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_3C_1T_3$	:	Sand method x 20$\pm$ 2^0C x 2% KNO_3 24 hrs.
$M_3C_1T_4$	:	Sand method x 20 $\pm$ 2^0C x 3% KNO_3 24 hrs.
$M_3C_2T_1$	:	Sand method x 25 $\pm$ 2^0C x Hydro-priming for 24 hrs.
$M_3C_2T_2$	:	Sand method x 25 $\pm$ 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_3C_2T_3$	:	Sand method x 25 $\pm$ 2^0C x 2% KNO_3 24 hrs.
$M_3C_2T_4$	:	Sand method x 25 $\pm$ 2^0C x 3% KNO_3 24 hrs.
$M_3C_3T_1$	:	Sand method x 30 $\pm$ 2^0C x Hydro-priming for 24 hrs.
$M_3C_3T_2$	:	Sand method x 30 $\pm$ 2^0C x GA_3 @ 100 ppm for 24 hrs.
$M_3C_3T_3$	:	Sand method x 30 $\pm$ 2^0C x 2% KNO_3 24 hrs.
$M_3C_3T_4$	:	Sand method x 30 $\pm$ 2^0C x 3% KNO_3 24 hrs.

The germination test was conducted with 10800 seeds of Sandalwood (*Santalum album* L.) which were counted randomly from treated and well mixed lot. Seeds were kept for germination in three replications, as per the treatment combination given above. The final count, was taken when the maximum number of seedling were observed. The number of normal seedling were observed in different method and expressed as percentage.

3.3 Details of observations

1. Germination percentage (%)

Hundred seeds were randomly taken from each treatment in three replications and germinated in different media as mentioned in 3.2.2 in germinator at,

three temperatures i.e. 20 ± 2^0C, 25 ± 2^0C and 30 ± 2^0C. The 85 ± 5% humidity was maintained in the germinator. The number of normal seedlings was counted up to 45days expressed in percentage.

2. Seedling length (cm)

Ten normal seedlings were selected randomly from germination test of all the replications. The Seedling length was measured from the tip of the shoot to the tip of root and length was expressed in centimeters.

3. Dry matter content of seedling (g)

Ten normal seedlings selected for shoot and root length measurement was kept in an oven maintained at 50^0C for 24 hours. After drying, the weight of dry seedlings was recorded and mean weight was calculated and expressed in grams (g).

4. Vigour index I

Ten normal seedlings were selected randomly immediately after germination test. Total root shoot length (cm) of ten seedlings was measured and average was worked out for calculating the seedling vigour index I.

The vigour index was computed by formula suggested by Abdul-Baki and Anderson (1973) as below.

Vigour Index-I = Mean seedling length (cm) × Germination(%)

5. Vigour index-II

The seedling selected for calculating seedling vigour index-I was oven dried and the oven dried weight of seedlings was used for calculating seedling vigour index II.

Seedling vigour index II was determined by using the formula given by Abdul-Baki and Anderson (1973) as below.

Vigour Index-II = Seedling dry weight (g) × Germination (%)

3.4 Statistical Analysis

The statistical data was analyzed by the FCRD method as per the procedure given by Snedecor and Cochran (1994).

4. RESULTS AND DISCUSSION

4.1 Standardization of seed germination protocol

The present investigation entitled, Standardization of germination protocol in sandalwood seed (*Santalum album* L.) was undertaken to standardize the suitable temperature and method for germination and to assess the effect of pre-soaking chemical treatments on seed germination of sandalwood. The results of present investigation have been presented in this chapter.

Table 1. Effect of seed treatments on germination (%) of sandalwood seed

Treatments	Germination (%)		
	Germination Period (Days)		
	30	45	60
Hydro-priming (T_1)	0.63	4.55	8.18
Priming with GA_3 @ 100 ppm for 24 hrs. (T_2)	2.77	21.18	25.55
Priming with 2 % KNO_3 for 24 hrs. (T_3)	1.48	14.14	18.25
Priming with 3 % KNO_3 for 24 hrs. (T_4)	1.85	15.25	20.88
S.E. $\pm$	0.10	0.27	0.29
CD at 5 %	0.28	0.77	0.82

4.1.1 Effect of seed treatments on germination (%) of sandalwood seed

It was observed from the data provided in the Table 1 that different seed treatments had significant effect on germination.

The germination (%) was increased with increase in germination period. The seed primed with GA_3 @ 100 ppm for 24 hrs. (T_2) recorded higher germination (2.77 %) at 30 days, while at 60 days it was significantly higher (25.55 %).

The seed when primed with GA_3 @100 ppm solution for 24 hrs. (T_2) resulted in the increase in germination percentage because the burning of hard seed coat resulted in the imbibition of optimum amount of water where imbibition is

the first phase of germination process also had ability to break the exogeneous dormancy. Acid scarification has been reported to disintegrate the leathery seed coat testa, the similar results were also reported by Norton (1986) in sandalwood seed.

4.1.2 Effect of germination methods on germination (%) of sandalwood seed

From the data provided in the Table 2 it was observed that the different germination methods had significant effect on germination of sandalwood seed. Sand method (M_3) recorded significantly higher germination (26.77 %) at 60 days than other two methods.

Table 2. Main factor effect of germination methods on germination (%) of sandalwood seed

Methods	Germination (%)		
	Germination Period (Days)		
	30	45	60
Between paper method (M_1)	1.611	16.00	19.58
Top of paper method (M_2)	0.38	4.72	8.30
Sand method (M_3)	3.05	20.63	26.77
S.E. $\pm$	0.08	0.24	0.25
CD at 5 %	0.24	0.67	0.71

Among the germination methods, sand method (M_3) recorded high germination. This might be due to the optimum surface area of seed comes in contact with sand media as compared to between paper method and top of paper method. So provision of optimum moisture and aeration helped the seeds to germinate faster in sand method as compared to other methods. Similar observations were also been made by Kalavathi (1996), in *Cassia angustifolia* and *Carthamus roseus.*

4.1.3 Effect of temperature on germination (%) of sandalwood seed

From the data, Table 3 it was observed that the different germination temperatures had significant effect on germination of sandalwood seed.

Table 3. Effect of temperature on germination (%) of sandalwood seed

Temperature	Germination (%)		
	Germination Period (Days)		
	30	45	60
20 ± 2^0C (C_1)	0.88	11.63	15.97
25 ± 2^0C (C_2)	1.00	11.88	16.22
30 ± 2^0C (C_3)	1.41	12.50	16.75
S.E. ±	0.08	0.24	0.25
CD at 5 %	0.24	0.67	0.71

At 30 ± 2^0C (C_3) temperature significantly higher (16.75 %) germination was recorded than the other two temperatures.

It has been also noticed that the 30 ± 2^0C (C_3) temperature was significantly superior over the other temperature, which recorded highest germination (16.75 %). This could be owing to high rate of imbibition of water by seed at high temperature, since high temperature known to cause increase in kinetic energy of water and decreases of its viscosity. The enzyme activities of seeds leading resumption of embryo growth might have been high at 30^0C temperature. Similar results was also been reported by Adarshkumar and Bhatnagar, (1976) in *Dalbergia sissoo.*

4.1.4 Interaction effect of germination methods and seed treatments on germination (%) of sandalwood seed

The data provided in the Table 4 revealed that, the interaction effect of germination methods and seed treatments had significant effect on germination (%). At 30 days the interaction of germination in sand method and seed primed with GA_3 @ 100 ppm solution for 24 hrs. (M_3T_2) showed significantly higher germination (5.22 %), and it was highest (37.44 %) at 60 days. This happened because sand provided the required moisture and allowed exchange of gases and GA_3 helped to break the seed dormancy.

Table 4. Interaction effect of germination methods and seed treatments on germination (%) of sandalwood seed

Treatment combinations	Germination (%)		
	Germination Period (Days)		
	30	45	60
M_1T_1	0.55	3.77	7.55
M_1T_2	2.33	23.55	26.77
M_1T_3	1.66	17.88	21.33
M_1T_4	1.88	18.77	22.66
M_2T_1	0.00	2.77	5.44
M_2T_2	0.77	7.88	12.44
M_2T_3	0.22	3.88	7.22
M_2T_4	0.55	4.33	8.11
M_3T_1	1.33	7.11	11.55
M_3T_2	5.22	32.11	37.44
M_3T_3	2.55	20.66	26.22
M_3T_4	3.11	22.66	31.88
S.E. $\pm$	0.17	0.47	0.50
CD at 5 %	0.49	1.34	1.42

4.1.5 Interaction effect of temperature and seed treatments on germination (%) of sandalwood seed

The data on interaction effect of temperature and seed treatments on germination are presented in the Table 5. It was observed that the interactions of temperature and seed treatments had significant effect on germination. At 30 days of observation the interaction of temperature 30 ± 2 ^{0}C and seed primed with GA_3 @ 100 ppm solution for 24 hrs. (C_3T_2) showed significantly higher germination (4.00 %) and it was significantly higher (31.22 %) at 60 days. The interaction of temperature 30 ± 2^{0}C and seed primed with GA_3 was found better by Khedkar (1996).

Table 5 Interaction effect of temperature and seed treatments on germination (%) of sandalwood seed.

Treatment combinations	Germination (%)		
	Germination Period (Days)		
	30	45	60
C_1T_1	0.11	3.55	6.77
C_1T_2	1.33	18.11	21.66
C_1T_3	0.88	11.55	16.88
C_1T_4	1.22	13.33	18.55
C_2T_1	0.55	4.55	7.77
C_2T_2	3.00	20.55	23.77
C_2T_3	1.66	14.11	18.33
C_2T_4	2.11	15.11	21.00
C_3T_1	1.22	5.55	10.00
C_3T_2	4.00	24.88	31.22
C_3T_3	1.88	16.77	19.55
C_3T_4	2.22	17.33	23.11
S.E. $\pm$	0.17	0.47	0.50
CD at 5 %	0.49	1.34	1.42

4.1.6 Interaction effect of germination methods and temperature on germination (%) of sandalwood seed

It was revealed from the data provided in the Table 6 that the interaction of germination method and temperature had significant effect on germination. Initially the interaction of germination in sand method at 30 ± 2^0C for germination (M_3C_3) showed significantly higher germination (4.66 %) than the other interactions. It was significantly higher (31.00%) at 60 days.This happened because the sand media provided optimum moisture and aeration to the seeds and the higher temperature of 30 ± 2^0C helped to activate the anti-dormin ezymes by increasing the kinetic energy and lowering the viscosity of water. Ganigara *et al.* (1995b) reported the similar results in *Tamarindus indica*.

Table 6. Interaction effect of germination methods and temperature on germination (%) of sandalwood seed

Treatment combinations	Germination (%)		
	Germination Period (Days)		
	30	45	60
M_1C_1	1.08	14.66	17.41
M_1C_2	1.91	16.25	20.16
M_1C_3	1.83	17.08	21.16
M_2C_1	0.25	3.083	6.50
M_2C_2	0.41	4.00	.667
M_2C_3	0.50	7.08	0.75
M_3C_1	1.33	17.16	24.00
M_3C_2	3.16	20.50	25.33
M_3C_3	4.66	24.25	31.00
S.E. $\pm$	0.15	0.415	0.43
CD at 5 %	0.42	1.16	1.23

4.1.7 Interaction effect of germination methods, temperature and seed treatments on germination (%) of sandalwood seed

The data regarding effect of interaction between germination methods, temperature and seed treatments on germination are presented in Table 7. It was revealed that the interaction of germination methods, temperature and seed treatments on germination had significant effect on germination of sandalwood seed. The interaction of germination in sand method at 30 ± 2 ^{0}C and seed primed with GA_3 @ 100 ppm solution for 24 hrs. showed significantly higher germination (8.33 %) at 30 days while at 60 days it was significantly higher (46.66 %). The best treatment combination for interaction was germination in sand method at 30 ± 20C (C_3) temperature when seed primed with GA_3 @100 ppm solution for 24 hrs.(T_2) recorded highest germination percentage. From the data, it was also clear that the germination differed significantly due to different seed treatment, germination methods and temperature during the period of germination. It was noticed that at 60

days of germination period the germination increased when seed primed with GA_3 @100 ppm solution for 24 hrs. (T_2) with the increase in germination period. This to be found that various germination methods respond differently at different temperature and seed treatment with regards to their effect on germination. Similar results were observed by Khedkar (1996).

Table 7. Interaction effect germination methods, temperature and seed treatments on germination (%) of sandalwood seed

Treatment combinations	Germination (%)		
	Germination Period (Days)		
	30	45	60
$M_1C_1T_1$	0.00	3.00	6.66
$M_1C_1T_2$	1.66	22.00	23.33
$M_1C_1T_3$	1.33	16.00	19.33
$M_1C_1T_4$	1.33	17.67	20.33
$M_1C_2T_1$	0.66	4.00	7.66
$M_1C_2T_2$	2.66	23.66	27.66
$M_1C_2T_3$	2.00	18.00	21.66
$M_1C_2T_4$	2.33	19.33	23.66
$M_1C_3T_1$	1.00	4.33	8.33
$M_1C_3T_2$	2.66	25.00	29.33
$M_1C_3T_3$	1.66	19.67	23.00
$M_1C_3T_4$	2.00	19.33	24.00
$M_2C_1T_1$	0.00	2.000	4.00
$M_2C_1T_2$	0.33	4.66	10.33
$M_2C_1T_3$	0.00	2.66	6.00
$M_2C_1T_4$	0.66	3.00	5.66
$M_2C_2T_1$	0.00	2.33	5.00
$M_2C_2T_2$	1.00	5.66	9.33
$M_2C_2T_3$	0.33	3.66	7.00
$M_2C_2T_4$	0.33	4.33	9.33
$M_2C_3T_1$	0.00	4.00	7.33
$M_2C_3T_2$	1.00	13.33	17.67
$M_2C_3T_3$	0.33	5.33	8.66
$M_2C_3T_4$	0.66	5.66	9.33
$M_3C_1T_1$	0.33	5.66	9.66
$M_3C_1T_2$	2.00	27.67	31.33
$M_3C_1T_3$	1.33	16.00	25.33
$M_3C_1T_4$	1.66	19.33	29.66
$M_3C_2T_1$	1.00	7.33	10.66
$M_3C_2T_2$	5.33	32.33	34.33

Table 7 contd…..

Treatment combinations	Germination (%)		
	Germination Period (Days)		
	30	45	60
$M_3C_2T_3$	2.66	20.66	26.33
$M_3C_2T_4$	3.66	21.66	30.00
$M_3C_3T_1$	2.66	8.33	14.33
$M_3C_3T_2$	8.33	36.33	46.66
$M_3C_3T_3$	3.66	25.33	27.00
$M_3C_3T_4$	4.00	27.00	36.00
S.E. $\pm$	0.30	0.83	0.87
CD at 5 %	0.85	2.33	2.46

4.1.8 Effect of seed treatments on seedling length (cm) of sandalwood seed

From the data provided in the Table 8 it was revealed that different seed treatments had significant effect on root length during the period of germination.

Table 8 shows that the seed primed with GA_3@ 100ppm solution for 24 hrs. (T_2) recorded higher seedling length (2.13 cm) at 30 days than the other treatments, it was significantly higher (17.33cm) at 60 days. Removal of dormancy is most important for early and faster germination of seed which ultimately leads to maximum seedling length. Ananthapadmanabha *et al.*, (1988) reported that gibberellic acid can remove the dormancy from seed.

Table 8. Effect of seed treatments on seedling length of sandalwood seed

Treatments	Seedling length (cm)		
	Germination Period (Days)		
	30	45	60
Hydro-priming (T_1)	0.85	8.30	13.53
Priming with GA_3 @ 100 ppm for 24 hrs. (T_2)	2.13	11.89	17.33
Priming with 2 % KNO_3 for 24 hrs. (T_3)	1.50	10.60	15.53
Priming with 3 % KNO_3 for 24 hrs. (T_4)	1.84	11.44	16.23
S.E. $\pm$	0.10	0.18	0.16
CD at 5 %	0.30	0.51	0.45

4.1.9 Effect of germination methods on seedling length (cm) of sandalwood seed

From the data provided in the Table 9 it was revealed that the different germination methods had significant effect on seedling length during all the period of germination.

The sand method (M_3) recorded significantly higher seedling length (2.66 cm) at 30 days while it was (19.20 cm) at 60 days.

Among the germination methods, sand method (M_3) recorded high seedling length. This might be due to the optimum support that sand media provides for growth and development of the root and shoot as compared to the Between paper method and top of paper method. The sand might have provided optimum moisture for imbibition by seed which is the first step in germination process Similar observations were also been made by Kalavathi, (1996), in *Cassia angustifolia and Carthamus roseus.*

Table 9. Effect of germination methods on germination seedling length (cm) of sandalwood seed

Methods	Seedling length(cm)		
	Germination Period (Days)		
	30	45	60
Between paper method (M_1)	1.36	10.02	14.31
Top of paper method (M_2)	0.72	9.62	13.46
Sand method (M_3)	2.66	12.03	19.20
S.E. $\pm$	0.09	0.15	0.14
CD at 5 %	0.26	0.44	0.39

4.1.10 Effect of temperature on seedling length (cm) of sandalwood seed

It was observed from the data provided in the Table 10 that the different germination temperatures had significant effect on seedling length of sandalwood seed.

At 30 ± 2^0C (C_3) temperature significantly higher seedling length (1.56 cm) was recorded at 30 days while it was significantly highest (14.98 cm) at 60 days.

The high temperature known to cause increase in kinetic energy of water and decreases its viscosity. The enzyme activities of seeds leading resumption of embryo growth might have been high at 30^0C temperature. This led to increase in seedling length. Similar results were also been reported by Adarshkumar and Bhatnagar (1976).

Table 10. Effect of temperature on seedling length (cm) of sandalwood seed

Temperature	Seedling length (cm)		
	Germination Period (Days)		
	30	45	60
20 ± 2^0C (C_1)	1.18	10.00	14.30
25 ± 2^0C (C_2)	1.41	10.28	14.58
30 ± 2^0C (C_3)	1.56	10.21	14.98
S.E. ±	0.09	0.15	0.14
CD at 5 %	0.26	0.44	0.39

4.1.11 Interaction effect of germination methods and seed treatments on seedling length (cm) of sandalwood seed

From the data provided in the Table 11, it was recorded that, the interaction of germination method and seed treatment had non-significant effect on seedling length at 30, 45 and 60 days.

Table 11. Interaction effect of germination methods and seed treatments on seedling length (cm) of sandalwood seed.

Treatment combinations	Seedling length (cm)		
	Germination Period (Days)		
	30	45	60
M_1T_1	0.64	7.82	12.17
M_1T_2	1.90	11.28	15.91
M_1T_3	1.38	9.98	13.95
M_1T_4	1.54	10.98	15.21
M_2T_1	0.00	7.17	11.54
M_2T_2	1.47	10.90	14.82
M_2T_3	0.36	9.74	13.74
M_2T_4	1.06	10.68	13.73
M_3T_1	1.92	9.90	16.86
M_3T_2	3.02	13.47	21.26
M_3T_3	2.76	12.07	18.91
M_3T_4	2.94	12.67	19.75
S.E. $\pm$	0.19	0.31	0.28
CD at 5 %	NS	NS	NS

4.1.12 Interaction effect of temperature and seed treatments on seedling length (cm) of sandalwood seed

The data on interaction effect of temperature and seed treatments on seedling length are presented in the Table 12. It was noticed that the interactions of temperature and seed treatments had non-significant effect at 30 days. At 45 and 60 days (C_3T_2) showed significantly higher (13.00 cm) and (19.81cm) seedling length respectively.

Table 12. Interaction effect of temperature and seed treatments on seedling length (cm) of sandalwood seed

Treatment combinations	Seedling length (cm)		
	Germination Period (Days)		
	30	45	60
C_1T_1	0.23	7.32	12.22
C_1T_2	1.64	11.47	15.28
C_1T_3	1.14	10.41	14.40
C_1T_4	1.71	10.81	15.30
C_2T_1	1.17	8.44	13.33
C_2T_2	2.22	11.20	16.90
C_2T_3	1.51	11.08	15.51
C_2T_4	1.65	11.83	15.63
C_3T_1	1.15	9.133	15.03
C_3T_2	2.53	13.00	19.81
C_3T_3	1.85	10.31	16.70
C_3T_4	2.17	11.70	17.76
S.E. $\pm$	0.18	0.31	0.28
CD at 5 %	NS	0.89	0.79

4.1.13 Interaction effect of germination methods and temperature on root length (cm) of sandalwood seed

It was revealed from the data provided in the Table 13 that the interaction of germination method and temperature (M_3C_3) on seedling length of sandalwood seed was non-significant at 30 and 45 days. At 60 days of germination the root shoot length (21.77 cm) was significantly higher over rest of the germination period.

Table 13. Interaction effect of germination methods and temperature on seedling length (cm) of sandalwood seed

Treatment combinations	Seedling length (cm)		
	Germination Period (Days)		
	30	45	60
M_1C_1	1.05	9.65	14.04
M_1C_2	1.43	10.025	13.22
M_1C_3	1.62	10.38	15.67
M_2C_1	0.50	8.65	11.46
M_2C_2	0.67	10.02	14.38
M_2C_3	0.99	10.19	14.53
M_3C_1	1.99	11.69	17.40
M_3C_2	2.81	11.87	18.42
M_3C_3	3.17	12.53	21.77
S.E. $\pm$	0.16	0.27	0.24
CD at 5 %	NS	NS	0.68

4.1.14 Interaction effect of germination methods, temperature and seed treatments on seedling length (cm) of sandalwood seed

It was noticed from the data provided in the Table 14 that the interaction of germination methods, temperature and seed treatments ($M_3C_3T_2$) on seedling length was non- significant at 30 and 45 days while at 60 days of germination the root shoot length (24.23 cm) was significantly higher over rest of the germination period.

The seedling length of seedling shown in result revealed that, there was significant differences in seedling length due to different germination methods, temperature and seed treatments. GA_3 removes dormancy Norton (1986), sand act as good medium for optimum growth and 30 $\pm$ 2^0C temperature activates growth enzymes.

Table 14. Interaction effect of germination methods, temperature and seed treatments on seedling length (cm) of sandalwood seed

Treatment combinations	Seedling length (cm)		
	Germination Period (Days)		
	30	45	60
$M_1C_1T_1$	0.00	7.06	11.20
$M_1C_1T_2$	1.80	11.50	15.46
$M_1C_1T_3$	1.16	9.60	13.73
$M_1C_1T_4$	1.23	10.46	15.76
$M_1C_2T_1$	0.76	7.76	12.00
$M_1C_2T_2$	2.00	9.70	14.20
$M_1C_2T_3$	1.43	10.83	13.26
$M_1C_2T_4$	1.53	11.80	13.43
$M_1C_3T_1$	1.16	8.63	13.33
$M_1C_3T_2$	1.90	12.66	18.06
$M_1C_3T_3$	1.56	9.53	14.86
$M_1C_3T_4$	1.86	10.70	16.43
$M_2C_1T_1$	0.00	5.70	10.10
$M_2C_1T_2$	0.66	9.63	12.43
$M_2C_1T_3$	0.00	9.66	11.76
$M_2C_1T_4$	1.36	9.63	11.56
$M_2C_2T_1$	0.00	8.26	11.56
$M_2C_2T_2$	1.73	10.96	14.90
$M_2C_2T_3$	0.46	10.00	15.53
$M_2C_2T_4$	0.50	10.86	15.53
$M_2C_3T_1$	0.00	7.56	12.96
$M_2C_3T_2$	2.03	12.10	17.13
$M_2C_3T_3$	0.63	9.56	13.93
$M_2C_3T_4$	1.30	11.53	14.10
$M_3C_1T_1$	0.70	9.20	15.36
$M_3C_1T_2$	2.46	13.26	17.96
$M_3C_1T_3$	2.26	11.96	17.70
$M_3C_1T_4$	2.53	12.33	18.56
$M_3C_2T_1$	2.76	9.30	16.43
$M_3C_2T_2$	2.93	12.93	21.60
$M_3C_2T_3$	2.63	12.43	17.73
$M_3C_2T_4$	2.93	12.83	17.93
$M_3C_3T_1$	2.30	11.20	18.80
$M_3C_3T_2$	3.66	14.23	24.23
$M_3C_3T_3$	3.36	11.83	21.30
$M_3C_3T_4$	3.36	12.86	22.76
S.E. $\pm$	0.32	0.55	0.48
CD at 5 %	NS	NS	1.37

4.1.15 Effect of seed treatments on dry matter content (g) of sandalwood seed

It was revealed from the data provided in Table 15 that different seed treatment had significant effect on dry matter content during the period of germination. When the seed primed with GA_3 @ 100 ppm solution for 24 hrs. (T_2) recorded higher dry matter content (0.23 g) at 30 days while at 60 days it was (0.92 g), which was significantly higher over other treatments. Dry matter content of seedling increases due to activation of enzymes and also energy produced during germination by acid treatment i.e. GA_3 (Norton ,1986) which resulted in elongation of root and shoot length.

Table 15. Effect of seed treatment on dry matter content (g) of sandalwood seed

Treatments	Dry matter content (g)		
	Germination Period (Days)		
	30	45	60
Hydro-priming (T_1)	0.09	0.51	0.73
Priming with GA_3 @ 100 ppm for 24 hrs. (T_2)	0.22	0.66	0.92
Priming with 2 % KNO_3 for 24 hrs. (T_3)	0.16	0.59	0.82
Priming with 3 % KNO_3 for 24 hrs. (T_4)	0.19	0.63	0.86
S.E. $\pm$	0.01	0.01	0.01
CD at 5 %	0.03	0.03	0.02

4.1.16 Effect of germination methods on dry matter content (g) of sandalwood seed

It was revealed from the data provided in the Table 16 that the different germination methods had significant effect on dry matter content (g). The sand method (M_3) recorded significantly higher dry matter content (0.28 g) than other two methods (M_1 and M_2). At 60 days it was significantly higher (1.00 g). Sand media is better for optimum growth. Similar results were found in Bael by Venudevan *et al.* (2013).

Table 16. Effect of seed germination method on dry matter content (g) of sandalwood seed

Methods	Dry matter content (g)		
	Germination Period (Days)		
	30	45	60
Between paper method (M_1)	0.15	0.57	0.78
Top of paper method (M_2)	0.08	0.55	0.72
Sand method (M_3)	0.28	0.67	1.00
S.E. $\pm$	0.01	0.009	0.008
CD at 5 %	0.03	0.02	0.02

4.1.17 Effect of temperatures on dry matter content (g) of sandalwood seed

It was observed from the data provided in the Table 17 that the different germination temperatures had significant effect on dry matter content of sandalwood seed.

At 30 ± 2^0C (C_3) temperature significantly higher dry matter content was observed. The dry matter content at 30 days of observation was (0.173 g) after at 60 days it was significantly highest (0.80g)Optimum temperature activates the growth enzymes in seeds leading to its growth and ultimate increase in dry matter content is observed 30 ± 2^0C is good for germination. Similar results were observed in *Tamarindus indica* by Ganigara *et al.* (1995b).

Table 17. Effect of seed germination temperature on dry matter content (g) of sandalwood seed

Temperature	Dry matter content (g)		
	Germination Period (Days)		
	30	45	60
20 ± 2^0C (C_1)	0.13	0.57	0.77
25 ± 2^0C (C_2)	0.15	0.58	0.79
30 ± 2^0C (C_3)	0.17	0.58	0.80
S.E. $\pm$	0.01	0.009	0.008
CD at 5 %	0.03	0.02	0.02

4.1.18 Interaction effect of germination methods and seed treatments on dry matter content (g)

From the data provided in the Table 18 it was revealed that, the interaction effect of germination method and seed treatment was non- significant.

Table 18. Interaction effect of germination methods and seed treatments on dry matter content (g) of sandalwood seed

Treatment combinations	Dry matter content(g)		
	Germination Period (Days)		
	30	45	60
M_1T_1	0.09	0.48	0.67
M_1T_2	0.20	0.63	0.85
M_1T_3	0.14	0.57	0.76
M_1T_4	0.16	0.60	0.83
M_2T_1	0.00	0.46	0.63
M_2T_2	0.17	0.60	0.80
M_2T_3	0.03	0.55	0.72
M_2T_4	0.12	0.59	0.73
M_3T_1	0.20	0.58	0.87
M_3T_2	0.31	0.74	1.12
M_3T_3	0.29	0.67	0.98
M_3T_4	0.30	0.69	1.02
S.E. $\pm$	0.02	0.01	0.01
CD at 5 %	NS	NS	NS

4.1.19 Interaction effect of germination temperature and seed treatments on dry matter content (g) of sandalwood seed

From the data provided in the Table 19 it was revealed that, the interaction effect of germination temperature and seed treatment was non- significant at 30 days while significant at 45 and 60 days. At 45 days interaction of germination at30 $\pm$ 2^0C and seed primed with GA_3 @ 100ppm solution (C_3T_2) recorded

significantly higher dry matter content (0.71 g) and at 60 days it was significantly highest (1.079 g).

Table 19. Interaction effect of temperature and seed treatments on dry matter content (g) of sandalwood seed

Treatment combinations	Dry matter content (g)		
	Germination Period (Days)		
	30	45	60
C_1T_1	0.02	0.47	0.66
C_1T_2	0.17	0.63	0.82
C_1T_3	0.13	0.59	0.78
C_1T_4	0.19	0.60	0.82
C_2T_1	0.12	0.50	0.72
C_2T_2	0.23	0.62	0.87
C_2T_3	0.16	0.61	0.83
C_2T_4	0.17	0.65	0.84
C_3T_1	0.14	0.56	0.79
C_3T_2	0.27	0.71	1.07
C_3T_3	0.18	0.58	0.84
C_3T_4	0.22	0.64	0.92
S.E. $\pm$	0.02	0.01	0.01
CD at 5 %	NS	0.05	0.04

4.1.20 Interaction effect of germination temperature and germination method on dry matter content (g) of sandalwood seed

From the data, Table 20, it was revealed that, the interaction effect of germination temperature and seed treatment was non-significant at 30 and 45 days. At 60 days (M_3C_3) recorded significantly higher dry matter content (1.140 g).

Table 20. Interaction effect of germination methods and temperature on dry matter content (g) of sandalwood seed

Treatment combinations	Dry matter content (g)		
	Germination Period (Days)		
	30	45	60
M_1C_1	0.10	0.55	0.77
M_1C_2	0.15	0.56	0.72
M_1C_3	0.18	0.60	0.84
M_2C_1	0.06	0.51	0.63
M_2C_2	0.06	0.57	0.77
M_2C_3	0.11	0.57	0.76
M_3C_1	0.23	0.65	0.91
M_3C_2	0.29	0.66	0.95
M_3C_3	0.32	0.70	1.14
S.E. $\pm$	0.01	0.01	0.01
CD at 5 %	NS	NS	0.04

4.1.21 Interaction effect of germination methods, temperature and seed treatments on dry matter content (g) of sandalwood seed

It was revealed from the data Table 21 that the interaction of germination methods, temperature and seed treatments on dry matter content (g) was non- significant at 30 and 45 days.

The interaction of sand method and kept at temperature 30 ± 2^0C and seed primed with GA_3 @ 100 ppm solution for 24 hrs. ($M_3C_3T_2$) recorded significantly higher dry matter content (1.377 g) at 60 days.

Table 21. Interaction effect of germination methods, temperature and seed treatments on dry matter content (g) of sandalwood seed

Treatment combinations	Dry matter content (g)		
	Germination Period (Days)		
	30	45	60
$M_1C_1T_1$	0.00	0.46	0.62
$M_1C_1T_2$	0.17	0.62	0.84
$M_1C_1T_3$	0.12	0.56	0.77
$M_1C_1T_4$	0.13	0.57	0.86
$M_1C_2T_1$	0.08	0.46	0.66
$M_1C_2T_2$	0.23	0.54	0.76
$M_1C_2T_3$	0.15	0.59	0.74
$M_1C_2T_4$	0.16	0.65	0.74
$M_1C_3T_1$	0.18	0.52	0.75
$M_1C_3T_2$	0.20	0.73	0.94
$M_1C_3T_3$	0.16	0.55	0.76
$M_1C_3T_4$	0.20	0.59	0.90
$M_2C_1T_1$	0.00	0.41	0.57
$M_2C_1T_2$	0.08	0.53	0.69
$M_2C_1T_3$	0.00	0.57	0.64
$M_2C_1T_4$	0.17	0.55	0.63
$M_2C_2T_1$	0.00	0.51	0.63
$M_2C_2T_2$	0.16	0.61	0.78
$M_2C_2T_3$	0.05	0.56	0.80
$M_2C_2T_4$	0.05	0.61	0.86
$M_2C_3T_1$	0.00	0.46	0.69
$M_2C_3T_2$	0.26	0.66	0.91
$M_2C_3T_3$	0.06	0.53	0.71
$M_2C_3T_4$	0.14	0.63	0.71
$M_3C_1T_1$	0.08	0.53	0.79
$M_3C_1T_2$	0.27	0.74	0.93
$M_3C_1T_3$	0.27	0.65	0.95
$M_3C_1T_4$	0.28	0.67	0.96
$M_3C_2T_1$	0.29	0.52	0.88
$M_3C_2T_2$	0.29	0.71	1.06
$M_3C_2T_3$	0.28	0.69	0.94
$M_3C_2T_4$	0.29	0.70	0.93
$M_3C_3T_1$	0.23	0.69	0.94
$M_3C_3T_2$	0.36	0.75	1.37
$M_3C_3T_3$	0.33	0.65	1.06
$M_3C_3T_4$	0.33	0.71	1.17
S.E. $\pm$	0.03	0.03	0.02
CD at 5 %	NS	NS	0.08

4.1.22 Effect of seed treatments on vigour index-I of sandalwood seed

It was revealed from the data Table 22 that different seed treatment had significant effect on vigour index-I. At 30 days the seed primed with GA_3 @ 100 ppm solution (T_2) recoded higher vigour index-I (7.71) than the other treatments, while at 60 days it was significantly higher (476.79).

Table 22. Effect of seed treatments on vigour index-I of sandalwood seed

Treatments	Vigour Index-I		
	Germination Period (Days)		
	30	45	60
Hydro-priming (T_1)	1.32	40.29	118.36
Priming with GA_3 @ 100 ppm for 24 hrs. (T_2)	7.71	263.36	476.79
Priming with 2 % KNO_3 for 24 hrs. (T_3)	3.40	155.15	298.15
Priming with 3 % KNO_3 for 24 hrs. (T_4)	4.55	180.86	364.91
S.E. $\pm$	0.37	4.21	5.95
CD at 5 %	1.04	11.83	16.74

4.1.23 Effect of germination methods on vigour index-I of sandalwood seed

It was revealed from the data, Table 23 that the different germination methods had significant effect on vigour index-I during all the period of germination.

The sand method (M_3) had significantly higher vigour index-I than Between paper method (M_1) and top of paper method (M_2). At 30 days it was (9.40) and progressively recorded highest (535.71) at 60 days. Due to availability of optimum moisture and proper exchange of gases in sand medium it records maximum growth of seedling and also the maximum germination percentage is observed in this method so ultimate increase in vigour index-I is also observed.

Sand media is better for good seed germination. Similar results were found in *Ephedra gerandiana* by Bhagat *et al.* (1992)

Table 23. Effect of seed germination methods on vigour index-I of sandalwood seed

Methods	Vigour Index-I		
	Germination Period (Days)		
	30	45	60
Between paper method (M_1)	2.61	170.27	290.91
Top of paper method (M_2)	0.72	48.58	117.03
Sand method (M_3)	9.40	260.89	535.71
S.E. ±	0.32	3.64	5.16
CD at 5 %	0.90	10.25	14.49

4.1.24 Effect of temperature on vigour index-I of sandalwood seed

It was observed from the data, Table 24 that the different germination temperatures had significant effect on vigour index-I during. At 30 ± 2^0C (C_3) significantly higher vigour index-I was recoded at 30 days and progressively increased upto (276.62) at 60 days. Optimum temperature gives optimum growth laed to maximum vigour index 30 ± 2^0C is good for germination. Similar results were observed in *Tamarindus indica* by (Ganigara *et al.*, 1995b).

Table 24. Effect of seed germination temperature on vigour index-I of sandalwood seed

Temperature	Vigour Index-I		
	Germination Period (Days)		
	30	45	60
20 ± 2^0C (C_1)	1.77	131.22	253.45
25 ± 2^0C (C_2)	2.01	134.02	258.26
30 ± 2^0C (C_3)	3.17	137.68	276.62
S.E. ±	0.32	3.64	5.16
CD at 5 %	0.90	10.25	14.49

4.1.25 Interaction effect of germination methods and seed treatments vigour index-I of sandalwood seed

It was observed from the data, Table 25 that, the interaction effect of germination method and seed treatment had significant effect on vigour index-I of sandalwood. At 30 days the interaction of germination in sand (M_3) method and seed

primed with GA_3 @ 100 ppm solution (T_2), (M_3T_2) recorded significantly higher vigour index-I (17.18) while at 60 days the vigour index-I was significantly highest (811.70). Kucera *et al.* (2005) concluded from his experiments that gibberellins counteract ABA effects and promote seed germination. Higher seed germination gives higher vigour index-I

Table 25. Interaction effect of germination methods and seed treatments vigour index-I of sandalwood seed

Treatment combinations	Vigour Index-I		
	Germination Period (Days)		
	30	45	60
M_1T_1	0.64	28.98	92.27
M_1T_2	4.46	266.71	428.60
M_1T_3	2.36	178.15	298.18
M_1T_4	3.00	207.25	344.61
M_2T_1	0.00	20.41	64.42
M_2T_2	1.47	89.16	190.07
M_2T_3	0.36	37.65	99.88
M_2T_4	1.05	47.12	113.75
M_3T_1	3.33	71.47	198.38
M_3T_2	17.18	434.21	811.70
M_3T_3	7.47	249.65	496.37
M_3T_4	9.61	288.22	636.38
S.E. $\pm$	0.64	7.29	10.32
CD at 5 %	1.80	20.50	28.99

4.1.26 Interaction effect of temperature and seed treatments on vigour index-I of sandalwood seed

It was observed from the data, Table 26 that the interaction effect of temperature and seed treatments on vigour index-I was significant. At 30 days of observation the interaction of temperature 30 ± 20C and seed primed with GA_3 @

100ppm solution (C_3T_2) recorded significantly higher vigour index-I (12.578) while at 60 days it was significantly highest (654.61).

Table 26. Interaction effect of temperature and seed treatments on vigour index-I of sandalwood seed

Treatment combinations	Vigour Index-I		
	Germination Period (Days)		
	30	45	60
C_1T_1	0.23	28.17	88.75
C_1T_2	2.95	222.00	351.17
C_1T_3	1.50	123.42	261.16
C_1T_4	2.42	151.30	312.72
C_2T_1	1.17	39.37	108.01
C_2T_2	7.60	236.63	424.58
C_2T_3	3.44	162.88	287.80
C_2T_4	4.94	184.43	333.18
C_3T_1	2.56	53.32	158.32
C_3T_2	12.57	331.45	654.61
C_3T_3	5.26	179.15	345.48
C_3T_4	6.30	206.86	448.84
S.E. $\pm$	0.64	7.29	10.32
CD at 5 %	1.80	20.50	28.99

4.1.27 Interaction effect of germination methods and temperature on vigour index-I of sandalwood seed

It was observed from the data, Table 27 that the interaction of germination method and temperature on vigour index-I was significant. At 30 days the interaction of germination in sand method at 30 ± 2^0C (M_3C_3) recorded significantly higher vigour index-I (15.89) than the other interactions while at 60 days it was significantly highest (698.70).

Table 27. Interaction effect of germination methods and temperature on vigour index-I of sandalwood seed

Treatment combinations	Vigour Index-I		
	Germination Period (Days)		
	30	**45**	**60**
M_1C_1	1.567	153.45	255.87
M_1C_2	3.142	170.83	272.55
M_1C_3	3.15	186.55	344.32
M_2C_1	0.50	27.86	76.425
M_2C_2	0.67	41.10	112.25
M_2C_3	0.99	76.79	162.42
M_3C_1	3.25	212.38	428.06
M_3C_2	9.05	255.58	480.37
M_3C_3	15.82	314.78	698.70
S.E. $\pm$	0.55	6.32	8.93
CD at 5 %	1.56	17.75	25.10

4.1.28 Interaction effect of germination methods, temperature and seed treatments on vigour index-I of sandalwood seed

It was observed from the data, Table 28 that the interaction of germination methods, temperature and seed treatments on vigour index-I was non- significant at 45 days. But it was significant at 30 and 60 days. The interaction of vigour index- I in sand method and kept at 30 ± 2^0C and seed primed with GA_3 @ 100ppm solution ($M_3C_3T_2$) showed significantly higher vigour index-I (30.667) at 30 days while at 60 days it was significantly highest (1131.267).

Table 28. Interaction effect of germination methods, temperature and seed treatments on vigour index-I of sandalwood seed

Treatment combination	Vigour index-I		
	Germination Period (Days)		
	30	45	60
$M_1C_1T_1$	0.00	20.80	75.26
$M_1C_1T_2$	3.00	253.93	362.00
$M_1C_1T_3$	1.56	152.86	265.03
$M_1C_1T_4$	1.70	186.20	321.20
$M_1C_2T_1$	0.76	30.20	91.26
$M_1C_2T_2$	5.36	229.76	393.46
$M_1C_2T_3$	2.86	195.13	288.00
$M_1C_2T_4$	3.56	228.23	317.50
$M_1C_3T_1$	1.16	35.96	110.30
$M_1C_3T_2$	5.03	316.43	530.33
$M_1C_3T_3$	2.66	186.46	341.53
$M_1C_3T_4$	3.73	207.33	395.13
$M_2C_1T_1$	0.00	11.40	40.53
$M_2C_1T_2$	0.66	45.16	128.70
$M_2C_1T_3$	0.00	26.00	70.80
$M_2C_1T_4$	1.36	28.90	65.66
$M_2C_2T_1$	0.00	19.56	57.46
$M_2C_2T_2$	1.73	61.83	139.30
$M_2C_2T_3$	0.46	36.33	108.33
$M_2C_2T_4$	0.50	46.70	143.93
$M_2C_3T_1$	0.00	30.26	95.26
$M_2C_3T_2$	2.03	160.50	302.23
$M_2C_3T_3$	0.63	50.63	120.53
$M_2C_3T_4$	1.30	65.76	131.67
$M_3C_1T_1$	0.70	52.33	150.46
$M_3C_1T_2$	5.20	366.90	562.83
$M_3C_1T_3$	2.93	191.40	447.66
$M_3C_1T_4$	4.20	238.80	551.30
$M_3C_2T_1$	2.76	68.36	175.30
$M_3C_2T_2$	15.70	418.30	741.00
$M_3C_2T_3$	7.00	257.20	467.06
$M_3C_2T_4$	10.76	278.36	538.13
$M_3C_3T_1$	6.53	93.73	269.40
$M_3C_3T_2$	30.66	517.43	1131.27
$M_3C_3T_3$	12.50	300.36	574.40
$M_3C_3T_4$	13.86	347.50	819.73
S.E. $\pm$	1.11	12.64	17.87
CD at 5 %	3.12	NS	50.21

4.1.29 Effect of seed treatments on vigour index-II of sandalwood seed

It was observed from the data, Table 29 that different seed treatment had significant effect on vigour index-II during the period of germination. The vigour index-II was increased with increase in germination period. At 30 days when the seed were primed with (T_2) recorded higher vigour index-II (0.797) than the other treatments, while at 60 days it was significantly highest (25.481).

Table 29. Effect of seed treatments on vigour index-II of sandalwood seed

Treatments	Vigour index-II		
	Germination Period (Days)		
	30	45	60
Hydro-priming (T_1)	0.14	2.47	6.30
Priming with GA_3 @ 100 ppm for 24 hrs. (T_2)	0.79	14.58	25.48
Priming with 2 % KNO_3 for 24 hrs. (T_3)	0.35	8.74	15.78
Priming with 3 % KNO_3 for 24 hrs. (T_4)	0.47	9.99	19.35
S.E. $\pm$	0.03	0.26	0.33
CD at 5 %	0.10	0.74	0.93

4.1.30 Effect of germination methods on vigour index-II of sandalwood seed

It was revealed from the data, Table 30 that the different germination methods had significant effect on vigour index-II. The sand method (M_3) had significantly higher vigour index-II than other two methods (M_1 and M_2). At 30 days vigour index-II of sandalwood seed was (0.963) while at 60 days it was significantly highest (28.130). Sand media is better for good seed germination. Similar results were found in *Ephedra gerandiana* by Bhagat *et al.* (1992). More is the germination (%) more will be the vigour index-II.

Table 30. Effect of germination methods on vigour index-II

Methods	Vigour index-II		
	Germination Period (Days)		
	30	45	60
Between paper method (M_1)	0.28	9.62	15.80
Top of paper method (M_2)	0.08	2.75	6.26
Sand method (M_3)	0.96	14.46	28.13
S.E. ±	0.03	0.22	0.28
CD at 5 %	0.09	0.64	0.81

4.1.31 Effect of temperature on vigour index-II of sandalwood seed

It was revealed from the data, Table 31 that the different germination temperatures had significant effect on vigour index-II. C_3 recorded the better effect than other temperatures. At 30 days vigour index-II was (0.344) while at 60 days it was significantly highest (14.606). 30 ± 2^0C is good for germination. Similar results were observed in *Tamarindus indica* by (Ganigara *et al.*, 1995b).

Table 31. Effect of temperature on vigour index-II of sandalwood seed

Temperature	Vigour index-II		
	Germination Period (Days)		
	30	45	60
20 ± 2^0C (C_1)	0.19	7.35	13.59
25 ± 2^0C (C_2)	0.22	7.49	13.87
30 ± 2^0C (C_3)	0.34	7.70	14.60
S.E. ±	0.03	0.22	0.28
CD at 5 %	0.09	0.64	0.81

4.1.32 Interaction effect of germination methods and seed treatments vigour index-II of sandalwood seed

It was revealed from the data, Table 32 that, the interaction effect of germination method and seed treatment on vigour index-II was significant. At 30 days the interaction of germination in sand method and seed primed with GA_3 @ 100ppm solution (M_3T_2) recorded significantly higher vigour index-II (1.734), while at 60 days it was significantly highest (4.363).

Table 32. Interaction effect of germination methods and seed treatments vigour index-II of sandalwood seed

Treatment combinations	Vigour index-II		
	Germination Period (Days)		
	30	**45**	**60**
M_1T_1	0.09	1.82	5.13
M_1T_2	0.48	15.02	22.85
M_1T_3	0.24	10.20	16.24
M_1T_4	0.32	11.43	18.97
M_2T_1	0.00	1.30	3.52
M_2T_2	0.17	4.95	10.22
M_2T_3	0.03	2.14	5.21
M_2T_4	0.12	2.63	6.08
M_3T_1	0.35	4.30	10.26
M_3T_2	1.73	23.78	43.36
M_3T_3	0.78	13.87	25.89
M_3T_4	0.98	15.91	33.00
S.E. $\pm$	0.06	0.45	0.57
CD at 5 %	0.18	1.28	1.62

4.1.33 Interaction effect of temperature and seed treatments on vigour index-II of sandalwood seed

It was revealed from the data, Table 32that the interaction effect of temperature and seed treatments on vigour index-II was significant. At 30 days the interaction of temperature 30 ± 2 ^{0}C and seed primed with GA_3 @ 100ppm solution (C_3T_2) recorded significantly higher vigour index-II (1.28) while at 60 days it was significantly highest (36.01).

Table 33. Interaction effect of temperature and seed treatments on vigour index-II of sandalwood seed

Treatment combinations	Vigour index-II		
	Germination Period (Days)		
	30	**45**	**60**
C_1T_1	0.02	1.75	4.76
C_1T_2	0.31	12.36	18.74
C_1T_3	0.17	6.99	14.27
C_1T_4	0.27	8.30	16.59
C_2T_1	0.12	2.30	5.86
C_2T_2	0.79	13.23	21.68
C_2T_3	0.36	9.05	15.60
C_2T_4	0.50	10.17	17.87
C_3T_1	0.28	3.36	8.29
C_3T_2	1.28	18.16	36.01
C_3T_3	0.52	10.17	17.46
C_3T_4	0.64	11.51	23.58
S.E. $\pm$	0.06	0.45	0.57
CD at 5 %	0.18	1.28	1.62

4.1.34 Interaction effect of germination methods and temperature on vigour index-II of sandalwood seed

It was revealed from the data, Table 34 that the interaction of germination method and temperature had significant effect on vigour index-II. At 30 days the interaction of germination in sand method at 30 ± 2^0C for germination (M_3C_3) recoded significantly higher vigour index-II (1.59) than the other interactions while at 60 days of the observed vigour index-II was significantly highest (37.22). Sand media is better for optimum growth. Similar results were found in Bael by Venudevan *et al.* (2013)

Table 34. Interaction effect of germination methods and temperature on vigour index-II of sandalwood seed

Treatment combinations	Vigour index-II		
	Germination Period (Days)		
	30	45	60
M_1C_1	0.16	8.58	14.14
M_1C_2	0.35	9.52	14.98
M_1C_3	0.34	10.75	18.27
M_2C_1	0.06	1.63	4.24
M_2C_2	0.06	2.34	6.02
M_2C_3	0.11	4.29	8.51
M_3C_1	0.37	11.83	22.40
M_3C_2	0.92	14.20	24.76
M_3C_3	1.59	17.36	37.22
S.E. $\pm$	0.05	0.39	0.50
CD at 5 %	0.16	1.11	1.40

4.1.35 Interaction effect of germination methods, temperature and seed treatments on vigour index-II of sandalwood seed

It was revealed from the data, Table 35 that the interaction effect of germination methods, temperature and seed treatments on vigour index-II was non – significant at 45 days but significant at 30 and 45 days.. The interaction of vigour index-II in sand method and kept at 30 ± 20C and seed primed with GA_3 @ 100 ppm solution ($M_3C_3T_2$) recorded significantly higher vigour index-II (3.06) while at 60 days vigour index-II was significantly highest (64.22). Vigour index-I and II was maximum when seed treated with GA_3 @100 ppm solution for 24 hrs. (T_2) and these kept at 30 ± 2^0C temperature in sand method for germination. Increased germination and seedling length has contributed to significant higher vigour index-I and II When the seed treatment with GA_3 @100 ppm solution for 24 hrs. (T_2) and these kept at 30

± 2^0C temperature in sand method exhibited highest seedling vigour index-I and II, Similar results had also been reported by Pallavi *et al.* (2014).

Table 35. Interaction effect of germination methods, temperature and seed treatments on vigour index-II of sandalwood seed

Treatment combinations	Vigour index-II		
	Germination Period (Days)		
	30	45	60
$M_1C_1T_1$	0.00	1.36	4.18
$M_1C_1T_2$	0.28	13.90	19.81
$M_1C_1T_3$	0.17	8.92	14.87
$M_1C_1T_4$	0.18	10.15	17.68
$M_1C_2T_1$	0.08	1.84	5.01
$M_1C_2T_2$	0.65	12.93	21.09
$M_1C_2T_3$	0.30	10.75	16.23
$M_1C_2T_4$	0.37	12.58	17.57
$M_1C_3T_1$	0.18	2.25	6.21
$M_1C_3T_2$	0.52	18.23	27.65
$M_1C_3T_3$	0.27	10.94	17.60
$M_1C_3T_4$	0.40	11.57	21.64
$M_2C_1T_1$	0.00	0.83	2.30
$M_2C_1T_2$	0.08	2.51	7.16
$M_2C_1T_3$	0.00	1.53	3.89
$M_2C_1T_4$	0.17	1.65	3.60
$M_2C_2T_1$	0.00	1.20	3.13
$M_2C_2T_2$	0.16	3.49	7.34
$M_2C_2T_3$	0.05	2.05	5.58
$M_2C_2T_4$	0.05	2.63	8.03
$M_2C_3T_1$	0.00	1.87	5.12
$M_2C_3T_2$	0.26	8.85	16.15
$M_2C_3T_3$	0.06	2.84	6.17
$M_2C_3T_4$	0.14	3.62	6.62
$M_3C_1T_1$	0.08	3.07	7.79
$M_3C_1T_2$	0.56	20.66	29.25
$M_3C_1T_3$	0.36	10.52	24.06
$M_3C_1T_4$	0.47	13.09	28.49
$M_3C_2T_1$	0.29	3.87	9.44

Table 35 contd….

Treatment combinations	Vigour index-II		
	Germination Period (Days)		
	30	**45**	**60**
$M_3C_2T_2$	1.57	23.26	36.61
$M_3C_2T_3$	0.75	14.37	24.98
$M_3C_2T_4$	1.07	15.31	28.01
$M_3C_3T_1$	0.66	5.97	13.55
$M_3C_3T_2$	3.06	27.40	64.22
$M_3C_3T_3$	1.25	16.73	28.62
$M_3C_3T_4$	1.39	19.33	42.49
S.E. $\pm$	0.11	0.79	1.00
CD at 5 %	0.31	NS	2.80

5. SUMMARY AND CONCULSION

The present investigation was undertaken to standardize seed germination testing procedure of sandalwood (*Santalum album* L.). The experiment was conducted during season 2016-2017, at Seed Technology Research Unit (STRU), M.P.K.V., Rahuri.

The sandalwood seeds were treated with different chemicals *viz.,* Hydro-priming for 24 hrs. (T_1), priming with GA_3 @ 100 ppm for 24 hrs. (T_2), priming with 2% KNO_3 (T_3) and priming 3 % KNO_3 for 24 hrs. (T_4).

The treated seeds were germinated with different germination methods *viz.,* between paper method (M_1), sand method (M_2), top of paper method (M_3) at three different temperatures *viz.,* 20 $\pm 2^0$C (C_1), 25 $\pm$ 2^0C (C_2) and 30 $\pm$ 2^0C (C_3) were used for standardization of germination protocol. The experiment was conducted in Factorial Completely Randomized Design (FCRD) with three replications to assess the suitable method, temperature and treatment for germination of sandalwood seed.

The observation of seed quality attributes were recorded *viz.,* germination (%), seedling length (cm), dry matter content of seedling (g), vigour index-I and vigour index-II.

5.1 Summary

The important findings of the investigation are summarized, as below.

5.1.1 Germination (%)

The Sandalwood seed exhibited consistently higher germination when seed primed with 100 ppm GA_3 than the other treatments. Gibberellins counteract ABA effects and promote seed germination. The sand method recorded highest germination when kept at 30 $\pm$ 2^0C temperature under the studies. During 60 days of germination period, the seeds treated with GA_3 @ 100ppm solution for 24 hrs. kept at 30 $\pm$ 2^0C in sand method for germination ($M_3C_3T_2$) recorded consistently higher germination than the other treatments, germination methods and temperatures. Therefore, 100 ppm GA_3 seed treatment, sand method and 30 $\pm$ 2^0C temperature found suitable for germination of sandalwood seed.

5.1.2 Root and shoot length (cm)

The seed treated with 100 ppm GA_3 solution and kept at 30 $\pm$ 2^0C temperature in sand showed consistently higher seedling length as its germination was higher. In the storage condition the seed when primed with 100ppm GA_3 solution kept at 30 $\pm$ 2^0C temperature in sand exhibited consistent high seedling length than combination.

5.1.3 Seedling dry matter content (g)

The seedling dry weight exhibited significantly higher value due to the seed primed with 100 ppm GA_3 for 24 hrs. During 60 days of germination period seeds primed with 100 ppm GA_3 kept at 30 $\pm$ 2^0C in sand for germination ($M_3C_3T_2$) recorded consistently higher seedling dry weight than the other treatments, germination methods and temperature.

5.1.4 Vigour index I and II

The seed primed with 100ppm GA_3 for 24 hrs. kept in sand method at 30 $\pm$ 2^0C temperature exhibited consistently higher vigour index than the other treatments, germination methods and temperature combination.

5.2 Conclusion

The following broad conclusions are drawn from the present studies.

1. It is concluded that the seed primed with GA_3 @ 100 ppm for 24 hrs. recorded higher germination (%) over other treatments.
2. The sand method was found as a suitable germination method for sandalwood seed for getting higher germination percentage.
3. The temperature 30 ± 2^OC was found suitable for germination of sandalwood seed.
4. The interaction of seeds priming with GA_3 @ 100 ppm for 24 hrs. and kept in sand method at 30 ± 2^0C ($M_3C_3T_2$) were the better conditions for higher germination (46.66 %) and also for other seed quality parameters like seedling length (24.23 cm), dry matter content (1.37g), vigour index-I (1131.27) and vigour index-II (64.22).

The above mentioned conclusions are based on the results of one season experiment and needs further experiment to confirm the results.

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7. VITAE

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