

EFFECT OF PRE SOWING TREATMENTS ON SEED GERMINATION AND ITS PARAMETERS IN SANDALWOOD (*Santalum album* L.)

By

MAMIDI HEMALATHA

(Registration No-2010118057)

B. Sc. (Hons.) Agri.



**DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY
COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH - 362 001**

SEPTEMBER - 2020

EFFECT OF PRE SOWING TREATMENTS ON SEED GERMINATION AND ITS PARAMETERS IN SANDALWOOD (*Santalum album* L.)

**A THESIS SUBMITTED TO
JUNAGADH AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF SCIENCE
IN
SEED SCIENCE AND TECHNOLOGY**

**BY
MAMIDI HEMALATHA**

(Registration No-2010118057)

B. Sc. (Hons.) Agri.



**DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY
COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH - 362 001**

SEPTEMBER - 2020

EFFECT OF PRE SOWING TREATMENTS ON SEED GERMINATION AND ITS PARAMETERS IN SANDALWOOD (*Santalum album* L.)

By

MAMIDI HEMALATHA

(Registration No-2010118057)

B. Sc. (Hons.) Agri.



**DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY
COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH - 362 001**

SEPTEMBER - 2020

**DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY
COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH – 362 001 (GUJARAT)**

Name of Student

MAMIDI HEMALATHA

Name of Major Guide

Dr. S. B. CHAUDHARI

**EFFECT OF PRE SOWING TREATMENTS ON SEED GERMINATION
AND ITS PARAMETERS IN SANDALWOOD (*Santalum album* L.)**

ABSTRACT

Key words: Pre sowing, germination, treatments, sandalwood, scarification, sandpaper, ultrasonic sound

The present investigation was conducted under greenhouse condition in the Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh during *rabi* 2019-20 with an aim to study the effect of pre sowing treatments like aging [A₁ (8 months old seeds) and A₂ (new seeds)], scarification [S₁ (manual scarification with sandpaper) and S₂ (ultrasonic sound)] and different treatments [T₁ (GA₃ 100 ppm), T₂ (GA₃ 300 ppm), T₃ (KNO₃ at 2%), T₄ (cow dung for 24 hours), T₅ (cow dung for 48 hours), T₆ (ethrel 100 ppm) and T₇ (control)] on seed germination and its parameters in sandalwood (*Santalum album* L.). But aging factor was not considered as the number of germinated seeds is observed to be very less. The characters *viz.*, germination per cent, time taken for initiation of germination (TTIG), time taken for completion of germination (TTCG), speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedlings (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (length) and seedling vigour index (mass) were analyzed by completely randomize design (factorial).

The analysis of variance for seed germination and its parameters revealed that scarification and different treatments manifested significant differences for seed germination and all its parameters that are studied except the factor scarification, which had shown non-significant difference for collar diameter.

The results indicated that the 8 months old seeds had poor germination because of loss of viability. Therefore, the old seeds should not be preferred over new seeds in sandalwood.

Manual scarification with sandpaper (S_1) produced significantly the earliest seed emergence (38.61 days) and also resulted in maximum days for completion of germination (84.66 days) with highest germination per cent (35.38%), speed of germination (0.60), mean weekly germination (2.93), root length (3.96 cm), shoot length (4.82 cm), seedling length (8.79 cm), seedling fresh weight (239.00 mg), seedling dry weight (47.19 mg), seedling vigour index (length) (315.72) and seedling vigour index (mass) (1687.57).

Seeds treated with GA_3 @300 ppm (T_2) produced significantly the earliest seed emergence (34.66 days) with highest germination per cent (35.38%), speed of germination (0.64), mean weekly germination (3.03), collar diameter (2.23 mm), seedling fresh weight (243.16 mg), seedling dry weight (50.00 mg), seedling vigour index (length) (319.15) and seedling vigour index (mass) (1743.83). TTCG was found significantly highest (85.33 days) in case of GA_3 @ 100 ppm (T_1). The root length (4.25 cm), shoot length (5.27 cm) and seedling length (9.55 cm) were found significantly highest in KNO_3 at 2% (T_3).

The treatment combination S_1T_2 (manual scarification with sandpaper treated with GA_3 @ 300 ppm) noted the earliest seed emergence (28.67 days) and relatively the maximum germination per cent (50.67%), speed of germination (0.96), mean weekly germination (4.34), seedling vigour index (length) (479.63) and seedling vigour index (mass) (2566.67).

The time taken for completion of germination was found highest (88 days) in case of S_1T_1 (manual scarification with sandpaper and treated with GA_3 @ 100 ppm). Highest root length (4.57 cm), seedling fresh weight (293.33 mg) and seedling dry weight (54.33 mg) were obtained from the seedlings treated with manual scarification with GA_3 @ 100 ppm (S_1T_1). The maximum shoot length (6.00 cm) and seedling length (10.40 cm) was observed in S_1T_3 (manual scarification with KNO_3 at 2%).

Overall, it can be concluded that aging, scarification and treatments played an important role on the seed germination and its parameters in sandalwood. Looking to the seed germination percentage, early emergence, SVI (length), SVI (mass), speed of germination and mean weekly germination it is suggested that the new seeds that had undergone manual scarification with sandpaper should be treated with GA_3 @ 300 ppm for enhancement of germination and its parameters in sandalwood.

**COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH**

C E R T I F I C A T E – I

This is to certify that the thesis entitled “**EFFECT OF PRE SOWING TREATMENTS ON SEED GERMINATION AND ITS PARAMETERS IN SANDALWOOD (*Santalum album* L.)**” submitted by **MAMIDI HEMALATHA** in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in the subject of **SEED SCIENCE AND TECHNOLOGY** to the Junagadh Agricultural University is a record of bonafide research work carried out by her under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title. The candidate had fulfilled all prescribe requirements. The assistance and help received during the course of investigation have been fully acknowledged. She has successfully completed the comprehensive / preliminary examination held on May 19, 2020 as required under the regulation for post-graduate studies. She has submitted kachcha bound thesis on **September 24, 2020**.

Place: Junagadh

Date: 24/09/2020

(Dr. S. B. Chaudhari)
Major Guide and Assistant Research Scientist
Department of Genetics and Plant Breeding
College of Agriculture
Junagadh Agricultural University
Junagadh

**COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH**

C E R T I F I C A T E - I I

Date: -10-2020

This is to certify that the thesis entitled **“EFFECT OF PRE SOWING TREATMENTS ON SEED GERMINATION AND ITS PARAMETERS IN SANDALWOOD (*Santalum album* L.)”** submitted by **Ms. MAMIDI HEMALATHA** to Junagadh Agricultural University, Junagadh in partial fulfillment of the requirements for award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in the subject of **SEED SCIENCE AND TECHNOLOGY** after recommendation by the external examiners were defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We, therefore, forward with recommendation.

(Rajiv Kumar)

Minor Guide and
Assistant Professor
Dept. of Genetics & Plant Breeding
College of Agriculture
J. A. U., Junagadh

(S. B. Chaudhari)

Major Guide and
Assistant Research Scientist
Dept. of Genetics & Plant Breeding
College of Agriculture
J. A. U., Junagadh

(J. B. Patel)

Professor and Head
Dept. of Seed Science & Technology
College of Agriculture
J. A. U., Junagadh

(K. A. Khunt)

Principal
College of Agriculture
J. A. U., Junagadh

Approved by

(V. P. Chovatia)

Director of Research and Dean of P. G. Studies
Junagadh Agricultural University
Junagadh.

ACKNOWLEDGEMENT

First of all, I fervently pray my obeisance to the “**Swamy narayan and Lord ganesha**” with whose grace and blessing I could be able to accomplish this task.

Every author owes a debt to the teachers. I seize this opportunity to express my deep sense of indebtedness and profound gratitude towards my Major Guide **Dr. S. B. Chaudhari**, Assistant Research Scientist, Department of Genetics and Plant Breeding, JAU, Junagadh, who has enlightened and guided me throughout my academic and research work. It is just because of his incessant motivation, valuable suggestions, ever helping attitude, amide behaviour, cheerful nature and parental care rendered to me during course of the investigation, that I have been able to succeed in the endeavor.

My heart is in a state of ecstasy to unveil a hearty sense of regards and admiration towards my Minor Guide **Dr. Rajiv Kumar**, Assistant Professor, Department of Genetics and Plant Breeding. I feel great indulgence in introducing my committee member **Dr. M. H. Sapovadiya**, Assistant Research Scientist, Department of Genetics and Plant Breeding; **Dr. C. A. Babariya**, Assistant Professor, Department of Seed Science and Technology; **Dr. U. K. Kandoliya**, Associate Professor, Department of Biotechnology, JAU, Junagadh for their keen interest, valuable guidance and constant encouragement during my Msc. programme.

I am sincerely thankful to **Dr. J. B. Patel**, Professor and Head, Department of Seed Science and Technology for his enormous help, most valuable advices and magnanimous attitude right from the first day.

I acknowledge with thanks for the facilities provided by **Dr. V. P. Chovatia**, Hon’ble Vice Chancellor and Director of Research and Dean, P.G. Studies, JAU, Junagadh and **Dr. K.A. Khunt**, Principal College of Agriculture, JAU, Junagadh and all staff members of academic branch as well as library staff for their necessary help and cooperation to me during the period of study.

My special thanks to **Dr. D. R. Mehta**, **Prof. Jyoti Sondarva**, **Dr. Lata Raval and G.U. Kulkarni** as well as library and college staff for necessary help and co-operation to me during the period of study. I wish to place my thanks to staff members Makwana bhai, Ozabhai, Massi and all laboratory assistant staff in Department of Genetics and Plant Breeding for providing me necessary time to time help and support

Acknowledgement

in laboratory activities, it seems proper blanket of thanks to everyone who helped directly and indirectly in entire course of study.

My acknowledgement would be incomplete if I do not pay thanks to batch mates, well-wishers who helped me a lot in various ways during the entire period of my investigation. So, I wish to extend my heartiest thanks to, **Vishal, Sampath, Monica, Manju, Anusha, Aarti, Khushbu, Mahesh** and all other classmates for their cooperation during the course of my study.

I have no words to express my deepest and heartiest gratitude to my parents so, I devote my cordial feelings of dedication to my parents **Mr. M. Sankar Rao** and **Mrs. M. Aruna** who sacrificed everything to give me the most and best education as possible as they can. It is due to them their dream comes true. I also deem to my beloved brother **M. Teja Krishna**, a family whose love and support were most precious thing throughout my life together.

There are number of well-wishers whom I can't forget and I thank to one and all associated with me directly and indirectly.

Place: Junagadh

(Mamidi Hemalatha)

Date: 24 /09/2020

CONTENT

CHAPTER NO.	TITLE	PAGE NO.
I	INTRODUCTION	1-5
II	REVIEW OF LITERATURE	6-25
	2.1 Aging	6
	2.2 Scarification	8
	2.3 Pre sowing treatments	15
III	MATERIALS AND METHODS	26-36
	3.1 Geographic conditions and location of experiment	26
	3.2 Climate and weather conditions	26
	3.3 Experimental material	26
	3.4 Methodology	27
	3.5 Observation recorded	31
	3.6 Statistical analysis	33
IV	EXPERIMENTAL RESULTS AND DISCUSSION	37-61
	4.1 Analysis of variance	39
	4.2 Effect of scarification and treatments on germination and its components	42
V	SUMMARY AND CONCLUSIONS	62-66
	5.1 Analysis of variance	62
	5.2 Effect of scarification	63
	5.3 Effect of different pre sowing treatments	63
	5.4 Interaction effect scarification and treatments	64
	BIBLIOGRAPHY	i-x
	APPENDICES	I

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
3.1	Treatment combinations	29
3.2	The structure of ANOVA for Factorial CRD	34
4.1	The number of seeds germinated in different treatments of old seeds (A_1) for about 88 days	38
4.2	Analysis of variance for experimental design (FCRD) for germination and its parameters in sandalwood	40
4.3	Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on germination (%), TTIG, TTCG and speed of germination in sandalwood	43
4.4	Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on mean weekly germination, root length (cm) and shoot length (cm) in sandalwood	49
4.5	Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on seedling length (cm), collar diameter (mm) and seedling fresh weight (mg) in sandalwood	54
4.6	Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on seedling dry weight (mg), seedling vigour index (length) and seedling vigour index (mass) in sandalwood	58

LIST OF FIGURES

FIGURE NO.	TITLE	AFTER PAGE NO.
3.1	Arrangement of different treatment combinations in greenhouse	28
4.1	Effect of scarification and different treatments on germination percentage (%) in sandalwood	44
4.2	Interaction effect of scarification and different treatments on germination percentage (%) in sandalwood	44
4.3	Effect of scarification and different treatments on TTIG in sandalwood	46
4.4	Interaction effect of scarification and different treatments on TTIG in sandalwood	46
4.5	Effect of scarification and different treatments on TTCG in sandalwood	46
4.6	Interaction effect of scarification and different treatments on TTCG in sandalwood	46
4.7	Effect of scarification and different treatments on speed of germination in sandalwood	48
4.8	Interaction effect of scarification and different treatments on speed of germination in sandalwood	48
4.9	Effect of scarification and different treatments on mean weekly germination in sandalwood	50
4.10	Interaction effect of scarification and different treatments on mean weekly germination in sandalwood	50
4.11	Effect of scarification and different treatments on root length (cm) in sandalwood	50
4.12	Interaction effect of scarification and different treatments on root length (cm) in sandalwood	50
4.13	Effect of scarification and different treatments on shoot length (cm) in sandalwood	52

FIGURE NO.	TITLE	AFTER PAGE NO.
4.14	Interaction effect of scarification and different treatments on shoot length (cm) in sandalwood	52
4.15	Effect of scarification and different treatments on seedling length (cm) in sandalwood	54
4.16	Interaction effect of scarification and different treatments on seedling length (cm) in sandalwood	54
4.17	Effect of scarification and different treatments on collar diameter (mm) in sandalwood	56
4.18	Interaction effect of scarification and different treatments on collar diameter (mm) in sandalwood	56
4.19	Effect of scarification and different treatments on seedling fresh weight (mg) in sandalwood	56
4.20	Interaction effect of scarification and different treatments on seedling fresh weight (mg) in sandalwood	56
4.21	Effect of scarification and different treatments on seedling dry weight (mg) in sandalwood	58
4.22	Interaction effect of scarification and different treatments on seedling dry weight (mg) in sandalwood	58
4.23	Effect of scarification and different treatments on seedling vigour index (length) in sandalwood	60
4.24	Interaction effect of scarification and different treatments on seedling vigour index (length) in sandalwood	60
4.25	Effect of scarification and different treatments on seedling vigour index (mass) in sandalwood	60
4.26	Interaction effect of scarification and different treatments on seedling vigour index (mass) in sandalwood	60

LIST OF PLATES

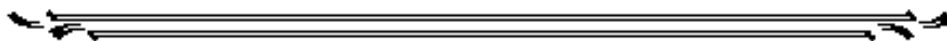
PLATE NO.	TITLE	AFTER PAGE NO.
3.1	Freshly collected sandalwood seeds before and after drying	27
3.2	Visual difference between scarified and non-scarified seeds in sandalwood	29
3.3	Scarification of sandalwood seeds with sandpaper	29
3.4	Scarified sandalwood seeds	29
3.5	Ultrasonic equipment used for scarification	29
3.6	An interior view of ultrasonic equipment with the sandalwood	29
3.7	Cow dung slurry prepared to treat sandalwood seeds	31
3.8	Sandalwood seeds are subjected to different treatments (GA ₃ 100 and 300 ppm, 2 % KNO ₃ and 100 ppm ethrel)	31
3.9	Germination tray used for sowing sandalwood seeds	31
3.10	Sand and soil is mixed in 3:1 proportion to fill germination trays	31
3.11	Filling the trays with sand and soil mixture	31
3.12	Irrigating the sandalwood seeds with pressure sprayer	31
3.13	Sandalwood germination trays are covered with polythene sheet	31
4.1	Different stages of seedling growth in sandalwood	42
4.2	Germination percentage (%) in case of A ₂ S ₁ T ₂ (new seeds with scarification by sandpaper and treated with GA ₃ @ 300 ppm).	42
4.3	Measurement of seedling root length in sandalwood	50
4.4	Measurement of seedling shoot length in sandalwood	52
4.5	Measurement of seedling collar diameter (mm) in sandalwood with the help of vernier caliper	54

LIST OF APPENDICES

APPENDIX		PAGE
NO.	TITLE	NO.
I	Weekly meteorological data (mean values) on maximum and minimum temperature, maximum and minimum relative humidity, rainfall and rainy days recorded during the sandalwood germination period (December 2019 – February2020) at Junagadh Agricultural University, Junagadh.	I

CHAPTER I

INTRODUCTION



Indian sandalwood (*Santalum album* L.) is one of the most primitive precious useful plants since ancient times. It is also known as chandan, santal oil, white saunders oil, white or yellow sandalwood oil and east Indian sandalwood oil. The widely distributed and economically important *Santalum* genus belongs to family Santalaceae, includes 30 genera with about 400 species, many of which being completely or partially parasitic. It is the second most expensive wood in the world. The word Sandal has been derived from Chandana (Sanskrit), Chandan (Persian), Savtador (Greek) and Santal (French). “Chandana” the Sanskrit name ascribed to *Santalum album* L. was known and used in India from the earliest historic times and is frequently mentioned in the ancient Sanskrit writings, some of which dated before Christian era. There is atleast three kinds of sandal namely white sandal (*Santalum album* L.) called “Sweta Chandana”, Red Sandal (*Pterocarpus santalinus* L.) called “Rakta Chandana” and Ku-chandana (*Adenanthera pavonina* L.). These plants belong to different species and families and have different properties as evidenced from their synonyms.

For more than 5000 years, India has been the traditional leader of sandalwood. It is also considered sacred in some religions and is used in different religious traditions. The high value of the species has caused its past exploitation, to the point where the wild population is vulnerable to extinction. Indian sandalwood still commands high prices for its essential oil, but due to lack of sizable trees it is no longer used for fine woodworking as before. The plant is widely cultivated and long lived, although harvest is only viable after many years.

Sandal is an evergreen large shrubs or small trees (*Santalum spicatum* (R.Br.) A. DC.) to tall trees of 20 m in height (*Santalum album* L. in India and *Santalum paniculatum* Hook. Am. in Hawaii). Ecologically sandal has adapted various agro-climatic and soil conditions for *in situ* regeneration. The most common soil type on which sandal occurs is the red ferruginous loam with underlying gneiss which has poor nutrients. It is able to withstand the soil pH up to 9.0 but unable to grow in waterlogged sites. The species is capable of growing where rainfall is 500 to even 5000 mm, long

dry season duration and elevation from 0–1800 meters above sea level. However, the sandalwood tree can occur even outside this climatic zone and able to tolerate extreme temperature from 4 to 46⁰ C. This plasticity is an added adaptation advantage for sandalwood when grown under some extreme site conditions. Sandalwood being a hemi-parasite requires a primary host, intermediate host as well as a long term secondary host which gives it tremendous scope in agroforestry. Sapwood is white to pale yellow, sharply demarcated from the yellowish brown to dark brown heartwood, hard, heavy, lustrous and straight-grained to slightly wavy, fine textured with pleasant characteristic smell. The major problem that can be addressed during planting stock production in nurseries is the low seed germination. Sandal starts flowering at an early age of two to three years and flowering and fruiting season vary. Ananthapadmanabha *et al.*, (1991) reported that sixty per cent of the trees flower and bear fruits twice a year (during March–May and September–December), 36% once a year (September–December) and 4% throughout the year. Fruit is a drupe, globose, 1.25 cm diameter, purplish-black, with hard-ribbed endocarp.

Sandalwood trees are famous and very costly because of its fragrant heartwood and oil. The price of sandalwood in India is everyday increasing Rs. 20,000 per tonne in 1980, Rs.200,000 per tonne in 1990; Rs. 4000,000 per tonne in 2004 and 7500,000 per tonne in 2014 (<http://sandalplantation.com>). Generally, in a one- acre land, one can grow 400 to 440 sandalwood tree plants. Sandalwood tree cultivation costs depend on many factors. Certain cultures place great significance on its fragrant and medicinal qualities. Sandalwood contains 3-6% essential oils, resin and tannins. The essential oils contains alpha-santalol and beta-santalol. Oil has been used in folk medicine for treatment of cold, bronchitis, skin disorders, heart ailments, fever etc. The central part of the tree, heartwood, is the only part of the tree that is used for its fragrance and due to its durability, is the perfect material for carving. India exports around 2000 tonnes of wood and 100 tonnes of oil annually to other countries and accounts for 99% sandalwood oil production in the world (Rai and Sarma, 1990).

The species (*Santalum album* L.) is distributed from Indonesia in the West to Juan Fernandez Islands in the East and from Hawaiian Archipelago in the North (30⁰ N) to New Zealand in the South (40⁰ S). It is believed that Sandal was introduced to India from Timor in Indonesia (Shetty, 1977). In India, *Santalum album* L. is mainly

distributed in the Deccan Plateau. The populations are more concentrated in the southern region, especially Karnataka, Tamil Nadu and Kerala. 8,200 sq. km. area of sandalwood distribution out of the total 9,000 sq. km. in India is in Karnataka and Tamil Nadu (Venkatesan *et al.*, 1995). The southern Indian states of Karnataka and Tamil Nadu together account for more than 90% of the natural population of sandalwood in India.

Sandalwood cultivation has been picking up in non-traditional states like Gujarat, Rajasthan, Andhra Pradesh, Madhya Pradesh and Maharashtra. The farmers in the state of Gujarat have been one of the most enterprising farmers and have started raising sandalwood plantations way back in 2006-07 period. The oldest private plantation of 15 years noticed was in Bhavnagar, Gujarat with grafted mango as secondary host. In Gujarat it is estimated that nearly 20,000 ha are under sandalwood cultivation as per data from Gujarat sandalwood growers association (Mishra *et al.*, 2018).

Sandalwood is nominated as one of the priority species in the establishment of industrial plantation forests. The execution of this programme faces many problems, such as limited seed source and seed handling techniques. Seed is available only from scattered natural stands. Seed weight of sandalwood varied significantly among various localities (Bagchi and Sharma, 1989). Sandalwood exhibits polymorphism in characters like seed shape, size and weight. The difference in weight of seeds play an important role in the germination of seeds and survival of seedlings. In addition, it also reflects the adoptive variability of the species.

Propagation of sandalwood plant commonly takes place by seeds which are produced only once or twice in a year (June to September and or November to February). Natural regeneration of sandalwood plant is done through endozoochory. Failure of the seed dispersal due to natural calamity or any other hindrances the natural regeneration is hampered. In fact presently there is no specific way of artificial means of propagation other than seed germination for the improvement of sandalwood plant population as required. Ecologically sandalwood plant has adapted in various agro-climatic as well as soil conditions for *in-situ* regeneration.

In sandalwood germination is sporadic and takes 4-12 weeks time to complete germination (Srinivasan *et al.*, 1992; Srimathi *et al.*, 1995). Fresh seeds show dormancy

for two months period. It is likely that the enforced dormancy of seeds is due to presence of hard seed coat or due to the presence of chemical substances in the seed coat which are impervious to water and gases. The failure of apparently ripe seed to germinate in a suitable environment may be due to a single factor or a combination of several factors. The main causes of seed dormancy are: impermeable seed coats, mechanically resistant seed coats, rudimentary embryos, physiologically immature embryos and morphologically mature but physiologically dormant embryos.

Sandalwood is one of the most primitive precious useful plants since ancient times. This plant was domesticated due to its multifarious usefulness. Though, it has the natural regeneration capability, but it needs further investigation towards artificial propagation through seed.

Natural germination of sandalwood seeds is having very low germination capacity as well as time consuming. Therefore the seed germination needs to be improved by artificial methods. There is however paucity of information in the area of silvicultural protocol for germinating the species in the nursery. This study sets out to investigate appropriate seed germination techniques for sandalwood. As sandalwood seeds takes more time for its emergence, this study would also help in early emergence of seed without taking more time.

Aging is an important factor affecting the viability of seeds. It was found that age plays a significant role in the decline of frequency of seed germination, which was effectively improved with the use of GA₃ and KNO₃ (Sarihan *et al.* 2005). The sandalwood seed viability decreases with storage time which is a common phenomenon for tree seeds. There is a negative relationship of germination percentage of sandalwood seeds over aging or storage time (Gamage *et al.* 2010).

Seeds with external dormancy require scarification. It involves weakening, opening or otherwise altering the coat of a seed to encourage germination and also speed up the natural processes which normally make seed coat permeable to water and air. As sandalwood seeds are impervious to water and gases which is an external dormancy preventing or delaying germination. Thus mechanical (sandpaper) and acid scarification decreases days to first emergence and mean days to emergence by increasing germination rate (Saied *et al.* 2008). Pamungkas and Nichols (2019) showed

that the cumulative germination was higher on the seed with scarification and soaked in GA₃ solution 300 and 500 ppm in sandalwood.

Redding (2016) invented ultrasonically enhanced seed germination system. It consists of a sonication and imbedding process for the uptake of water and/or other beneficial substances into a seed for the purposes of reducing the time needed for germination of a plant and the time needed for full maturity growth of the resultant plant. These results demonstrated that ultrasound stimulated seeds probably have faster rates of water uptake is achieved very rapidly compared to the rates of water uptake of just soaked seeds. Thus, the sonication process fundamentally enhanced the rate of uptake of substances into the seeds, speeding both seed germination and the growth of mature plants when compared to non-sonicated seeds.

Gibberellic acid is the most important plant hormone for the regulation of internal seed dormancy and is often used on seeds with complex internal dormancy and with those species having underdeveloped embryos. Sandalwood is a species that has been successfully germinated using gibberellic acid. Preferred concentrations vary, but most nurseries use 500 to 1000 parts per million (ppm). High concentrations can cause seeds to germinate, but the resulting seedlings may be of poor quality. The rate and uniformity of sandalwood germination was increased by the gibberellic acid treatment (Vira and Smith, 1996).

Therefore, the present study was conducted to investigate the effect of pre sowing treatments on seed germination and its parameters in sandalwood (*Santalum album* L.) with the following specific objectives:

- 1) To study the impact of aging of seed on germination and quality parameters in sandalwood
- 2) To study the effect of scarification on germination and quality parameters in sandalwood
- 3) To study the effect of different pre sowing treatments on germination in sandalwood

CHAPTER II

REVIEW OF LITERATURE



Sandalwood a precious plant is found to grow in the vast area of southern part of India. The remaining part of country is devoid of wide population of sandal excepting few patches in some areas. In Gujarat it is estimated that nearly 20,000 ha are under sandalwood cultivation as per data from Gujarat sandalwood growers association (Mishra *et al.* 2018). Natural spreading of this plant over a large area is hindered due to poor percentage of germination of seeds as well as time consuming. Therefore the seed germination needs to be improved by artificial methods which sets out to investigate appropriate seed germination techniques for sandalwood. As sandalwood seeds takes more time for its emergence, this study helps in early emergence of seed without taking more time. Therefore, the present study was conducted to investigate the effects of aging, scarification, different pre-sowing seed treatment and interaction among them on seed germination under greenhouse conditions in Saurashtra regions. The research works on the sandalwood is scarce hence reviews of other crops/plants have been incorporated. The literature on various aspects pertaining to the research problem envisaged is reviewed under the following heads:

2.1 Aging

Christidis (1954) studied on seed vitality and other cotton characters as affected by the age of seed. The results obtained that as the aging increases, germination percentage decreases. It showed that at the age of 4 years the germination % is 94 and at the age of 11 years the germination % decreased to 83.

Akhter *et al.* (1992) carried out the experiment to ascertain the effect of aging on wheat and barley seeds. The results showed that the germination percentage of different year's old wheat and barley seeds were found to decrease gradually with an increase of the storage time. The germination percentages of wheat seeds were much lower than that of barley seeds.

Parrish and Leopold (1978) studied the performance capability of seeds in general and soybeans in particular declines during storage. This aging or loss of vigor is evidenced by delayed germination and emergence, slower growth, increased

susceptibility to environmental stresses and ultimately a decline in germinability. Seed aging is therefore a serious problem in agriculture, leading to loss of viability and vigor.

Rice and Dyer (2001) studied seed aging, delayed germination and reduced competitive ability in *Bromus tectorum* L. They used aged (4 year-old) and freshly produced seed to investigate the importance of seed age on seedling vigor and competitive ability. Aged seed from the meadow steppe population exhibited delay in germination that reduced plant growth and final biomass when the plants were grown with competition.

Khan *et al.* (2003) studied the effect of ageing on viability, vigour and chromosomal damage in pea (*Pisum sativum* L.) seeds. In this study seeds were exposed to high temperature and high humidity, a technique widely used to study seed storability and deterioration. The effect of environmental treatments on seed germinability, seedling vigour, electrolyte leakage and chromosomal aberration in pea seeds was compared. Ageing treatment showed rapid and significant reductions in rate of seed germination and seedling vigour. Loss of viability and declining vigour were associated with the increased leakage and chromosomal aberrations.

Sarihan *et al.* (2005) studied the role of GA₃ and KNO₃ in improving the frequency of seed germination in *Plantago lanceolata* L. The objective of the study was to establish a relationship between seed age and germination percentage. Highest germination of 97% was obtained from the seeds of the crop of 2001, which decreased to 78.8% in the seeds of the crop of 1992 in untreated germination.

Gamage *et al.* (2010) studied the change of seed germination rate with storage time of sandalwood seeds. The maximum germination percentage of >80% was observed when the storage period was three weeks under the GA₃ treatment and the germination rate was less than 40%, when seeds were soaked in water. Germination of 50% was achieved at the 7th week of storage and the germination rate was zero percent after 28 weeks of storage under the GA₃ treatment.

Pradhan and Badola (2012) studied the effect of storage conditions and storage periods on seed germination in eleven populations of *Swertia chirayita*: a critically endangered medicinal herb in himalaya. Study indicated that the seed deterioration rates

may vary depending on the storage conditions and the germination percent and/or seed viability gradually declines with increase in storage period.

Mohammadi *et al.* (2012) reported on effects of seed aging on subsequent seed reserve utilization and seedling growth in soybean. Germination characteristics and seedling growth from aged soybean seeds were studied; seeds were incubated at two different temperatures of 34°C and 40°C for varying times. The results indicated that seed deterioration results in decreased percentage and rate of germination and decreased percentage of normal seedlings.

Subasinghe (2014) studied on effect of seed storage on germination in *Santalum album* L. The germination was over 80% at the 3rd week of storage when soaked with 0.05% GA₃ and it was less than 40% when soaked with water. However, from the 12th week, both treatments produced approximately similar results. Germination of 50% when soaked with 0.05% GA₃ was achieved at the 7th week of storage and the germination was 0% after 28 weeks of storage under the same treatment.

Oboho and Igharo (2017) reported the effect of pre-germination treatments on germination and watering regimes on the early growth of *Pycnanthus angolensis* (Welw) Warb. Five pre-germination treatments; control (old), control (fresh), red aril removal, 48 hours soaking in water, aril and seed coat removal were used for germination studies. Germination started 31 days after sowing and the period of germination was 18 days after emergence. The aril removal treatment had the best germination performance (83.33%), followed by seeds soaked for 48 hours (70%), aril and seed coat removal (36.6%), control (fresh) (3.3%) and control (old) (0%). Fresh seeds with the red aril removed have been recommended for raising the seedlings.

2.2 Scarification

Weinberger and Burton (1981) studied the effect of sonication on the growth of some tree seeds. Air-dry seeds of jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.) tamarack (*Larix europaea* L.) and white spruce (*Picea glauca* (Moench) Voss) were subjected for 30 min to 1 MHz ultrasound at one of three intensities of ultrasound ranging from 0.5 to 6.0 W/cm². Subsequent germination was assessed in terms of percent germination, mean daily germination and peak velocity of germination.

The results indicated that only jack pine responded to the ultrasonic treatments by giving rise to higher mean daily germination and germination value.

Muir and Pitman (1987) reported on improving germination rate of the florida legume *Galactia elliottii* Nutt. The results obtained from this study indicate that mechanical scarification with sand-paper and treatment with sulfuric acid effectively increased both total germination and rate of germination compared to the untreated control.

Rinaldelli (2000) reported the effect of ultrasonic waves on seed germination of *Capparis spinosa* L. as related to exposure time, temperature, and gibberellic acid. A specially prepared apparatus made it possible to carry out the ultrasonic treatments in water at controlled temperatures. A significant increase in germination percentage was found for exposure times from 10 min to 6 hr. Optimal temperatures for the treatment were 25 and 30°C. The highest germination percentages (above 50%) were obtained when ultrasonic treatment was carried out in the presence of gibberellic acid (400 mg l⁻¹).

Bhat *et al.* (2001) reported the assessment of propagation techniques for forest species of the western ghat region of India. In this study, attempts were made to identify suitable methods for propagating 85 tree species growing in the Western Ghats region of peninsular India. Of these 85, 28 species were easily propagated with no special treatment were identified. The responses of other species to seed treatments to enhance germination, such as scarification, acid and hot water were examined. Scarification was, generally, the most successful treatment. With scarification, more than 75% germination was observed in eight species and in two other species (*Bombax malabarica* and *Dalbergia latifolia*) the germination was 50-75%.

Saied *et al.* (2008) studied the effects of different scarification methods on germination of *Ziziphus spina-christi* seeds. This study explored two mechanical methods (hilum abrasion using sand paper and cracking of the seed coat) and three acid scarification treatments by the immersion of seeds in sulphuric acid (97%) for 30, 60 and 120 minutes. Emergence percentage was highest after immersing seeds in acid for 120 minutes, but was not significantly different from other scarification treatments, with the exception of the 30 minutes acid treatment. Mechanical and acid scarification,

with the exception of the 30 minutes acid treatment, decreased days to first emergence by 2-4 days, days to 50% emergence by 10-12 days and mean days to emergence by 2-4 days.

Choudhury *et al.* (2009) studied on seed dormancy and germination in *Gymnocladus assamicus*: An endemic legume tree from northeast India. Pretreatment of *G. assamicus* seeds showed improvement in germination percentage. While untreated seeds showed around 42% germination, mechanical scarification and hot water treatment improved germination percentage significantly to the level of 65-80%.

Zaman *et al.* (2009) studied the effect of pre-germination treatments on seed germination of *Helianthemum lippii* (L.)Dum. Cours. Five different pretreatment were applied to enhance seed germination. Scarification followed by germination at 6 different constant temperatures (10, 15, 20, 25, 30 and 35°C) with continuous light or dark, Scarification followed by GA₃ soaking (100, 250,500,750 and 1000 ppm), Heat and moist stratification (only intact seeds), KNO₃ and H₃BO₃ soaking (only intact seeds). The results obtained from this study indicate that germination in *H. lippii* was promoted by scarification. Scarification of seeds resulted in high germination while increasing germination temperature (35°C) decreased the germination of scarified seeds.

Al-Menaie *et al.* (2010) studied the effects of different treatments on seed germination of the *Cassia fistula* L. and *Cassia nodosa* Buch.-Ham. ex Roxb. Three experiments were conducted on both species to determine the effect of various treatments such as surface sterilization, mechanical scarification, hot water, sulfuric acid, water soaking, growth regulators and acid scarification on seed germination. In all the experiments, daily observations were recorded for two months after sowing. For experiment 1, mechanical scarification with sandpaper resulted in better germination for heavy seeds of *C. nodosa* compared to unscarified seeds.

Azad *et al.* (2010) studied the effects of pre-sowing treatments on seed germination of *Melia azedarach* L. The seeds were treated with five pre-sowing treatments (control, immersion in cold water and in hot water, scarification with sand paper and immersion in concentrated H₂SO₄) to study seed germination. The results revealed that the germination rates of pre-sowing treated seeds were significantly

increased compared to those in control, except for cold water treatment. The highest germination success (80%) was found in scarification with sand paper, followed by 74% and 69% in immersion in H₂SO₄ and hot water treatment, respectively.

Azad *et al.* (2011) studied the effects of different pre-sowing treatments on seed germination percentage and growth performance of *Acacia auriculiformis* A. Cunn. Ex Benth. It is treated with five pre-sowing treatments (control, immersion in cold water, immersion in hot water, scarification with sand paper and immersion in concentrated H₂SO₄). Results reveal that pre-sowing treatments influences the germination rates of seeds that significantly increase the percentage germination compared with those in control (43%) and cold water treatment (52%). The highest germination success rate was found 83% in hot water treatment followed by 78% in scarification with sand paper, and 75% with immersion in H₂SO₄.

Fattahi *et al.* (2011) studied the effect of pre-sowing treatments and light on seed germination of sandpaper; 3, 5 and 10 min soaking in sulfuric acid; 15 min in sodium hypochlorite; 24 h in water, hot water and boiling water; 50, 150, and 250 mg l⁻¹ of Gibberellic acid; 1000, 2000, 4000, and 6000 mg l⁻¹ of KNO₃ and water (control) are used as pre-sowing treatments. It was observed that both the physical and chemical scarification methods were effective in enhancing *D. Kotschy* seed germination and growth. In the first stage, up to day 20, sulfuric acid (10 min) and sandpaper scarification treated seed had shown germination more than 70% whereas control seeds did not begin germination until day 20. The highest germination rate was observed with sandpaper and sulfuric acid in compare with other treatments. Also the highest vigor index was found in sulfuric acid and sand paper treated seeds and the lowest occurred in sodium hypochlorite treatments.

Okunlola *et al.* (2011) investigated the most effective pre-sowing treatments to break seed dormancy, to stimulate seed germination and to identify morphological traits for the assessment of *Parkia biglobosa* seedling vigour. The seeds were subjected to pre-treatment that includes: soaking in 100% sulphuric acid for one minute, mechanical scarification with sandpaper, soaking in boiling water for two minutes, soaking in cold water (at room temperature) for 24 h. At 12 weeks, the seedlings growth parameters were assessed: seedling height, leaf production and diameter and branch production. The results obtained from the study showed that all the treatments except soaking in

boiling water improved seed germination and reduced Mean Germination Time (MGT). The mechanical scarification appeared to be the most effective method of pre-treatment having the highest germination percentage 91.7%.

Abari *et al.* (2012) studied on maximizing seed germination in two *Acacia* species. Germination percentage and germination rate differed significantly by treatment and species, and in the interaction of treatments and species. Final seed germination percentages for two species scarified by sandpaper and soaked in sulfuric acid and H₂O₂ were high (>80%). Whereas, seeds soaked in water for 48 h and also seeds soaked in H₂SO₄ and then soaked in tap water for 24 hours showed the lowest germination percentage in *A. oerfota* and *A. tortilis*, respectively.

Anand *et al.* (2012) studied the effects of pre-sowing seed treatments on germination and seedling growth performance of *Melia dubia* CAV: an important multipurpose tree. Seeds were subjected to seven pre-sowing treatments. The results showed that cow dung slurry treatment for seven days had significantly enhanced germination and seedling growth. Seed germination started 32 days after sowing and continued up to 66 days. The highest germination percentage (34.3 %) was observed in the soaking of seeds in cow dung slurry for seven days followed by (31.5 %) 100 ppm Gibberlic acid for 24 hours. The lowest germination percentage (18.7 %) was obtained from control. The highest germination value (2.2) and germination energy (25) was also obtained in cow dung slurry, which was significantly different from the control and other treatments. Shoot length, root length, collar diameter and leaf number followed the same trend of higher value for cow dung slurry and 100 ppm gibberlic acid. Similar trend was also observed in shoot, root and total seedling dry weight.

Ali *et al.* (2012) investigated the effects of different dormancy breaking treatments on the germination of *Rhynchosia capitata* (Roth) DC. a common summer annual weed. Seeds were soaked in thiourea, KNO₃, HCl, HNO₃, and H₂SO₄, and they were also mechanically scarified (sandpaper). Results indicated that *R. capitata* seeds show signs of physical dormancy that is mainly due to the impermeability of their coat. Mechanical scarification and acid scarification (soaking of seeds in H₂SO₄ for 60 and 80 min and in HCl for 12 and 15 h) were very efficient in breaking dormancy and promoting germination.

Talei *et al.* (2012) reported a rapid and effective method for dormancy breakage and germination of king of bitters (*Andrographis paniculata* Nees.) seeds. Among the different physical and chemical scarification methods the fastest and the highest germination percentage were obtained from the seeds scarified with sandpaper. After three days of the scarification, 72.7% of the seeds germinated and this percentage was further increased to 90.4% after 15 days with a mean germination time of 4 days.

Yildiztugay *et al.* (2012) investigated on dormancy breaking and germination requirements for seeds of *sphaerophysa kotschyana* boiss. It included acid (soaking in H₂SO₄, HNO₃ and HCl for 15, 30, 60, 90 and 180 minutes), hot water (soaking in dH₂O at 50, 70 and 90 °C for 5, 10, 15 and 30 minutes) and mechanical scarification with sandpaper. It can be suggested that H₂SO₄ treatments and sandpapering were the most effective methods in germination of *S.kotschyana* seeds.

Jayawardena *et al.* (2015) conducted experiment on sandalwood seeds were subjected to two pre-germination treatments, firstly, imbibition treatment where samples of scarified and non-scarified seeds were placed on moist tissue papers in petri dishes. Secondly, samples of non-scarified seeds and scarified seeds were placed on tissue papers moistened with 100 ppm or 500 ppm GA₃ treatment. The results of imbibition showed that non-scarified seeds germination at 20 – 22 %, while that of manually scarified seeds increased 27 – 29 %. Treatment with GA₃, especially with 500 ppm for both non-scarified and scarified seeds significantly enhanced the germination whereas 100 ppm GA₃ treatment was less effective

Miano *et al.* (2015) studied the effect of ultrasound technology on barley seed germination and vigour. This work investigated whether ultrasound technology affected the germination and vigour of four lots of barley seeds. It was demonstrated that ultrasound did not negatively affect germination and vigour and improved germination rate. Therefore, ultrasound technology can be used to enhance the hydration process without negatively affecting seed quality. The results showed that the seeds treated with ultrasound had higher germination and vigour when compared to control.

Sharififar *et al.* (2015) assessed the effect of ultrasonic waves on seed germination of *Atriplex lentiformis* (Torr.), *Cuminum cyminum* L. and *Zygophyllum eurypterum* L. Seeds were treated with ultrasonic waves for 1, 3, 5, 7, and 9 min. The

percentage of germination of each culture revealed a significant positive effect of ultrasonic wave exposures. Treatments of 5 and 7 min of exposure had the highest seed germination percentage, but 9 min of exposure had negative influence on germination in comparison with other treatments.

Ivanova and Panchev (2016) studied effect of pre sowing treatment with ultrasound and stratification of *Laurocerasus officinalis* L. seeds on some growth behavior of seedlings. The seeds were treated with 0, 5, 10 and 15 min ultrasound and 2 months stratification. The results showed that the percentage of germinated seeds and quality root system are dependent on the exposition time. The largest number of germinated seeds was obtained with ultrasound treatment of 10 min. The stratification resulted in the obtaining of roots with the greatest length. High doses of ultrasound will provide the breaking of seeds and weak, brittle root system, which reduces the chances of successful adaptation in replanting.

Redding (2016) invented ultrasonically enhanced seed germination system. It consists of a sonication and imbedding process for the uptake of water and/or other beneficial substances into a seed for the purposes of reducing the time needed for germination of a plant and the time needed for full maturity growth of the resultant plant. These results demonstrated that ultrasound stimulated seeds probably have faster rates of water uptake is achieved very rapidly compared to the rates of water uptake of just soaked seeds. Thus, the sonication process fundamentally enhanced the rate of uptake of substances into the seeds, speeding both seed germination and the growth of mature plants when compared to non-sonicated seeds.

Liu *et al.* (2016) studied the effects of ultrasonication on increased germination and improved seedling growth of aged grass seeds of tall fescue and Russian wild rye. For the four ultrasonic factors, the optimal conditions were a sonication time of 36.7 min, a sonication temperature of 35 °C, an output power of 367 W and a seed soaking time 4.1 h. The ultrasonic treatment has the potential to improve seedling growth. The highest germination percentage was 89.3% in treatment with a sonication time of 15 min, a sonication temperature of 45 °C, an output power of 350 W and a seed soaking time of 1 h. The lowest germination percentage was in the ultrasonic conditions with a sonication time of 35 min, temperature of 45 °C, an output power of 500 W and a seed soaking time of 9 h.

Lopez-Ribera and Vicient (2017) investigated on use of ultrasonication to increase germination rates of *Arabidopsis* seeds. Experiment have been performed using a frequency of 45 kHz at constant temperature (24 °C). No germination rate differences were observed when using freshly collected seeds. However, using artificially deteriorated seeds, results showed that short ultrasonic stimulation (<1 min) significantly increased germination.

Andriamparany and Buerkert (2019) studied the effect of ultrasonic dormancy breaking on seed germination and seedling growth of three wild yam species (*Dioscorea* spp.). These consisted of chilling at 5°C for 2 weeks, submersion in a water bath at 40 kHz for 10 min and 20 min, and a control whereby seeds were sown after soaking in running water for 1 h. Treatment effects on germination were species-specific. For *D. alatis* and *D. fandra*, ultrasonic treatments enhanced seed germination, with the highest value observed at 10 min ultrasonication after 18 weeks after sowing. Although pre-chilling induced early germination in *D. fandra*, leading to an increase of germination speed, the final germination rate was lower compared to the ultrasonication treatments.

Pamungkas and Nichols (2019) studied the influence of scarification and media containing vesicular arbuscular mycorrhiza on germination of sandalwood seeds. Five scarification treatments (control, soaked in water for 24 and 48 hours, GA₃ 300 and 500 ppm for 17 hours) and two VAM application (with and without VAM) were employed. The result showed that the cumulative germination was higher on the seed with scarification and soaked in GA₃ solution 300 and 500 ppm than control, soaked in water 24 h. and 48 h. This pattern also appeared on germination index. Mean germination time showed slower on control, soaked in water 24 h. and 48 h. than the use of GA₃ 300 and 500 ppm. The use of VAM did not significantly affect the cumulative germination, germination index and mean germination time.

2.3 Pre sowing treatments

2.3.1 Sandalwood

Vira and Smith (1996) conducted germination studies on *Santalum austrocaledonicum* L. seeds to determine the rate and uniformity of seed germination. The seeds were soaked in GA₃, water for overnight and also soaked in 60°C water. The

study resulted that rate and uniformity of sandalwood germination was increased by the gibberellic acid treatment when compared to other treatments and control.

Nikam and Barmukh (2009) GA₃ enhances in vitro seed germination in sandalwood. Seeds pre-treated with 2, 4, 6 and 8 mM gibberellic acid (GA₃) for 12 h, then inoculated on Murashige and Skoog's (MS) medium fortified with or without 2.0 or 4.0 µM benzylamino purine (BA). The imbibition of seeds in 4 mM GA₃ not only improved final germination to 80.67% in 30 days as compared to 46% germination in non-treated seeds, but also reduced mean germination time.

Das and Tah (2013) studied the effect of GA₃ on seed germination of sandalwood. The seeds were treated with hot and cold water as well as GA₃ in different concentrations for its artificial germination. The results obtained in their study are soaking in cold water or hot water or alternate soaking in hot and cold water did not improve either the rate of germination or the percentage of germination. Soaking the seeds in 0.05% GA₃ for 16 to 24 hours gave good germination of sandalwood seeds.

Subasinghe (2014) studied on effect of different seed treatments on germination in sandalwood. Seeds treated with 0.05% gibberellic acid (GA₃) showed 15% germination rate and 0.1% benzyl amino purine (BAP) showed 10% germination rate after one week of sowing. Seeds treated with 0.05% GA₃, 1% BAP and scarification, showed a germination percentage of 60%, 10% and 5% respectively after two weeks. The results of experiment revealed that the treatment of 0.05% GA₃ was identified as the best treatment for sandalwood.

Sutheesh *et al.* (2016) focused on influence of various organic and inorganic seed pretreatment on germination and seedling vigour in sandalwood. The mature seeds of sandalwood were collected and were subjected to 16 pre-treatments. The results of the study indicated that the highest germination (74.33%) was observed in soaking of seeds in 500mg l⁻¹ GA₃ for 24 h and lowest (44.33) in soaking of seeds in H₂SO₄ for 5 minutes. Acid scarification and boiling water treatments decreased the germination percentage of the seeds than control. With regards to germination energy, soaking the seeds in 1000 mg l⁻¹ GA₃ for 24 hours recorded the highest germination energy (44.67%) followed by seeds soaked in 500 mg l⁻¹ GA₃. Soaking in cow dung slurry for 24 hours also recorded comparable germination energy (38%).

Karmakar *et al.* (2018) took a venture to promote sandalwood seed germination with the help of different concentration of GA₃ chemical. Three types of seeds viz. (i) natural scarified (ii) non – scarified (iii) random (natural scarified and non-scarified) were used for the experiment. Three treatments namely (i) control (ii) 500 ppm GA₃ (iii) 700 ppm GA₃ were applied in this experiment. The results for days to first seed germination, plant height and leaf number showed highest in case of the scarified and random seeds when treated with 500 and 700 ppm GA₃.

Shankar and Devakumar (2018) studied the effect of pre-sowing treatments on seed germination and seedling qualities of sandalwood. Seeds of sandalwood were collected from three different locations and subjected to two different concentrations of gibberellic acid (GA₃) i.e., 100 ppm and 500 ppm for 24 hours. Germination related parameters such as germination percentage, mean daily germination, peak value and germination value varied significantly compared to control. The quality seedling characters such as seedling height and seedling vigour index also shown the highest values in seed treated with 500 ppm GA₃ for 24 hours.

Turagavuli (2018) studied the techniques for improving germination of papua New Guinea Sandalwood. The techniques used were soaking of seeds in gibberellic acid (GA₃) for 12 hours which achieved a germination percentage of 15 and 60 after 1 and 2 weeks respectively. Other treatments involved; 0.1% benzyl amino purine (BAP), scarification, 50mM potassium nitrate (KNO₃), concentrated sulphuric acid (Conc. H₂SO₄) and water. According to the results, 0.05% GA₃ was identified as the best treatment for sandalwood.

2.3.2 Other crops

Barman and Sarma (1985) studied the effect of ethrel (2-chloroethyl phosphonic acid) on germination and seedling growth of tea *Camellia sinensis* (L.) O. Kuntz. Considering the hard seed coat of the seeds, experiments were laid out in two ways viz; (1) with intact (without scarification) and (2) scarified seeds. Both intact and scarified seeds were separately soaked in two sets of beaker for 24 hr in respective concentrations (0, 10, 50, 100, 250, 500 and 1000 µg/ml) of ethrel. Results showed that ethrel at 10 µg/ml induced higher per cent germination of intact seed and better seedling growth,

while it inhibited germination of scarified seeds and seedling growth. The magnitude of inhibition increased with the rise in ethrel concentrations.

Rehman and Park (2000) studied the effect of scarification, GA₃ and chilling on the germination of goldenrain-tree (*Koelreuteria paniculata* Laxm.) seeds. He observed exogenous application of 100, 200 and 300 ppm of GA₃ increased germination of scarified seeds from 0 (control) to 17, 18 and 15%, respectively. Pre-chilling distilled water (DW) for 60 days increased germination to 44%. Compared with distilled water-chilled seeds, the germination of seeds chilled in gibberellic acid (GA-chilled) was significantly increased after 15 days of chilling and maximum germination of seeds chilled in 100, 200 and 300 ppm GA₃ was 60, 51 and 54%, respectively, achieved after 30 days. A combination of GA₃ and chilling (GA₃+chilling) helped to alleviate seed dormancy in a relatively short period of time.

Venkatesh *et al.* (2000) studied the effect of growth stimulants on seed germination and morpho-physiological attributes in *Pongamia pinnata* L. The growth regulators and chemicals used in this study were IAA (100 ppm), IBA (100 ppm), GA (100 ppm), kinetin (100 ppm), NAA (100 ppm), ethrel (100 ppm), KC1 (1%), KNO₃, (1%), ZnSO₄ (1%), KH₂PO₄ (1%), FeSO₄ (1%) and MgSO₄ (1%). The seeds were soaked in the respective solutions for 12 h. Water-soaked seeds served as control. Seeds soaked in IBA (100 ppm) gave high germination. IBA also enhanced the root length. GA₃ (100 ppm) enhanced the shoot length, total leaf area, total dry weight and total chlorophyll content more than other treatments. The values for most of the above parameters recorded for IBA (100 ppm) were comparable with those of GA₃ (100 ppm).

Tambat *et al.* (2006) improved germination of *Gymnacranthera canarica* Warb. An endangered, endemic tree species of *Myristica swamps*, wester ghats, India. Among the 14 treatments, seed coat removal itself enhanced germination by 20 per cent (60%) over control (40%) showing partial permeability of seed coat to water. GA₃ @ 50,100 and 250 ppm with partial removal of seed coat showed significantly higher germination by 39, 33 and 30 per cent respectively over control.

Anand *et al.* (2012) conducted to explore the effects of different seed treatments on germination and seedling growth parameters of a multipurpose plant, *Melia dubia*. The results showed that cow dung slurry treatment for seven days had significantly

enhanced germination and seedling growth. Seed germination started 32 days after sowing and continued up to 66 days. The highest germination percentage was observed in the soaking of seeds in cow dung slurry for seven days followed by 100 ppm Gibberlic acid for 24 hours. The lowest germination percentage was obtained from control. Shoot length, root length, collar diameter and leaf number followed the same trend of higher value for cow dung slurry and 100 ppm Gibberlic acid respectively. Similar trend was also observed in shoot, root and total seedling dry weight.

Caliskan *et al.* (2012) reported the influences of presowing treatments on the germination and emergence of fig seeds (*Ficus carica* L.). experiment was carried out to evaluated the effects of several treatments (priming with water for 24h, GA₃ at 500 and 1000 ppm for 24h, 3% KNO₃ for 24h, and stratification at 4°C for 7, 14 and 21 days) on seed germination and emergence of ‘Bursa Siyahi’ and ‘Sarilop’ fig cultivars. The application of GA₃ increased the germination and emergence of these fig seeds. The highest percentages of germination and emergence were obtained with GA₃ at 500 or 1000 ppm for both cultivars. The application of GA₃ at 500 ppm or 1000 ppm reduced the time to germination and emergence from the seeds of both cultivars.

Giri and Tamta (2012) examined the effect of various pre-sowing treatments on seed germination of an important and vulnerable high value medicinal plant, *Hedychium spicatum* Sm. with different plant growth regulators (PGRs) and nitrogenous compounds under different conditions. Out of various used treatments, gibberellic acid (GA₃) and potassium nitrate (KNO₃) were significantly effective treatments regarding seed germination of this species.

Vachhani *et al.* (2014) studied the influence of chemicals, PGR's and cow-dung slurry as seed treatment on germiability, growth and development of Khirnee (*Manilkara hexandra* Roxb) under net house condition. The seeds were treated with PGRs and chemicals viz., GA₃ (100 and 200 mg/l), KNO₃ (1%), K₂HPO₄ (1%), ethrel (1000 and 2000 mg/l), thiourea (1%) and cow-dung slurry. The results of experiment revealed that the treatment of GA₃ 200 ppm recorded the higher percentage of germination and maximum seedling length, root length, plant height, number of leaves and number of branches.

Vasantha *et al.* (2014) studied on effect of growth regulators and bio-fertilizers on seed germination and seedling growth of tamarind (*Tamarindus indica* L.). The seeds of tamarind were subjected to pre-sowing treatments with GA₃ (200 and 300 ppm), NAA (200 and 300 ppm), KNO₃ (1 and 2 per cent), biofertilizers like Phosphate Solubilising Bacteria (PSB), Azospirillum, Azatobactor, Vesicular Arbuscular Mycorrhiza and mixture of biofertilizers [biomix (PSB + *Azospirillum* + *Trichoderma viridae* + *Pseudomonas fluorescens*)] 50g/kg of seeds, scarifications like mechanical scarification, acid scarification and also seeds were soaked in cow urine 5% and distilled water as control for sixteen hours. Germination and seedling growth parameters at definite intervals were recorded to find out the effect of these pre-treatments on germination of tamarind. The increase in germination percentage, rate of germination and decrease in number of days taken for initiation of germination was noticed in seeds subjected to mechanical scarification and GA₃ 200 ppm treatment. The maximum plant height, seedling girth, number of leave, fresh and dry weight of shoots, fresh and dry weight of roots, vigour index-I and vigour index-II were recorded in GA₃ 200 ppm at 150 days after sowing while, the minimum values were recorded in control.

Vijendrkumar *et al.* (2014) reported the effect of pre-sowing growth regulator treatments on germination and seedling growth of garden rue (*Ruta graveolens* Linn). The seeds of garden rue were subjected to pre- sowing treatments with gibberellic acid (50, 100, 200, 300 and 400ppm), benzyl adenine (25, 50, 100 and 200ppm), ethrel (100,200,300,400 ppm) and distilled water as control for three hours. Germination and seedling growth parameters at definite intervals were recorded to find out the effect of these pre-treatments on germination of garden rue. The maximum germination percentage, plant height, collar diameter, root length, root number, fresh weight of shoots and vigour index I were recorded in the seeds treated with GA₃ at 400 ppm. Whereas, GA₃ 300 ppm recorded the highest rate of germination, compound leaves, dry weight of shoots, fresh and dry weight of roots and vigour index II.

Sebastian *et al.* (2015) reported the seed quality as influenced by dormancy breaking treatments in foxtail millet genotypes. Seeds were subjected to various physico-chemical treatments viz., control, exposure to sun light for 48 hr, exposure to 45°C for 24 hr and 48 hr, water soaking for 12 and 24 hr, soaking in KNO₃ at 0.5 and 1 per cent, soaking in HNO₃ at 0.5 and 1 per cent, soaking in ethrel at 25 and 50 ppm,

hot water treatment at 50°C and 60°C for 1 min and soaking in thiourea at 0.5 and 1 per cent. Among the treatments, ethrel at 25 ppm followed by pre-heat treatment for 48 hr was most effective in release of dormancy in foxtail millet genotypes. Seeds treated with ethrel at 25 ppm recorded highest seed germination, seedling length, dry matter and lowest electrical conductivity.

Sujatha and Manjappa (2015) reported the effect of pre-sowing treatments on seed germination of *Melia azedarach* L. Eight pre-sowing treatments with one control were tried to know their effect on germination. In cold water treatment (T₁), the seeds were soaked in water for 24 hours. In hot water treatment (T₂), the seeds were dipped in hot water with temperature of 80°C for 10 minutes. In T₃, the seeds were dipped in concentrated H₂ SO₄ for 10 minutes. In treatment T₄, seeds were soaked in 200 molar KNO₃ solution for 24 hours. In treatment T₅, the seeds were soaked in 100 ppm of Gibberllic acid solution for 8 hours. In treatment T₆, the seeds were dipped in cow dung slurry for 6 days. In treatment T₇, the seeds were dipped in biogas slurry obtained from a biogas plant for 6 days. In mini sachet method (T₈), the seeds were kept in airtight polythene bag and then these sachets were exposed to direct sunlight for five days. In control (T₉), seeds were sown without any treatment. Among the pre-sowing treatments, 200 Molar KNO₃ solution recorded significantly higher seed germination followed by biogas slurry and cow dung slurry.

Ogbu *et al.* (2016) conducted the efficacy of pre-sowing soaking treatment of african mahogany (*Afzelia africana* sm.) seeds for enhanced germination. Seeds were soaked in water, solutions of potassium nitrate (KNO₃) and hydrogen peroxide (H₂O₂) for varying durations as method of breaking seed dormancy and enhancing germination. Results showed that seeds treated with pre-sowing soaking in H₂O₂ for four hours and 0.1% KNO₃ treatment for three hours had earliest mean day to first germination of 3 days after sowing (DAS) and 5 DAS respectively, as against non-soaked seeds (7.5 DAS) and cool water treatment for 12 hours (7 DAS). It was concluded therefore that pre-sowing treatment with 0.1% KNO₃ solution for six hours or 0.2% KNO₃ solution for three hours could be used to enhance uniform and massive germination of *A. africana* seeds within earliest possible time of 15 DAS.

Patil and Krishna (2016) reported the influence of pre - sowing treatments on seed germination and seedling quality in canes. In control, seeds were sown without

any treatment. For treatment T₂ the outer sarcotesta part of the fruit was removed. In T₃ the hilum part of the fruit was removed. In treatment T₄, T₅ seeds were soaked in ratio of 1:2 proportions seed to chemical solution (Gibberllic acid with 500 ppm and 1000 ppm) respectively for 8 hours. In treatment T₆ seeds were rubbed in hard surface with sand for reducing the hardness of the seed. In treatment T₇ seed were soaked in chemical solution KNO₃ for 8 hours. In treatment T₈ seeds were soaked in cow dung slurry for 5 days. In treatment T₉ seeds were dipped in boiling water for 5 min. Apart from sarcotesta removal treatment, GA₃, 1000 ppm, GA₃ 500 ppm 8 hrs, boiling water treatment 5 min and sand scarification also recoded higher seed germination in *Calamus thwaitesii*.

Sandeep *et al.* (2016) studied impact of GA₃ seed pre- treatment on seedling growth in *Delonix Regia*. Seeds are treated with GA₃ (i.e. Control, 700, 710, 720, 730, 740, 750, 760, 770, 780, 790 and 800 ppm concentration) on seedling growth in *Delonix regia*. Seeds physically treated with at 790 ppm significantly enhanced the plant height, number of bipinnate leaves, maximum root length, seedling fresh biomass and dry biomass at 45 Days after sowing (DAS).

Pamei *et al.* (2017) conducted study on effect of different treatments on the germination parameters and seedling quality index of *Tectona grandis* L. f. (Teak) under nursery condition. Seeds were subjected to 14 treatments including control i.e. T₀ (Control), T₁ (Soaked in normal water for 3 days), T₂ (Sunlight for 3 days), T₃ (Alternate wet 12hrs and drying 12hrs for 10 days), T₄ (Soaked in cow urine for 6 days), T₅ (Soaked in Cow dung slurry for 7 days), T₆ (Hammer treatment), T₇ (Sand paper), T₈ (Boiling 2 min), T₉ (Boiling 5 min), T₁₀ (Conc. H₂SO₄ 15 min), T₁₁ (Conc. H₂SO₄ 20 min), T₁₂ (HNO₃ 15 min), and T₁₃ (HNO₃ 20 min). Findings of the data revealed that pre-treatment of seed before sowing enhanced seed germination and seedling growth. The highest germination percentage was observed in T₃ (Alternate wet and drying) followed by T₅ (Cow dung slurry 40%) and T₁₁ (H₂SO₄ 20 min 33.3%). The lowest germination was recorded in T₂, T₄ and T₁₂ (sunlight, cow urine and HNO₃ 15 min) respectively.

Palepad *et al.* (2017) studied the effect of seed treatments on germination, seedling vigour and growth rate of custard apple (*Annona squamosa* L.). The experiment was laid out in Completely Randomized Design with twelve treatments viz.,

GA₃ – 500ppm, 1000ppm seed soaking for 24 hours in distilled water, KNO₃ (1%) and (2%) soaking for 24 hours in distilled water, 2 min. con. H₂SO₄ followed by seed soaking for 24 hours in distilled water, seed soaking for 24 and 48 hours in cow dung slurry, seed soaking in cow dung slurry for 24 and 48 hours followed by seed wrap for 72 hours in wet gunny bag, seed soaking in tap water for 24 hours and control (untreated), which were replicated three times. The seeds treated with GA₃ 1000 ppm solution minimized the days taken for germination and improved the germination percentage. Similar trend was observed in growth parameters, Viz. seedlings height, girth of plant, number of leaves, leaf area, fresh and dry weight of plant and survival percentage.

Bajaniya *et al.* (2018) reported the influence of pre-soaking treatment on seedling growth of Khirni (*Manilkara hexandra* Roxb) Seedling cv. Local. The experiment was conducted with three repetitions and twelve pre-soaking treatments control, water soaking, cow-dung Slurry, GA₃ 150 mg/l, GA₃ 200 mg/l, GA₃ 250 mg/l, KNO₃ 0.5 %, KNO₃ 1.0 %, KNO₃ 1.5 %, Thiourea 0.5 %, Thiourea 1.0 %, Thiourea 1.5 %. The effect of GA₃ 200 mg/l, was found most effective for the maximum plant height other observation like growth number of leaves, number of branches, leaf area, stem diameter, fresh weight of stem and dry weight of stem and total dry weight at 180 DAS.

Gavit (2018) conducted experiment on effect of pre-sowing seed treatment on germination and growth of Khirini (*Manilkara hexandra* L.). The seeds were treated with 12 treatments. Among the different presoaking treatments tested, the maximum germination percentage was recorded when the seeds were presoaked with fresh cow dung + cow urine + jiggery while the treatment GA₃ @ 200 ppm requires minimum days (30) to germinate.

Mane *et al.* (2018) studied the effect of different pre-sowing treatment on seed germination and growth in custard apple (*Annona squamosa* L.). The experiment was laid out in Randomized Block Design with eight treatments replicated thrice, comprising eight treatments of KNO₃ (0.1%), urea (0.1%), hot water, cold water, thiourea (1.0%), cow urine (10%), cow dung slurry (10.00%) and control. The results of the investigation revealed that, there were significant variations in germination and seedling growth of custard apple due to presowing treatments. Amongst the different

treatments, the seed soaked in thiourea (1.0%) solution for 12 hours to sowing resulted in maximum germination percentage, however, minimum days required for germination, more number of leaves, maximum stem diameter, maximum height, maximum leaf area at 30, 60 and 90 DAS respectively, maximum fresh weight of seedling, maximum dry weight of seedling, maximum length of root, maximum primary roots, maximum secondary roots, fresh weight of root, dry weight of root and maximum final survival percentage was observed under treatment T₅ i.e. thiourea (1%) for 12 hours followed by cow dung slurry.

Opoku *et al.* (2018) reported effect of pre-sowing treatments on seed germination and seedling growth of silver butterfly tree (*Bauhinia rufescens* Lam.). There were 4 treatments in experiment 1, 7 in experiment 2 and 6 in experiment 3. Each experiment was replicated five (5) times. The results showed that *Bauhinia rufescens* seeds soaked in hot water at 65⁰ C for 60 minutes gave the highest mean germination rate, tallest plant height and highest number of leaves per plant at 49 days after soaking. It also had the widest stem diameter, highest fresh shoot and root weight, highest fresh root and dry root weight and number of roots per seedling. Seeds soaked in 500 ppm Gibberelic acid (GA₃) produced the highest number of leaves per plant and tallest plants at 49 DAS. Seeds soaked in 750 ppm GA₃ had the highest number of leaves per plant at 49 DAS and highest fresh shoot weight.

Patel *et al.* (2018) studied on effect of different pre-sowing treatments and growing conditions on germination of red sandalwood (*Pterocarpus santalinus* L. f.). Among different pre-sowing treatments, seed pre-treated with GA₃ @ 500 ppm for one day registered earlier sprouting and higher germination percentage, collar diameter, plant height, number of leaves per plant, root length, fresh of plant, dry weight of plant and survival percentage. The next best pre-sowing treatments are GA₃ @ 250 ppm for one day and separating seeds from pods with a sharp knife or scalpel and sown directly. The seeds which were not treated (control) were found poorest for all parameters under study.

Shim *et al.* (2008) reported the effect of potassium nitrate priming on seed germination of seashore paspalum. Seeds were subjected to priming in petri dishes with solutions of KNO₃ at 25 ⁰C for 24, 48, and 72 h in growth chambers. Germination percentage differed by priming duration as well as concentration of priming media.

Based on the germination percentage 14 days after imbibition, the most promising priming condition was the treatment with 0.2% or 0.5% KNO₃ for 72 h at a constant temperature of 30 °C and 0.2% or 0.5% KNO₃ for 48 to 72 h at alternating temperature of 25/35 °C. Both concentrations showed reasonable germination percentage greater than 85% at alternating temperature condition. Priming with KNO₃ solution for 48 to 72 h improved not only germination percentage, but also uniformity.

Thanuja *et al.* (2018) studied enhancement of germination and seedling growth attributes of a medicinal tree species *Pterocarpus marsupium* Roxb. through pre sowing seed treatments. Seeds were treated with different treatment includes growth regulators (GA₃, NAA, Cytokinine), acid scarification (KNO₃, HCl, H₂SO₄) and organics (hot water, cow urine, cow dung slurry), among all the treatments seeds treated with H₂SO₄ (2%) recorded the higher germination percentage followed by 1:1 of cowdung slurry and the lowest germination percentage was observed in case of seeds treated with hot water at 80 °C for 20 minutes showed lowest germination percentage of 9.17 percent followed by control 19.17 percent.

Thanuja *et al.* (2019) studied the effect of pre sowing seed treatments on seed germination and seedling growth in rakta chandana (*Pterocarpus santalinus* L.). The experiment was planned to treat the seeds which helps to break dormancy with acid scarification (KNO₃, HCL, H₂SO₄), growth regulators (GA₃, NAA, cytokinin) and soaking of seeds in organic solutions (cow urine, cow dung slurry, hot water treatment). It was found that, the higher germination percentage, seedling length, collar girth and seedling dry weight were found in seed treatment with cow dung slurry while control showed poor germination and growth. The study indicated that soaking seeds for 48 hours in cow dung slurry resulted in good germination and better seedling growth. All other treatments were also found to be significant and superior over control.

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled “**Effect of pre sowing treatments on seed germination and its parameters in sandalwood (*Santalum album* L.)**” was carried out during *rabi* 2019-20 in greenhouse of Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh. The details of the materials used, experimental methods followed and techniques adopted during the course of present investigation is described in this chapter.

3.1 GEOGRAPHIC CONDITIONS AND LOCATION OF EXPERIMENT

The Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh is located in South Saurashtra Agro-Climatic Zone-VII of Gujarat state. Geographically, Junagadh is situated at 21.5⁰ N latitude and 70.5⁰ E longitudes with an elevation of 60 meters above the mean sea level.

The location of experiment was under greenhouse condition in the Department of Genetics and Plant Breeding, JAU, Junagadh. The germination trays are filled with sand and soil mixture and placed under greenhouse.

3.2 CLIMATE AND WEATHER CONDITIONS

The Saurashtra region has a typical wet and dry climate, with three distinct seasons observed, a mild and dry winter from the month of November to February, a hot and dry summer from the month March to June, and a monsoon from the month of July to October. In greenhouse both temperature and relative humidity are maintained for better growth of seedlings. The temperature is maintained by cooling pads through evaporation mechanism. The daily meteorological data of greenhouse pertaining to the temperature and the relative humidity prevailed during study period are presented in Appendix I.

3.3 EXPERIMENTAL MATERIAL

The experimental material comprised of seeds of sandalwood was obtained from Paritalav botanical garden, Junagadh Agricultural University, Junagadh. Chemicals like GA₃, KNO₃ and ethrel were provided by the Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh. Cow dung was

obtained from CBF (Cattle Breeding Farm), Veterinary College in Junagadh Agricultural University, Junagadh.

3.4 METHODOLOGY

3.4.1 Experimental details

- 1. Year and season of experiment** : *Rabi* 2019-20
- 2. Location of experiment** : Green house of Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh
- 2. Experimental design** : Completely Randomized Design (Factorial)
- 3. Number of replications** : 3
- 4. Number of factors** : 3
- 5. Number of treatment combinations** : Twenty eight
- 6. Number of seeds per treatments** : 100
- 7. Germination Method** : Germination trays (sand + soil)

3.4.2 Collection of seed material

The sandalwood seeds required for the present studies was collected from the Paritalav botanical garden, Junagadh Agricultural University, Junagadh. Old seeds were collected during March-April 2019, whereas new seeds were collected during Oct-November, 2019. Both new and old seeds were collected during the fruiting season and the seeds were dried to remove all adhering pulp and used for carrying out the experiment.

3.4.3 Treatment details

Pre-sowing seed treatments for finding their effects on sandalwood germination and its parameters:

Factor I: Age (A)

- 1) (A₁) Old (8 months)
- 2) (A₂) New (fresh seeds)

Factor II: Scarification (S)

- 1) (S₁) Sand paper
- 2) (S₂) Ultrasonic sound

Factor III: Treatment (T)

- 1) (T₁) GA₃ 100 ppm
- 2) (T₂) GA₃ 300ppm
- 3) (T₃) KNO₃ at 2%
- 4) (T₄) Cow dung for 24 hours
- 5) (T₅) Cow dung for 48 hours
- 6) (T₆) Ethrel 100 ppm
- 7) (T₇) Control

Table 3.1: Treatment combinations

Sr.no.	Treatments	Sr.no.	Treatments	Sr.no.	Treatments	Sr.no.	Treatments
1.	T ₁ : A ₁ S ₁ T ₁	8.	T ₈ : A ₁ S ₂ T ₁	15.	T ₁₅ : A ₂ S ₁ T ₁	22.	T ₂₂ : A ₂ S ₂ T ₁
2.	T ₂ : A ₁ S ₁ T ₂	9.	T ₉ : A ₁ S ₂ T ₂	16.	T ₁₆ : A ₂ S ₁ T ₂	23.	T ₂₃ : A ₂ S ₂ T ₂
3.	T ₃ : A ₁ S ₁ T ₃	10.	T ₁₀ : A ₁ S ₂ T ₃	17.	T ₁₇ : A ₂ S ₁ T ₃	24.	T ₂₄ : A ₂ S ₂ T ₃
4.	T ₄ : A ₁ S ₁ T ₄	11.	T ₁₁ : A ₁ S ₂ T ₄	18.	T ₁₈ : A ₂ S ₁ T ₄	25.	T ₂₅ : A ₂ S ₂ T ₄
5.	T ₅ : A ₁ S ₁ T ₅	12.	T ₁₂ : A ₁ S ₂ T ₅	19.	T ₁₉ : A ₂ S ₁ T ₅	26.	T ₂₆ : A ₂ S ₂ T ₅
6.	T ₆ : A ₁ S ₁ T ₆	13.	T ₁₃ : A ₁ S ₂ T ₆	20.	T ₂₀ : A ₂ S ₁ T ₆	27.	T ₂₇ : A ₂ S ₂ T ₆
7.	T ₇ : A ₁ S ₁ T ₇	14.	T ₁₄ : A ₁ S ₂ T ₇	21.	T ₂₁ : A ₂ S ₁ T ₇	28.	T ₂₈ : A ₂ S ₂ T ₇

3.4.4 Preparation of stock solutions

GA₃ stock solution:

The stock solution of 2000 ppm was prepared by dissolving 500 mg of pure GA₃ in 50 ml alcohol and making volume to 250 ml with distilled water. The working solution of desired strength was prepared by taking appropriate quantities of stock solution and then diluting the same with distilled water to get required concentration of GA₃ i.e. 100 and 300 ppm.

Ethrel stock solution:

The ethrel stock solution of 1000 ppm was prepared by taking 175 mg ethrel and making volume to 175 ml with distilled water. The working solution of desired strength was prepared by taking appropriate quantities of stock solution and then diluting the same with distilled water to get required concentration of ethrel i.e. 100 ppm.

3.4.5 Seed treatment

3.4.5.1 Age:

Old seeds: Old seeds were of age 8-9 months collected from the tree during April, 2019 for sowing.

New seeds: New seeds were of age 1-2 month collected from the tree during November, 2019 for sowing.

3.4.5.2 Scarification:

The required amount of both old and new aged seeds were rubbed against the sandpaper to rupture the seed coat and after that the seeds were soaked in chemical treatments for required amount of time before sowing.

3.4.5.3 Ultrasonic sound:

The required amount of both old and new aged seeds were treated with ultrasonic sound for about 15 minutes.

3.4.5.4 Preparation of 100 ppm GA₃ solution:

100 ppm GA₃ solution was prepared by pipetting out 60 ml from stock solution and made volume to 1200 ml.

3.4.5.5 Preparation of 300 ppm GA₃ solution:

300 ppm GA₃ solution was prepared by pipetting out 180 ml from stock solution and making volume to 1200 ml.

3.4.5.6 Preparation of 100 ppm Ethrel solution:

100 ppm Ethrel solution was prepared by pipetting out 120 ml from stock solution and making volume to 1200 ml.

3.4.5.7 Preparation of 2% KNO₃ solution:

It was prepared by taking 24 gms KNO₃ in a cylindrical flask and making volume to 1200 ml.

3.4.5.8 Preparation of cow dung slurry:

It was prepared by mixing fresh cow dung in water to get slurry.

3.4.5.9 Soaking of seeds:

The required amount of both old and new aged seeds which were treated with scarification and ultrasonic sound were soaked in 100 ppm GA₃, 300 ppm GA₃, 100 ppm ethrel, 2% KNO₃ for about 12 hrs and in cow dung slurry for about 12 and 24 hrs respectively.

3.4.5.9 Control:

The required amount of old and new aged seeds were not treated with any one of the treatments is used as control for sowing.

3.4.6 Preparation of germination trays:

3.4.6.1 For sowing of seeds:

The required amount of sand and soil is mixed in 3:1 proportion. Then the mixture was sieved in 3mm size sieve. This sieved mixture is used to fill the germination trays. Later the soaked seeds were sown in the mixture @ 100 seeds per tray. Proper care was taken while sowing the seeds. The depth of sowing was maintained at 2 cm. The care was taken to cover the seeds with the thin layer of sand and soil mixture.

3.4.6.2 Other operations:

The other operations like irrigation and weeding were carried as per requirement. The irrigation was given with the help of pressure sprayer and care was taken to maintain optimum soil moisture in germination trays. Weeding was done as and when required to remove weeds in germination trays in order to avoid competition of weeds with seedlings for nutrients and moisture. Trays are covered with polythene to conserve moisture by reducing evaporation losses.

3.5 OBSERVATIONS RECORDED

Five competitive plants per treatment in each replication were selected randomly for recording observations under greenhouse conditions and their averages were used in the statistical analysis. Laboratory observations were recorded for the seedlings produced in each of the treatment for each replication.

3.5.1 Germination per cent (%)

The seeds germinated normally during the germination period was counted and the total number of seeds germinated was divided by the total number of seeds sown and the result was expressed in percentage.

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

3.5.2 Time taken for initiation of germination (TTIG)

Number of days taken to initiation of germination was recorded for each treatment. The seeds were considered as germinated only when the sprouted plumule along with the cotyledons was protruded about 0.5 cm above the surface.

3.5.3 Time taken for completion of germination (TTCG)

Number of days taken from sowing to completion of germination was recorded for each treatment.

3.5.4 Speed of Germination

An index of speed of germination was calculated by summing up the quotient of the daily counts divided by the number of days of germination.

$$\text{Speed of germination (SG)} = G1/D1 + G2/D2 + G3/D3 + \dots + G_n/D_n$$

Where G1, G2, G3....G_n is the number of seeds newly germinated on 1, 2, 3... nth day respectively. D1, D2, D3...D_n count on 1, 2, 3... nth day respectively.

3.5.5 Mean weekly germination

Mean weekly germination was calculated by dividing the cumulative germination to number of weeks after sowing.

$$\text{MWG} = \frac{\text{Cumulative germination percent}}{\text{Number of weeks after sowing}}$$

3.5.6 Root Length of seedling (cm)

Normal seedlings of each treatment were randomly selected for measuring root length from collar region to tip of roots in centimeters.

3.5.7 Shoot length (cm)

The shoot length was measured from selected seedlings used for measuring the root length. The length between collar region and tip of the shoot was considered as shoot length.

3.5.8 Seedling length (cm)

Seedling length was the summation of root length and shoot length.

$$\text{Seedling length (cm)} = \text{Root length (cm)} + \text{Shoot length (cm)}.$$

3.5.9 Collar diameter (mm)

Collar diameter was measured at the time of height measurement with the help of digital caliper and observations were expressed in mm.

3.5.10 Seedling fresh weight (mg)

Randomly taken normal seedlings were used for fresh weight of seedling was recorded on an electronic balance and expressed in milligram.

3.5.11 Seedling dry weight (mg)

The seedlings after measuring fresh weight was dried in shade for 12 hour and then hot air oven dried at 100 °C for 24 hour and were weighed in milligrams.

3.5.12 Seedling vigour index (Length)

Seedling vigour index was computed by using the formula suggested by Abdul-Baki and Anderson (1973).

$$\text{SVI (length)} = \text{Germination (\%)} \times \text{Seedling length (cm)}$$

3.5.13 Seedling vigour index (mass)

Vigour index in terms of mass was determined by multiplication of germination percentage with seedling dry weight on the day of final count.

$$\text{SVI (Mass)} = \text{Germination (\%)} \times \text{Seedling dry weight (mg)}$$

3.6 Statistical analysis

The statistical analysis on following aspects was carried out:

Analysis of variance for Completely Randomized Design (Factorial) was computed as per the method of Gomez and Gomez (1984).

The characters viz., germination per cent (%), time taken for initiation of germination (TTIG), time taken for completion of germination (TTCG), speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedlings (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (Length), seedling vigour index (Mass) were analyzed by Completely Randomized Design (Factorial).

3.6.1 Completely Randomized Design (Factorial)

Analysis of variance for Completely Randomized Design (Factorial) was computed as per the method of Gomez and Gomez (1984), which is based on the following mathematical model:

$$Y_{ijkl} = \mu + a_i + b_j + c_k + (abc)_{ijk} + e_{ijkl}$$

Where,

Y_{ijkl} = Phenotypic expression of i^{th} level of factor A, the j^{th} level of factor B and the k^{th} level of factor C in L^{th} replication

μ = Population mean

a_i = Effect of the i^{th} level of factor A

b_j = Effect of the j^{th} level of factor B

c_k = Effect of the k^{th} level of factor C

$(ab)_{ijk}$ = Effect of the interaction between the i^{th} level of factor A and the j^{th} level of factor B and k^{th} level of factor C

e_{ijkl} = Random error associated with the l^{th} replication in cell (i, j, k).

The form of analysis of variance as presented in the Table 3.2 was constructed for individual characters viz., germination per cent (%), time taken for initiation of germination (TTIG), time taken for completion of germination (TTCG), speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedlings (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (length), seedling vigour index (mass).

Table 3.2: The structure of ANOVA for Factorial CRD

Source of variation	d.f	S.S	M.S	Cal F
Factor (A)	A-1	SS_A	MS_A	MS_A / MS_E
Factor (B)	B-1	SS_B	MS_B	MS_B / MS_E
Interaction (AxB)	(A-1) (B-1)	SS_{AB}	MS_{AB}	MS_{AB} / MS_E
Factor (C)	C-1	SS_C	MS_C	MS_C / MS_E
Interaction (AxC)	(A-1) (C-1)	SS_{AC}	MS_{AC}	MS_{AC} / MS_E
Interaction (BxC)	(B-1) (C-1)	SS_{BC}	MS_{BC}	MS_{BC} / MS_E
Interaction (AxBxC)	(A-1) (B-1) (C-1)	SS_{ABC}	MS_{ABC}	MS_{ABC} / MS_E
Error (E)	(ABC) (R-1)	SS_E	MS_E	
Total	(ABCR-1)	SS_T		

Where,

A = Number of treatments in the first factor,

B = Number of treatments in the second factor,

C = Number of treatments in the third factor,

SS_A = Sum of square due to treatments in factor A,

SS_B = Sum of square due to treatments in factor B,

SS_{AB} = Sum of square due to interaction treatments in factor A and factor B,

SS_C = Sum of square due to treatments in factor C,

SS_{AC} = Sum of square due to interaction treatments in factor A and factor C,

SS_{BC} = Sum of square due to interaction treatments in factor B and factor C,

SS_{ABC} = Sum of square due to interaction treatments in factor A, factor B and factor C,

SS_E = Sum of square due to error,

SS_T = Total sum of square,

MS_R = Mean square due to replication,

MS_A = Mean square due to treatments in factor A,

MS_B = Mean square due to treatments in factor B,

MS_{AB} = Mean square due to interaction treatments in factor A x factor B, and

MS_E = Mean square due to error.

R = Number of replications

Mean squares due to different sources were tested against error mean square (MS_E) by calculating 'F' values.

The standard error of mean (S. Em.) was calculated using following formula.

$$\text{S.Em for factor A} = \sqrt{\frac{\text{Error M.S}}{rBC}}$$

$$\text{S.Em for factor B} = \sqrt{\frac{\text{Error M.S}}{rAC}}$$

$$\text{S.Em for factor C} = \sqrt{\frac{\text{Error M.S}}{rAB}}$$

$$\text{S.Em for factor A} \times \text{B interaction} = \sqrt{\frac{\text{Error M.S}}{rC}}$$

$$\text{S.Em for factor A} \times \text{C interaction} = \sqrt{\frac{\text{Error M.S}}{rB}}$$

$$\text{S.Em for factor B} \times \text{C interaction} = \sqrt{\frac{\text{Error M.S.}}{rA}}$$

$$\text{S.Em for factor A} \times \text{B} \times \text{C interaction} = \sqrt{\frac{\text{Error M.S.}}{r}}$$

The critical difference (C.D.) to compare the mean of any two genotypes was calculated using following formula.

$$\text{C.D.} = \text{S.Em} \times \sqrt{2} \times t$$

Where,

‘t’ = Table value of ‘t’ at 5 per cent level of significant at error degree of freedom

The coefficient of variation (C.V.) was determined according to the following formula

$$\text{C. V. (\%)} = \frac{\sqrt{\text{EMS}}}{\bar{x}} \times 100$$

Where,

$\bar{x}$ = General mean

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION



The experiment was conducted at the greenhouse, Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh during *rabi* 2019-20 to study the “Effect of pre sowing treatments on seed germination and its parameters in sandalwood (*Santalum album* L.)”. The characters viz., germination per cent (%), time taken for initiation of germination (TTIG), time taken for completion of germination (TTCG), speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedling (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (length) and seedling vigour index (mass) were analyzed by completely randomize design (factorial) as per the method suggested by of Gomez and Gomez (1984).

Aging is one of the most important factors affecting seed germination. As the aging increases, germination percentage decreases (Christidis, 1954; Akhter *et al.*, 1992; Rice and Dyer, 2001; Mohammadi *et al.*, 2012) in cotton, wheat and barley seeds, *Bromus tectorum* and soybean, respectively. The maximum germination percentage of >80% was observed when the storage period was 3 weeks under the GA₃ treatment and the germination rate was less than 40%, when seeds were soaked in water. Germination of 50% was achieved at the 7th week of storage and the germination rate was zero after 28 weeks of storage under the GA₃ treatment in sandalwood (Gamage *et al.*, 2010). Therefore new aged seeds are preferred for sowing rather than old aged seeds in sandalwood.

The germination and its parameters like time taken for initiation of germination, time taken for completion of germination, speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedling (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (length) and seedling vigour index (mass) depend on different pre-sowing seed treatments like scarification, ultrasonic sound, GA₃ treatment, KNO₃, cow dung and ethrel. Jack pine (*Pinus banksiana* Lamb.) responded to the ultrasonic treatments by giving rise to higher mean daily germination and germination value

(Weinberger and Burton; 1981). Mechanical scarification with sandpaper and treatment with sulfuric acid effectively increased both total germination and rate of germination compared to the untreated control in florida legume *Galactia elliottii* Nutt. (Muir and Pitman; 1987). The cumulative germination was higher on the seed with scarification of seeds soaked in GA₃ solution 300 and 500 ppm (Pamungkas and Nichols; 2019). Soaking the seeds in 0.05% GA₃ for 16 to 24 hours gave good germination of sandalwood seeds (Das and Tah; 2013). Farmers are also not much interested in cultivating sandalwood due to its low germination rate. Thus the germination rate as well as the early emergence of seeds can be enhanced by different pre-sowing seed treatments.

After sowing the old seeds and waiting for about 88 days hardly any of these had germinated. Only for specific treatments and in some of the replications the old seeds showed positive results as shown in Table 4.1.

Table 4.1: The number of seeds germinated in different treatments of old seeds (A₁) for about 88 days

Treatments	Rep.- I	Rep.- II	Rep.- III
A ₁ S ₁ T ₁	0	0	0
A ₁ S ₁ T ₂	0	1	1
A ₁ S ₁ T ₃	0	0	1
A ₁ S ₁ T ₄	2	2	1
A ₁ S ₁ T ₅	0	1	1
A ₁ S ₁ T ₆	1	0	1
A ₁ S ₁ T ₇	5	5	5
A ₁ S ₂ T ₁	0	0	1
A ₁ S ₂ T ₂	0	0	0
A ₁ S ₂ T ₃	1	1	1
A ₁ S ₂ T ₄	1	1	0
A ₁ S ₂ T ₅	1	0	0
A ₁ S ₂ T ₆	1	1	2
A ₁ S ₂ T ₇	1	2	1

Old seeds were sown after 8 months from the time of collection. It is because of this reason, the viability of the old seeds had lost. Thereby, the number of germinated seeds is observed to be very less. Similar observations were reported by (Gamage *et al.*, 2010) in the case of sandalwood, where the germination rate was found to be zero per

cent after 28 weeks of storage under the GA₃ treatment. Therefore the old seeds were not preferred when compared to the new ones.

The intension of this work is to study the impact of aging, scarification and treatments (chemical/organic) on the growth of sandalwood seeds. However, it is evident from the data presented in Table 4.1 that there is no need to consider aging as one of the factors. Moreover, if the data for the old seeds is considered for computing the C.V %, it would result in erroneous values. The reason for this being the dormancy of the old seeds in some of the replications and the germination in the rest for a given combination of treatments. Therefore, for the reasons mentioned above only two factors (scarification and treatments) were considered to find out the best combination of treatments when applied to the new seeds.

Keeping all these above facts in view, the present study was undertaken to determine the effect of pre sowing treatments on seed germination and its parameters in sandalwood (*Santalum album* L.). The results are presented and discussed herewith.

4.1 Analysis of variance

The analysis of variance for seed germination and its parameters are presented in Table 4.2. The results showed that scarification factor (manual scarification with sandpaper and ultrasonic sound) manifested significant differences for all the characters included in the study, except for collar diameter where the effect of scarification resulted in non-significant difference. Different treatments also exerted significant difference for seed germination and its parameters like time taken for initiation of germination, time taken for completion of germination, speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedling (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (length) and seedling vigour index (mass).

Mean squares due to interaction effects of scarification and treatments were found to be significant for all the characters taken under study.

Table 4.2: Analysis of variance for experimental design (FCRD) for germination and its parameters in sandalwood

Source of Variation	d.f	Mean Sum of Squares					
		Germination (%) (MSS)	TTIG (MSS)	TTCG (MSS)	Speed of germination (MSS)	Mean weekly germination (MSS)	Root length (cm) (MSS)
Scarification (S)	1	5531.52*	521.52*	493.71*	1.60*	35.42*	0.25*
Treatments (T)	6	336.04*	132.35*	63.43*	0.12*	2.48*	0.48*
Scarification x Treatments (SxT)	6	86.52*	147.91*	103.32*	0.032*	0.55*	0.60*
Error (E)	28	0.38	0.35	0.33	0.0001	0.003	0.02

*** Significant at 5 per cent level**

Table 4.2: Contd..

Source of Variation	d.f	Mean Sum of Squares						
		Shoot length (cm)	Seedling length (cm)	Collar diameter (mm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	SVI (length)	SVI (mass)
Scarification (S)	1	3.77*	6.17*	0.0002	18062.88*	1010.38*	494347.70*	15406949.00*
Treatments (T)	6	0.92*	2.64*	0.10*	2098.43*	136.20*	36158.60*	1021875.00*
Scarification x Treatments (SxT)	6	1.30*	3.26*	0.11*	4866.88*	182.04*	8997.35*	238090.70*
Error (E)	28	0.03	0.03	0.01	39.40	0.59	53.74	955.71

* Significant at 5 per cent level

4.2 Effect of scarification (S) and treatments (T) on germination and its components

4.2.1 Germination per cent (%)

The data on seed germination percentage of sandalwood was influenced by scarification and treatments are presented in Table 4.3 and graphically depicted in Figure 4.1.

4.2.1.1 Effect of scarification (S)

The results revealed that effect of aging had showed significant influence on germination per cent (%) (Table 4.2). Manually scarified seeds (S_1) noted comparatively the maximum germination per cent (35.38%) over ultrasonic sound (S_2) (12.42%). The scarification process, resulted in ruptured seed leading to reduction in the dormancy period. When compared to ultrasonic sound scarification for about 15 minutes, manual scarification with sandpaper resulted in cell layer damage after sandpapering and germination occurs with water penetration. The results are in accordance to the findings of Muir and Pitman (1987) in *Galactia elliottii*, Abari *et al.* (2012) in *Acacia*, Bhat *et al.* (2001) in forest species, Saied *et al.* (2008) in *Ziziphus spina-christi*, Zaman *et al.* (2009) in *Helianthemum lippii* (L.), Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss., Talei *et al.* (2012) in *Andrographis paniculata* Nees., Yildiztugay *et al.* (2012) in *sphaerophysa kotschyana* boiss. and Jayawardena *et al.* (2015) in sandalwood.

4.2.1.2 Effect of treatments (T)

The effect of treatments had produced significant influence on germination per cent (Table 4.2). Significantly the highest germination per cent was observed in T_2 (GA_3 @300 ppm) (34.66%) which was at par with T_1 (GA_3 @ 100 ppm) (33.83%) and followed by T_3 (KNO_3 @2%) (23.33%). Significantly minimum germination per cent was observed in T_6 (ethrel 100 ppm) (16.16%).

The enhancement of germination by GA_3 can be attributed to the fact that it antagonize the ill effect of inhibitors and induce *de novo* synthesis of proteolytic enzymes like alpha amylase and ribonuclease. These enzymes hydrolyse starch in the endosperm providing the essential sugar for the initiation of growth process in the developing embryo. The results obtained in the present investigation are in accordance with the findings of Vira and Smith (1996) and Nikam and Barmukh (2009) in

Table 4.3: Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on germination (%), TTIG, TTCG and speed of germination

Treatment	Germination (%)	TTIG	TTCG	Speed of germination
Scarification (S)				
S₁	35.38	38.61	84.66	0.60
S₂	12.42	45.66	77.80	0.21
S. Em±	0.13	0.13	0.12	0.002
CD at 5 %	0.39	0.37	0.36	0.006
Treatments (T)				
T₁	33.83	41.16	85.33	0.54
T₂	34.66	34.66	78.50	0.64
T₃	23.33	39.00	82.33	0.40
T₄	17.16	47.16	80.33	0.27
T₅	21.33	48.33	75.83	0.33
T₆	16.16	43.33	82.66	0.26
T₇	20.83	41.33	83.66	0.36
S. Em±	0.25	0.24	0.23	0.004
CD at 5 %	0.72	0.70	0.68	0.01
Scarification (S) x Treatments (T)				
S₁T₁	41.33	39.00	88.00	0.68
S₁T₂	50.67	28.67	81.67	0.96
S₁T₃	34.67	29.67	81.33	0.62
S₁T₄	26.67	51.67	84.33	0.40
S₁T₅	38.33	41.33	87.33	0.59
S₁T₆	23.67	44.67	82.00	0.39
S₁T₇	32.33	35.33	88.00	0.58
S₂T₁	26.33	43.33	82.67	0.42
S₂T₂	18.67	40.67	75.33	0.33
S₂T₃	12.00	48.33	83.33	0.20
S₂T₄	7.67	42.67	76.33	0.14
S₂T₅	4.33	55.33	64.33	0.07
S₂T₆	8.67	42.00	83.33	0.15
S₂T₇	9.33	47.33	79.33	0.16
Mean	23.90	42.14	81.23	0.40
S. Em±	0.35	0.34	0.33	0.006
CD at 5 %	1.03	0.99	0.96	0.01
CV %	2.58	1.41	0.71	2.63

sandalwood, Anand *et al.* (2012) in *Melia dubia*, Caliskan *et al.* (2012) in fig seeds, Jayawardena *et al.* (2015) and Suthesh *et al.* (2016) in sandalwood, Patil and Krishna (2016) in canes, Palepad *et al.* (2017) in custard apple, Shankar and Devakumar (2018) and Pamungkas and Nichols (2019) in sandalwood.

4.2.1.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments on germination % was found to be significant. On comparison the maximum germination per cent was recorded in S₁T₂ (manual scarification with sandpaper along with GA₃ @ 300 ppm) (50.67%) followed by S₁T₁ (manual scarification with sandpaper along with GA₃ @ 100 ppm) (41.33%) while the minimum germination per cent was found in S₂T₅ (ultrasonic sound with cow dung for 48 hrs) (4.33%). Manual scarification with sandpaper results in cell layer damage after sandpapering and germination occurs with water penetration. The enhancement of germination by GA₃ can be attributed to the fact that it antagonize the ill effect of inhibitors and induce *de novo* synthesis of proteolytic enzymes like alpha amylase and ribonuclease. These enzymes hydrolyse starch in the endosperm providing the essential sugar for the initiation of growth process in the developing embryo. The results obtained in the present investigation are in accordance with the findings of Zaman *et al.* (2009) in *Helianthemum lippii* (L.) Dum. Cours, Tambat *et al.* (2006) in *Myristica swamps*, Jayawardena *et al.* (2015) and Karmakar *et al.* (2018) in sandalwood.

4.2.2 Time taken for initiation of germination (TTIG)

The effect of scarification and treatments on TTIG are presented in Table 4.3 and graphically depicted in Figure 4.2.

4.2.2.1 Effect of scarification (S)

Analysis of data showed that the effect of manual scarification (S₁) and ultrasonic sound (S₂) had produced significant influence on TTIG. The time taken for initiation of germination was found faster in case of S₁ (manual scarification with sandpaper) (38.61 days) whereas the time taken for initiation of germination in case of S₂ (ultrasonic sound) had taken longer time (45.66 days) than S₁. Because of the scarification process, the seed coat was ruptured leading to reduction in the dormancy period. When compared to ultrasonic sound scarification for about 15 minutes, manual scarification by hand with sand paper had reduced dormancy period leading to early

emergence of the seedling from seed thus reducing time taken for initiation of germination. The results obtained in the present investigation are in accordance with the findings of Bhat *et al.* (2001) in forest species of the western ghat region of India, Saied *et al.* (2008) in *Ziziphus spina-christi* seeds, Azad *et al.* (2011) in *Acacia auriculiformis* A. Cunn. Ex Benth. and Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss.

4.2.2.2 Effect of Treatments (T)

Highly significant variation in respect to TTIG was recorded among the different seed treatments. The time taken for initiation of germination was found faster in case of T₂ (GA₃ @ 300 ppm) (34.66 days) followed by T₃ (KNO₃ at 2%) (39.00 days), T₁ (GA₃ @ 300 ppm) (41.16 days), T₇ (control) (41.33 days), T₆ (ethrel 100 ppm) (43.33 days), T₄ (cow dung for 24 hours) (47.16) days and late initiation in case of T₅ (cow dung for 48 hours) (48.33 days). Gibberellins help to increase the availability of stored material for growing embryo by increasing the amylase enzyme activities in the seeds which leads to the faster and more germination of seeds. The results obtained in the present investigation are in accordance with the findings of Nikam and Barmukh (2009) in sandalwood, Caliskan *et al.* (2012) in fig seeds, Palepad *et al.* (2017) in custard apple and Pamungkas and Nichols (2019) in sandalwood.

4.2.2.3 Interaction effect of Scarification (S) x Treatments (T)

The interaction effect of scarification and treatments had produced significant influence on TTIG. The time taken for initiation of germination was found faster in S₁T₂ (manual scarification with sandpaper and treated with GA₃ @ 300 ppm) (28.67 days) which was at par with S₁T₃ (manual scarification with sandpaper and treated with KNO₃ at 2%) (29.67 days) while the time taken for initiation of germination had taken long time in case of S₂T₅ (ultrasonic sound treated with cow dung for 48 hours) (55.33 days). Because of the scarification process, the seed coat was ruptured leading to reduction in the dormancy period and gibberellins help to increase the availability of stored material for growing embryo by increasing the amylase enzyme activities in the seeds which leads to the faster and more germination of seeds. The results obtained in the present investigation are in accordance with the findings of Zaman *et al.* (2009) in *Helianthemum lippii* (L.) Dum. Cours, Tambat *et al.* (2006) in *Myristica swamps*, Jayawardena *et al.* (2015) and Karmakar *et al.* (2018) in sandalwood.

4.2.3 Time taken for completion of germination (TTCG)

The effect of scarification and treatments on TTCG are presented in Table 4.3 and graphically depicted in Figure 4.3.

4.2.3.1 Effect of Scarification (S)

The result showed that the effect of manual scarification (S_1) and ultrasonic sound (S_2) had produced significant influence on TTCG. Time taken for completion of germination was found highest in S_1 (manual scarification with sandpaper) (84.66 days) when compared to S_2 (ultrasonic sound) (77.80 days). An extended period of germination by manual scarification may be an advantage for continuation of germination leading to highest germination per cent. The results obtained in the present investigation are in accordance with the findings of Bhat *et al.* (2001) in forest species of the western ghat region of India, Azad *et al.* (2011) *Acacia auriculiformis* A. Cunn. Ex Benth. and Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss.

4.2.3.2 Effect of Treatments (T)

The effect of treatments exhibited significant differences on TTCG. Time taken for completion of germination was found highest in case of T_1 (GA_3 @ 100 ppm) (85.33 days), followed by T_7 (control) (83.66 days) which was at par with T_6 (ethrel 100 ppm) (82.66 days) and T_3 (KNO_3 at 2%) (82.33 days), followed by T_4 (cow dung for 24 hours) (80.33 days) and T_2 (GA_3 @ 300 ppm) (78.5 days) while the time taken for completion of germination was lowest in case of T_5 (cow dung for 48 hours) (75.83 days). Time taken for completion of germination was found highest in case of T_1 (GA_3 @ 100 ppm) may be due to highest germination percentage which leads to extension of period of germination and an extended period of germination by control may be an adaptation to allow them to wait for favorable conditions for germination and adaptation. The results obtained in the present investigation are in accordance with the findings of Bhat *et al.* (2001) in forest species of the western ghat region of India.

4.2.3.3 Interaction effect of Scarification (S) x Treatments (T)

The interaction effect of scarification and treatments had produced significant influence on TTCG. The time taken for completion of germination was found highest in case of S_1T_1 (manual scarification with sandpaper and treated with GA_3 @ 100 ppm) and S_1T_7 (manual scarification with sandpaper and control) (88.00 days) which were at par with S_1T_5 (manual scarification with sandpaper and treated with cow dung for 48

hours) (87.33 days) while the time taken for completion of germination was lowest in case of S₂T₅ (ultrasonic sound treated with cow dung for 48 hours) (64.33 days). An extended period of germination by manual scarification and GA₃ may be an advantage for continuation of germination leading to highest germination per cent in S₁T₁.

4.2.4 Speed of Germination

The speed of germination affected by scarification and treatments of sandalwood during the experiment are presented in Table 4.3 and graphically depicted in Figure 4.4.

4.2.4.1 Effect of Scarification (S)

The effect of manual scarification (S₁) and ultrasonic sound (S₂) exhibited significant differences on speed of germination. The maximum speed of germination was found in S₁ (manual scarification with sandpaper) (0.60) and minimum in case of S₂ (ultrasonic sound) (0.21). Maximum speed of germination by manual scarification due to rupture of hard seed coat leading to highest germination and speed of germination. The results obtained in the present investigation are in accordance with the findings of Fattahi *et al.* (2011) in *Dracocephalum kotschyi* Boiss. and Yildiztugay *et al.* (2012) in *Sphaerophysa kotschyana* Boiss.

4.2.4.2 Effect of Treatments (T)

Analysis of data showed that different treatments had produced significant influence on speed of germination. Significantly highest speed of germination was found in case of T₂ (GA₃ @ 300 ppm) (0.64) followed by T₁ (GA₃ @ 100 ppm) (0.54), T₃ (KNO₃ at 2%) (0.40), T₇ (control) (0.36) and T₅ (cow dung for 48 hours) (0.33), whereas significantly minimum speed of germination was recorded in T₆ (ethrel 100 ppm) (0.26) and it was at par with T₄ (cow dung for 24 hours) (0.27) Maximum speed of germination by GA₃ might be due to enhanced enzymatic reactions along with suppression of inhibitors. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Caliskan *et al.* (2012) in fig seeds, Vijendrkumar *et al.* (2014) in garden rue, Patil and Krishna (2016) in canes and Pamungkas and Nichols (2019) in sandalwood.

4.2.4.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for speed of germination was found significant. However, the maximum speed of germination was found in S₁T₂ (scarification with GA₃ @ 300 ppm) (0.96) followed by S₁T₁ (scarification with GA₃ @ 100 ppm) (0.68) and S₁T₃ (scarification with KNO₃ at 2%) (0.62), while the minimum speed of germination was recorded in S₂T₅ (ultrasonic sound with cow dung for 48 hours) (0.07). Due to rupture of hard seed coat and increased germination by manual scarification combined with change in enzymatic reactions by GA₃ had led to maximum speed of germination in S₁T₂. The results obtained in the present investigation are in accordance with the findings of Tambat *et al.* (2006) in *Myristica swamps* and Zaman *et al.* (2009) in *Helianthemum lippii* (L.) Dum. Cours.

4.2.5 Mean weekly germination

The data on mean weekly germination of sandalwood was influenced by scarification and treatments are presented in Table 4.4 and graphically depicted in Figure 4.5.

4.2.5.1 Effect of Scarification (S)

It is evident from the results that the effect of manual scarification (S₁) and ultrasonic sound (S₂) had produced significant influence on mean weekly germination. The maximum mean weekly germination was found in S₁ (manual scarification with sandpaper) (2.93) and minimum in case of S₂ (ultrasonic sound) (1.09). Due to rupture of hard seed coat in sandalwood leading to reduction in dormancy by increasing germination per cent this might leads to maximum mean weekly germination in manual scarification. The results obtained in the present investigation are in accordance with the findings of Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss, Yildiztugay *et al.* (2012) in *sphaerophysa kotschyana* Boiss. and Patil and Krishna (2016) in canes.

4.2.5.2 Effect of Treatments (T)

An examination of data (Table 4.4) showed that different treatments exerted their significant influence on mean weekly germination. The mean weekly germination was found highest in case of T₂ (GA₃ @ 300 ppm) (3.03) followed by T₁ (GA₃ @ 100 ppm) (2.77), T₃ (KNO₃ at 2%) (2.00) and T₅ (cow dung for 48 hours) (1.77) which was at par with T₇ (control) (1.70), while the lowest mean weekly germination was observed in T₆ (ethrel 100 ppm) (1.37) followed by T₄ (cow dung for 24 hours) (1.45). The

Table 4.4: Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on mean weekly germination, root length (cm) and shoot length (cm)

Treatment	Mean weekly Germination	Root length (cm)	Shoot length (cm)
Scarification (S)			
S₁	2.93	3.96	4.82
S₂	1.09	3.80	4.22
S. Em±	0.01	0.03	0.04
CD at 5 %	0.03	0.09	0.12
Treatments (T)			
T₁	2.77	4.08	4.45
T₂	3.03	4.18	4.81
T₃	2.00	4.25	5.27
T₄	1.45	3.84	4.35
T₅	1.77	3.68	4.36
T₆	1.37	3.61	4.27
T₇	1.70	3.55	4.13
S. Em±	0.02	0.06	0.07
CD at 5 %	0.07	0.18	0.22
Scarification (S) x Treatments (T)			
S₁T₁	3.31	4.57	5.40
S₁T₂	4.34	4.20	5.29
S₁T₃	2.99	4.33	6.00
S₁T₄	2.21	3.86	4.50
S₁T₅	3.09	4.03	4.47
S₁T₆	2.02	3.73	4.43
S₁T₇	2.59	3.03	3.67
S₂T₁	2.23	3.60	3.50
S₂T₂	1.73	4.17	4.33
S₂T₃	1.01	4.17	4.56
S₂T₄	0.70	3.83	4.21
S₂T₅	0.47	3.33	4.25
S₂T₆	0.73	3.50	4.11
S₂T₇	0.82	4.07	4.60
Mean	2.01	3.88	4.52
S. Em±	0.03	0.09	0.10
CD at 5 %	0.10	0.26	0.31
CV%	2.98	4.05	4.20

inhibitory compounds in seed coat which affects the germination process are neutralized by GA₃ and promotes germination which leads to increase in mean weekly germination. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Caliskan *et al.* (2012) in fig seeds, Tambat *et al.* (2006) in *Myristica swamps*, Patil and Krishna (2016) in canes and Shankar and Devakumar (2018) and Pamungkas and Nichols (2019) both in sandalwood.

4.2.5.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for mean weekly germination was found significant. The maximum mean weekly germination was found in S₁T₂ (scarification with GA₃ @ 300 ppm) (4.34) followed by S₁T₁ (scarification with GA₃ @ 100 ppm) (3.31), S₁T₅ (scarification with cow dung for 48 hours) (3.09) which was at par with S₁T₃ (scarification with KNO₃ at 2%) (2.99) and S₁T₇ (scarification with control) (2.59) while the minimum mean weekly germination was recorded in S₂T₅ (ultrasonic sound with cow dung for 48 hours) (0.47). The interaction S₁T₂ had shown maximum mean weekly germination due to maximum germination per cent was found in case of manual scarification with sandpaper along with GA₃ treated seeds. The results obtained in the present investigation are in accordance with the findings of Tambat *et al.* (2006) in *Myristica swamps*.

4.2.6 Root length (cm)

The data on root length (cm) of sandalwood was influenced by scarification and treatments are presented in Table 4.4 and graphically depicted in Figure 4.6.

4.2.6.1 Effect of Scarification (S)

Significant variation in respect to root length per seedling was recorded by the scarification. Manual scarification (S₁) produced (3.96 cm) as mean root length whereas ultrasonic sound (S₂) produced (3.80 cm). Due to proper rupture of seed coat in the manual scarification, the seeds are capable of absorbing higher food reserves when compared to those subjected to ultrasonic sound scarification. Sufficient supplement of nutrients is perhaps the reason for highest germination percentage and longest root length in S₁ seeds. The results obtained in the present investigation are in accordance with the findings of Patil and Krishna (2016) in canes and Lopez-Ribera and Vicient (2017) in *Arabidopsis* seeds.

4.2.6.2 Effect of Treatments (T)

The root length (cm) was significantly affected by treatments. The root length was found highest in case of T₃ (KNO₃ at 2%) (4.25 cm) which was at par with T₂ (GA₃@ 300 ppm) (4.18 cm) and T₁ (GA₃@ 100 ppm) (4.08 cm) followed by T₄ (cow dung for 24 hours) (3.84 cm) and T₅ (cow dung for 48 hours) (3.68 cm) which was at par with T₆ (ethrel 100 ppm) (3.61 cm) while the lowest root length was found in case of T₇ (control) (3.55 cm). This might be due to the fact that the KNO₃ and GA₃ treatments might have supplied more food materials to the growing seeds compared to the other treatments which resulted in longer root length. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Sandeep *et al.* (2016) in *Delonix Regia*, Patil and Krishna (2016) in canes and Pamei *et al.* (2017) in *Tectona grandis* L.f.

4.2.6.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for root length was found significant. However, relatively the maximum root length was found in S₁T₁ (manual scarification with GA₃ @ 100 ppm) (4.57 cm) followed by S₁T₃ (manual scarification with KNO₃ at 2%) (4.33 cm) which was at par with S₁T₂ (scarification with GA₃ @ 300 ppm) (4.20 cm) while the minimum root length was noted in treatment combination S₁T₇ (3.03 cm). S₁T₁ interaction may have resulted in change of metabolic, chemical and enzymatic reactions of seeds which had lead to the supply of more food reserves, thus helped in improving the length of root.

4.2.7 Shoot length (cm)

The data on shoot length (cm) of sandalwood was influenced by scarification and treatments during the experimentation are presented in Table 4.4 and graphically depicted in Figure 4.7.

4.2.7.1 Effect of Scarification (S)

The shoot length (cm) was significantly affected by scarification. Significantly the maximum shoot length (4.82 cm) was recorded in the manually scarified seeds (S₁) followed by S₂ (ultrasonic sound) (4.22 cm). Due to proper rupture of seed coat in the manual scarification, the seeds are capable of absorbing higher food reserves when compared to those subjected to ultrasonic sound scarification. Sufficient supplement of nutrients is perhaps the reason for highest germination percentage and longest shoot

length in S_1 seeds. The results obtained in the present investigation are in accordance with the findings of Patil and Krishna (2016) in canes.

4.2.7.2 Effect of Treatments (T)

The difference in the production of shoot length caused by the different treatments was found to be statistically notable. The shoot length was found highest in case of T_3 (KNO_3 at 2%) (5.27 cm) followed by T_2 (GA_3 @ 300 ppm) (4.81 cm) and T_1 (GA_3 @ 100 ppm) (4.45 cm) which was at par with T_5 (cow dung for 48 hours) (4.36 cm), T_4 (cow dung for 24 hours) (4.35 cm) and T_6 (ethrel 100 ppm) (4.27 cm) while, the lowest shoot length was found in T_7 (control) (4.13 cm). This might be due to the fact that the KNO_3 and GA_3 treatments might have supplied more food materials to the growing seeds compared to the other treatments which resulted in longer shoot length. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Sujatha and Manjappa (2015) in *Melia azedarach* L., Patil and Krishna (2016) in canes and Pamei *et al.* (2017) in *Tectona grandis* L. f.

4.2.7.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for shoot length was found significant. On comparison the maximum shoot length was found in S_1T_3 (manual scarification with KNO_3 at 2%) (6.00 cm) followed by S_1T_1 (manual scarification with GA_3 @ 100 ppm) (5.40 cm) which was at par with S_1T_2 (manual scarification with GA_3 @ 300 ppm) (5.29 cm) while the minimum shoot length was observed in S_2T_1 (ultrasonic sound with GA_3 @ 100 ppm) (3.50 cm) which was at par with S_1T_7 (manual scarification with control) (3.67 cm). Due to proper rupture of seed coat in the manual scarification combined with changes in metabolic reaction by KNO_3 treatment, the seeds are capable of absorbing high food reserves so, this interaction (S_1T_3) resulted in highest shoot length.

4.2.8 Seedling length (cm)

The seedling length (cm) of sandalwood was influenced by scarification and treatments are presented in Table 4.5 and graphically depicted in Figure 4.8.

4.2.8.1 Effect of Scarification (S)

The effect of manual scarification (S_1) and ultrasonic sound (S_2) had produced significant influence on seedling length. However, numerically highest seedling length was observed in S_1 (scarification) (8.79 cm) while S_2 (ultrasonic sound) recorded (8.02

cm). Both root length and shoot length had shown significantly maximum results in case of manual scarification, this resulted in maximum seedling length in case of S₁.

4.2.8.2 Effect of Treatments (T)

The seedling length (cm) was significantly affected by treatments. The seedling length was found highest in case of T₃ (KNO₃ at 2%) (9.55 cm), followed by T₂ (GA₃@ 300 ppm) (8.98 cm), T₁ (GA₃@ 100 ppm) (8.53 cm) and T₄ (cow dung for 24 hours) (8.18 cm) which was at par with T₅ (cow dung for 48 hours) (8.03 cm) while the lowest seedling length was found in T₇ (control) (7.68 cm) which was at par with T₆ (ethrel 100 ppm) (7.88 cm). This might be due to the fact that the KNO₃ and GA₃ treatments might have supplied more food materials to the growing seeds compared to the other treatments which resulted in longer seedling length. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Patil and Krishna (2016) in canes, Pamei *et al.* (2017) in teak and Shankar and Devakumar (2018) in sandalwood.

4.2.8.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for seedling length was found significant. Highest seedling length was recorded in S₁T₃ (manual scarification with KNO₃ at 2%) (10.40 cm) followed by S₁T₁ (manual scarification with GA₃ @ 100 ppm) (9.97 cm) and S₁T₂ (manual scarification with GA₃ @ 300 ppm) (9.47 cm) while the lowest seedling length was observed in S₁T₇ (manual scarification with control) (6.70 cm). Due to proper rupture of seed coat in the manual scarification combined with changes in metabolic reaction by KNO₃ treatment (S₁T₃), the seeds are capable of absorbing highest food reserves, which perhaps cause the highest root length, shoot length and in turn, longer seedling length.

Table 4.5: Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on seedling length (cm), collar diameter (mm) and seedling fresh weight (mg)

Treatment	Seedling length (cm)	Collar diameter (mm)	Seedling fresh weight (mg)
Scarification (S)			
S₁	8.79	2.10	239.00
S₂	8.02	2.11	197.52
S. Em±	0.03	0.02	1.36
CD at 5 %	0.11	NS	3.96
Treatments (T)			
T₁	8.53	2.06	228.33
T₂	8.98	2.23	243.16
T₃	9.55	1.86	236.66
T₄	8.18	2.21	199.66
T₅	8.03	2.13	203.33
T₆	7.88	2.21	220.00
T₇	7.68	2.05	196.66
S. Em±	0.07	0.04	2.56
CD at 5 %	0.21	0.12	7.42
Scarification (S) x Treatments (T)			
S₁T₁	9.97	1.83	293.33
S₁T₂	9.47	2.20	259.67
S₁T₃	10.40	1.87	273.33
S₁T₄	8.33	2.17	220.00
S₁T₅	8.50	2.10	226.67
S₁T₆	8.17	2.40	233.33
S₁T₇	6.70	2.20	166.67
S₂T₁	7.10	2.30	163.33
S₂T₂	8.50	2.27	226.67
S₂T₃	8.70	1.87	200.00
S₂T₄	8.03	2.27	179.33
S₂T₅	7.57	2.17	180.00
S₂T₆	7.60	2.03	206.67
S₂T₇	8.67	1.90	226.67
Mean	8.40	2.11	218.26
S. Em±	0.10	0.06	3.62
CD at 5 %	0.30	0.18	10.49
CV%	2.16	5.16	2.87

4.2.9 Collar diameter (mm)

The data exerted on collar diameter (mm) of sandalwood was influenced scarification and treatments are presented in Table 4.5 and graphically depicted in Figure 4.9.

4.2.9.1 Effect of Scarification (S)

The results presented in Table 4.5 revealed that the effect of scarification was found non-significant for collar diameter. Manually scarified seeds (S₁) and ultrasonic sound (S₂) showed results as (2.10 mm) and (2.11 mm) respectively. Like manual scarification with sandpaper ultrasonic sound treatment also resulted in damage to seed coat which helps to improve germination and its parameters, this resulted in non-significant findings for collar diameter. The results obtained in the present investigation are in accordance with the findings of Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss and Patil and Krishna (2016) in canes.

4.2.9.2 Effect of Treatments (T)

A perusal of data (Table 4.5) revealed that different treatments exerted their significant influence on collar diameter. The collar diameter was found highest in case of T₂ (GA₃@ 300 ppm) (2.23 mm) which was at par with T₄ (cow dung for 24 hours) (2.21 mm) and T₆ (ethrel 100 ppm) (2.21 mm) while the lowest collar diameter was found in T₃ (KNO₃ at 2%) (1.86 mm). The enhanced enzymatic reactions along with suppression of inhibitors might have acted in the absorption of food reserves properly, thus resulted in maximum collar diameter due to pre-soaking treatments. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Patil and Krishna (2016) in canes, Palepad *et al.* (2017) in *Annona squamosa* L., Bajaniya *et al.* (2018) in *Manilkara hexandra* Roxb, Opoku *et al.* (2018) in *Bauhinia rufescens* Lam. and Pamei *et al.* (2017) in teak.

4.2.9.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for collar diameter was found significant. However, relatively the maximum collar diameter was found in S₁T₆ (scarification with ethrel 100 ppm) (2.40 mm) followed by S₂T₁ (ultrasonic sound with GA₃@ 100 ppm) (2.30 mm) which was at par with S₂T₂ (ultrasonic sound with GA₃@ 300 ppm) (2.27 mm) and S₂T₄ (ultrasonic sound with cow dung for 24 hours) (2.27mm)

while the minimum collar diameter was observed in S₁T₁ (scarification with GA₃@ 100 ppm) (1.83 mm).

4.2.10 Seedling fresh weight (mg)

The data exerted on seedling fresh weight (mg) of sandalwood was influenced by scarification and treatments are presented in Table 4.5 and graphically depicted in Figure 4.10.

4.2.10.1 Effect of Scarification (S)

Scarification recorded significant differences on seedling fresh weight (mg). On comparison the highest seedling fresh weight was observed in S₁ (scarification) (239.00 mg) followed by S₂ (ultrasonic sound) (197.52 mg). Seedling fresh weight was found maximum in case of manual scarification by sandpaper due to production of maximum collar diameter, retention of more reserved food and uptake of water through seed coat due to manual scarification. The results obtained in the present investigation are in accordance with the findings of Pamei *et al.* (2017) in teak.

4.2.10.2 Effect of Treatments (T)

The seedling fresh weight (mg) was significantly affected by treatments. The seedling fresh weight was found highest in case of T₂ (GA₃@ 300 ppm) (243.16 mg) which was at par with T₃ (KNO₃ at 2%) (236.66 mg) and followed by T₁ (GA₃@ 100 ppm) (228.33 mg), T₆ (ethrel 100 ppm) (220.00 mg) and T₅ (cow dung for 48 hours) (203.33 mg), while the lowest seedling fresh weight was found in T₇ (control) (196.66 mg) which was at par with T₄ (cow dung for 24 hours) (199.66 mg). Enhanced enzymatic reactions along with suppression of inhibitors by GA₃ and KNO₃ leads to production of maximum collar diameter by promoting maximum water content, thus resulting in maximum seedling fresh weight. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*., Sandeep *et al.* (2016) in *Delonix Regia*, Pamei *et al.* (2017) in *Tectona grandis* L. f., Palepad *et al.* (2017) in *Annona squamosa* L., Bajaniya *et al.* (2018) in *Manilkara hexandra* Roxb and Opoku *et al.* (2018) in *Bauhinia rufescens* Lam.

4.2.10.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for seedling fresh weight was found significant. The maximum seedling fresh weight was found in S₁T₁ (scarification with GA₃@ 100 ppm) (293.33 mg) followed by S₁T₃ (manual scarification with KNO₃

at 2%) (273.33 mg), S₁T₂ (scarification with GA₃@ 300 ppm) (259.67 mg) and S₁T₆ (scarification with ethrel 100 ppm) (233.33 mg), while the minimum seedling fresh weight was observed in S₂T₁ (ultrasonic sound with GA₃@ 100 ppm) (163.33 mg) which was at par with S₁T₇ (manual scarification with control) (166.67 mg). Combined effect of manual scarification with GA₃ enhanced enzymatic reactions by restoring high water content in seeds, this leads to maximum seedling fresh weight. The results are in accordance to the findings of Zaman *et al.* (2009) in *Helianthemum lippii* (L.) Dum. Cours.

4.2.11 Seedling dry weight (mg)

The data on seedling dry weight (mg) of sandalwood was significantly influenced by scarification and treatments and are presented in Table 4.6 and graphically depicted in Figure 4.11.

4.2.11.1 Effect of Scarification (S)

The effect of scarification had shown significant influence on seedling dry weight. Significantly the maximum seedling dry weight was observed in S₁ (scarification) (47.19 mg) when compared to S₂ (ultrasonic sound) (37.38 mg). High food reserves in seed resulted in maximum root length and shoot length in manual scarification with sandpaper, which perhaps cause high seedling dry weight. The results obtained in the present investigation are in accordance with the findings of Anand *et al.* (2012) in *Melia dubia*, Pamei *et al.* (2017) in teak.

4.2.11.2 Effect of Treatments (T)

Significant differences on dry weight of seedling were noticed due to the effect of seedling dry weight. The seedling dry weight was found highest in case of T₂ (GA₃@ 300 ppm) (50.00 mg) followed by T₆ (ethrel 100 ppm) (46.33 mg), T₁ (GA₃@ 100 ppm) (43.66 mg), T₃ (KNO₃ at 2%) (41.83 mg) and T₇ (control) (39.50 mg) which was at par with T₅ (cow dung for 48 hours) (38.16 mg) while the lowest seedling dry weight was found in T₄ (cow dung for 24 hours) (36.50 mg). Due to maximum seedling fresh weight in GA₃ might resulted in greater dry weight. The results obtained in the present investigation are in accordance with the findings of Sandeep *et al.* (2016) in *Delonix Regia*, Opoku *et al.* (2018) in *Bauhinia rufescens* Lam., Palepad *et al.* (2017) in *Annona squamosa* L., Bajaniya *et al.* (2018) in *Manilkara hexandra* Roxb and Anand *et al.* (2012) in *Melia dubia*.

Table 4.6: Effect of pre-sowing seed treatment on seed germination and its parameters after 88 days of sowing on seedling dry weight (mg), seedling vigour index (length) and seedling vigour index (mass)

Treatment	Seedling dry weight (mg)	Seedling Vigour Index (length)	Seedling Vigour Index (mass)
Scarification (S)			
S ₁	47.19	315.72	1687.57
S ₂	37.38	98.74	476.23
S. Em±	0.16	1.59	6.74
CD at 5 %	0.48	4.63	19.54
Treatments (T)			
T ₁	43.66	299.45	1557.33
T ₂	50.00	319.15	1743.83
T ₃	41.83	232.45	1061.33
T ₄	36.50	141.91	685.16
T ₅	38.16	179.31	975.50
T ₆	46.33	129.58	786.66
T ₇	39.50	148.76	763.50
S. Em±	0.31	2.99	12.62
CD at 5 %	0.91	8.67	36.56
Scarification (S) x Treatments (T)			
S ₁ T ₁	54.33	411.93	2245.67
S ₁ T ₂	50.67	479.63	2566.67
S ₁ T ₃	49.33	360.50	1710.33
S ₁ T ₄	42.67	222.27	1137.67
S ₁ T ₅	47.67	325.83	1827.00
S ₁ T ₆	51.33	193.30	1215.33
S ₁ T ₇	34.33	216.60	1110.33
S ₂ T ₁	33.00	186.97	869.00
S ₂ T ₂	49.33	158.67	921.00
S ₂ T ₃	34.33	104.40	412.33
S ₂ T ₄	30.33	61.57	232.67
S ₂ T ₅	28.67	32.80	124.00
S ₂ T ₆	41.33	65.87	358.00
S ₂ T ₇	44.67	80.93	416.67
Mean	42.28	207.23	1081.90
S. Em±	0.44	4.23	17.84
CD at 5 %	1.29	12.26	51.70
CV%	1.82	3.53	2.85

4.2.11.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for seedling dry weight was found significant difference. Relatively, the maximum seedling dry weight was found in S₁T₁ (scarification with GA₃@ 100 ppm) (54.33 mg) followed by S₁T₆ (scarification with ethrel 100 ppm) (51.33 mg) which was at par with S₁T₂ (scarification with GA₃@ 300 ppm) (50.67 mg) and followed by S₁T₃ (scarification with KNO₃ at 2%) (49.33 mg) while the minimum seedling dry weight was observed in S₂T₅ (ultrasonic sound with cow dung for 48 hours) (28.67 mg). Combined effect of manual scarification with GA₃ (S₁T₁) enhanced root length and shoot length, which ultimately caused maximum seedling dry weight. The results obtained in the present investigation are in accordance with the findings of Pamei *et al.* (2017) in teak.

4.2.12 Seedling vigour index (length)

The results on seedling vigour index (length) as influenced by scarification and treatments are presented in Table 4.6 and graphically depicted in Figure 4.12.

4.2.12.1 Effect of Scarification (S)

Significant differences on seedling vigour index (length) were noticed due to the effect of scarification. The highest seedling vigour index (length) was observed in S₁ (scarification) (315.72) when compared to S₂ (ultrasonic sound) (98.74). As manual scarification resulted in maximum germination per cent and seedling length this leads to production of maximum SVI (length). The results obtained in the present investigation are in accordance with the findings of Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss and Patil and Krishna (2016) in canes.

4.2.12.2 Effect of Treatments (T)

The seedling vigour index (length) was significantly affected by treatments. The seedling vigour index (length) was found highest in case of T₂ (GA₃@ 300 ppm) (319.15) followed by T₁ (GA₃@ 100 ppm) (299.45), T₃ (KNO₃ at 2%) (232.45), T₅ (cow dung for 48 hours) (179.31) and T₇ (control) (148.76) which was at par with T₄ (cow dung for 24 hours) (141.91) while the lowest seedling vigour index (length) was found in T₆ (ethrel 100 ppm) (129.58). GA₃@ 300 ppm resulted in maximum germination per cent leading to greater SVI (length). The results obtained in the present investigation are in accordance with the findings of Patil and Krishna (2016) in canes, Shankar and Devakumar (2018) in sandalwood.

4.2.12.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for seedling vigour index (length) was found significant. On comparison, the maximum seedling vigour index (length) was found in S₁T₂ (scarification with GA₃@ 300 ppm) (479.63) followed by S₁T₁ (scarification with GA₃@ 100 ppm) (411.93), S₁T₃ (scarification with KNO₃ at 2%) (360.50), S₁T₅ (scarification with cow dung for 48 hours) (325.83) and S₁T₄ (scarification with cow dung for 24 hours) (222.27) while the minimum seedling vigour index (length) was recorded in S₂T₅ (ultrasonic sound with cow dung for 48 hours) (32.80) followed by S₂T₄ (ultrasonic sound with cow dung for 24 hours) (61.57) which was at par with S₂T₆ (ultrasonic sound with ethrel 100 ppm) (65.87). Due to greater germination per cent in manual scarification by sandpaper and also in GA₃@ 300 ppm, this interaction (S₁T₂) resulted in maximum seedling vigour index (length). The results obtained in the present investigation are in accordance with the findings of Zaman *et al.* (2009) in *Helianthemum lippii* (L.) Dum. Cours and Tambat *et al.* (2006) in *Myristica swamps*.

4.2.13 Seedling vigour index (mass)

The results on seedling vigour index (mass) was influenced by scarification and treatments and the data are presented in Table 4.6 and graphically depicted in Figure 4.13.

4.2.13.1 Effect of Scarification (S)

Significant differences on seedling vigour index (mass) were noticed due to the effect of scarification. The highest seedling vigour index (mass) was observed in S₁ (scarification) (1687.57) and minimum in case of with S₂ (ultrasonic sound) (476.23). SVI (mass) was found highest in case of manual scarification because this resulted in maximum germination per cent and seedling dry weight. The results obtained in the present investigation are in accordance with the findings of Fattahi *et al.* (2011) in *Dracocephalum kotschy* Boiss and Patil and Krishna (2016) in canes.

4.2.13.2 Effect of Treatments (T)

The effect of treatments had produced significant influence on seedling vigour index (mass). The seedling vigour index (mass) was found highest in case of T₂ (GA₃@ 300 ppm) (1743.83) followed by T₁ (GA₃@ 100 ppm) (1557.33), T₃ (KNO₃ at 2%) (1061.33), T₅ (cow dung for 48 hours) (975.50), T₆ (ethrel 100 ppm) (786.66) which was at par with T₇ (control)

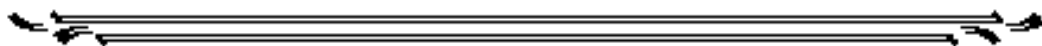
(763.50) while the lowest seedling vigour index (mass) was found in T₄ (cow dung for 24 hours) (685.16). GA₃@ 300 ppm had produced maximum SVI (mass) this may due to production of maximum seedlings during germination. The results obtained in the present investigation are in accordance with the findings of Patil and Krishna (2016) in canes, Thanuja *et al.* (2018) in *Pterocarpus marsupium* Roxb. and Shankar and Devakumar (2018) in sandalwood.

4.2.13.3 Interaction effect of Scarification (S) x Treatments (T)

Interaction effect of scarification and treatments for seedling vigour index (mass) was found significant. However, comparatively the maximum seedling vigour index (mass) was found in S₁T₂ (scarification with GA₃@ 300 ppm) (2566.67) followed by S₁T₁ (scarification with GA₃@ 100 ppm) (2245.67), S₁T₅ (scarification with cow dung for 48 hours) (1827.00) and S₁T₃ (scarification with KNO₃ at 2%) (1710.33) while the minimum seedling vigour index (mass) was recorded in S₂T₅ (ultrasonic sound with cow dung for 48 hours) (124.00) followed by S₂T₄ (ultrasonic sound with cow dung for 24 hours) (232.67) and S₂T₆ (ultrasonic sound with ethrel 100 ppm) (358.00). The results obtained in the present investigation are in accordance with the findings of Zaman *et al.* (2009) in *Helianthemum lippii* (L.) Dum. Cours and Tambat *et al.* (2006) in *Myristica swamps*.

CHAPTER V

SUMMARY AND CONCLUSION



The present investigation entitled “**Effect of pre sowing treatments on seed germination and its parameters in sandalwood (*Santalum album* L.)**” was carried out during *rabi* 2019-20 under greenhouse in Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh. The experiment included three factors *viz.*, aging [A_1 (8 months old seeds) and A_2 (new seeds)], scarification (S) *i.e.* sand paper (S_1) and ultrasonic sound (S_2) and treatments (T) *i.e.* GA₃ 100 ppm (T_1), GA₃ 300 ppm (T_2), KNO₃ at 2% (T_3), Cow dung for 24 hours (T_4), Cow dung for 48 hours (T_5), Ethrel 100 ppm (T_6) and Control (T_7). The experiment was laid out under greenhouse as per completely randomized design (Factorial) with three replications. But aging factor was not considered as the number of germinated seeds is observed to be very less. The characters *viz.*, germination per cent (%), time taken for initiation of germination (TTIG), time taken for completion of germination (TTCG), speed of germination, mean weekly germination, root length of seedling (cm), shoot length of seedling (cm), seedling length (cm), collar diameter (mm), seedling fresh weight (mg), seedling dry weight (mg), seedling vigour index (length), seedling vigour index (mass) were analyzed by Completely Randomized Design (Factorial). The results presented and discussed in the previous chapter are summarized as below.

5.1 Analysis of variance

The analysis of variance for seed germination and its parameters revealed that scarification and different treatments manifested significant differences for seed germination and all its parameters that are studied except the factor scarification, which had shown non-significant difference for collar diameter. Mean squares due to interaction effects of scarification and treatments were found to be significant for all the characters taken under study.

The results obtained in earlier chapters are briefed here,

5.2 Effect of scarification (S)

- Significantly the maximum germination per cent (35.38%) was recorded in manual scarification with sandpaper (S₁), whereas significantly the minimum germination per cent (12.42%) was recorded in ultrasonic sound (S₂).
- TTIG was found fastest in manual scarification with sandpaper (S₁) (38.61 days) when compared to ultrasonic sound scarification (S₂) (45.66 days).
- TTCG was found highest in manual scarification with sandpaper (S₁) (84.66 days) when compared to ultrasonic sound scarification (S₂) (77.80 days).
- Manual scarification with sandpaper (S₁) produced significantly the highest speed of germination (0.60), mean weekly germination (2.93) with the maximum root length (3.96 cm), shoot length (4.82 cm), seedling length (8.79 cm), seedling fresh weight (239.00 mg), seedling dry weight (47.19 mg), seedling vigour index (length) (315.72) and seedling vigour index (mass) (1687.57).
- Significantly the lowest speed of germination (0.21), mean weekly germination (1.09), root length (3.80 cm), shoot length (4.22 cm), seedling length (8.02 cm), seedling fresh weight (197.52 mg), seedling dry weight (37.38 mg), seedling vigour index (length) (98.74) and seedling vigour index (mass) (476.23) were recorded in ultrasonic sound scarification (S₂).

5.3 Effect of different pre sowing treatments (T)

- Among the different treatments, GA₃ @300 ppm (T₂) recorded the significantly highest germination per cent (34.66%), while significantly lowest germination per cent (16.16%) was noted in ethrel 100 ppm (T₆). The next best treatment with respect to germination per cent was GA₃ @ 100 ppm (T₁).
- TTIG was found fastest (34.66 days) in case of GA₃ @300 ppm (T₂) and late initiation (48.33 days) was observed in cow dung for 48 hours (T₅). TTCG was found highest (85.33 days) in case of GA₃ @ 100 ppm (T₁).
- Significantly the highest speed of germination (0.64), mean weekly germination (3.03), collar diameter (2.23 mm), seedling fresh weight (243.16 mg), seedling dry weight (50.00 mg), seedling vigour index (length) (319.15) and seedling vigour index (mass) (1743.83) were observed in GA₃ @300 ppm (T₂). The next best pre-sowing treatment with respect to speed of germination, mean weekly germination, seedling vigour index (length) and seedling vigour index (mass)

was GA₃ @ 100 ppm (T₁). For collar diameter, seedling fresh weight and seedling dry weight the next best treatments were cow dung for 24 hours (T₄), KNO₃ at 2% (T₃) and ethrel 100 ppm (T₆) respectively.

- Root length (4.25 cm), shoot length (5.27 cm) and seedling length (9.55 cm) were found significantly highest in KNO₃ at 2% (T₃). The next best pre-sowing treatment with respect to root length, shoot length and seedling length was GA₃ @300 ppm (T₂).
- Significantly the lowest speed of germination (0.26), mean weekly germination (1.37) and seedling vigour index (length) (129.58) were observed in ethrel 100 ppm (T₆). For root length (3.55 cm), shoot length (4.13 cm), seedling length (7.68 cm) and seedling fresh weight (196.66 mg), control (T₇) was observed as lowest.
- Collar diameter (1.86 mm) was found to be lowest in KNO₃ at 2% (T₃) and seedling dry weight (36.50 mg) was found to be lowest in cow dung for 24 hours (T₄).

5.4 Interaction effect scarification and treatments

- Comparatively the highest germination per cent (50.67%) was observed in treatment combination S₁T₂ (manual scarification with sandpaper along with GA₃ @ 300 ppm). The next best treatment combination for this trait was S₁T₁ (manual scarification with sandpaper along with GA₃ @ 100 ppm) (41.33%) and lowest germination per cent (4.33%) was observed in S₂T₅ (ultrasonic sound with cow dung for 48 hrs).
- The time taken for initiation of germination was found faster (28.67 days) in S₁T₂ (manual scarification with sandpaper and treated with GA₃ @ 300 ppm) and the next best treatment combination was S₁T₃ (manual scarification with sandpaper and treated with KNO₃ at 2%) (29.67 days).
- The time taken for completion of germination was found highest (88 days) in case of S₁T₁ (manual scarification with sandpaper and treated with GA₃ @ 100 ppm).
- Relatively the maximum speed of germination (0.96), mean weekly germination (4.34), seedling vigour index (length) (479.63) and seedling vigour index (mass) (2566.67) was observed in manual scarification with sandpaper (S₁) treated with GA₃ @ 300 ppm (S₁T₂). Manual scarification with sandpaper (S₁) treated with

GA₃ @ 100 ppm (S₁T₁) was the next best treatment combination for all these traits.

- Relatively the maximum root length (4.57 cm), seedling fresh weight (293.33 mg) and seedling dry weight (54.33 mg) were noted in S₁T₁ (manual scarification with GA₃ @ 100 ppm). The maximum shoot length (6.00 cm) and seedling length (10.40 cm) was observed in S₁T₃ (manual scarification with KNO₃ at 2%).
- Comparatively the maximum collar diameter was reported in S₁T₆ (scarification with ethrel 100 ppm) (2.40 mm).
- The minimum germination percentage (4.33%), TTCCG (64.33 days), speed of germination (0.07), mean weekly germination (0.47), seedling dry weight (28.67 mg), seedling vigour index (length) (32.80) and seedling vigour index (mass) (124.00) was noted in ultrasonic sound scarification treated with cow dung for 48 hours (S₂T₅).

The overall, following conclusion could be drawn from the present investigation:

1. The results indicated that the 8 months old seeds had poor germination because of loss of viability. Therefore, the old seeds should not be preferred over new seeds in sandalwood.
2. Scarification and treatment played an important role on seed germination and its parameters in sandalwood, manual scarification with sandpaper (S₁) irrespective of different seed treatments noted significantly the highest values for germination per cent, TTCCG, speed of germination, mean weekly germination, root length, shoot length, seedling length, seedling fresh weight, seedling dry weight, seedling vigour index (length) and seedling vigour index (mass) than ultrasonic sound scarification (S₂). Time taken for initiation of germination was also found faster in manual scarification with sandpaper (S₁). Collar diameter for scarification factor had shown non-significant results.
3. Similarly, irrespective of scarification, seeds treated with GA₃ @300 ppm (T₂) treatment also produced significantly the faster initiation of germination and showed highest germination per cent, speed of germination, mean weekly germination, collar diameter, seedling fresh weight, seedling dry weight,

seedling vigour index (length) and seedling vigour index (mass). Significantly the highest root length, shoot length and seedling length were noted in KNO₃ at 2% (T₃).

4. Among the different combinations of scarification and treatments, manual scarification with sandpaper treated with GA₃ @ 300 ppm (S₁T₂) was found a best suited, as it having early seed emergence with the highest germination per cent, speed of germination, mean weekly germination, seedling vigour index (length) and seedling vigour index (mass). However, the maximum root length, seedling fresh weight and seedling dry weight were noted in S₁T₁ (manual scarification with GA₃ @ 100 ppm). Thereby, the next best treatment combination was found to be manual scarification with sandpaper treated with GA₃ @ 100 ppm.

Therefore, looking to the seed germination percentage, early emergence, SVI (length), SVI (mass), speed of germination and mean weekly germination it is suggested that the seeds treated with manual scarification with sandpaper should be treated with GA₃ @ 300 ppm for enhancement of germination and its parameters in sandalwood.

BIBLIOGRAPHY



- Abari, A. K.; Nasr, M. H.; Hodjati, M.; Bayat, D. and Radmehr, M. (2012). Maximizing seed germination in two *Acacia* species. *Journal of Forestry Research*, **23**(2): 241-244.
- Abdul-Baki, A. A. and Anderson, J. D. (1973). Vigour determination in soybean by multiple criteria. *Crop Science*, **13**(3): 630-633.
- Akhter, F. N.; Kabir, G.; Mannan, M. A. and Shaheen, N. N. (1992). Aging effect of wheat and barley seeds upon germination mitotic index and chromosomal damage. *Journal of Islamic Academic of Science*, **5**(1): 44-48.
- Ali, H. H.; Tanveer, A. and Nadeem, M. A. (2012). Evaluation of some seed dormancy breaking methods on germination of *Rhynchosia capitata* (Roth DC). *Pakistan Journal of Weed Science Research*, **18**(4): 423-432.
- Al-Menaie, H. S.; Al-Ragam, O.; Al-Shatti, A.; Mathew, M. and Suresh, N. (2010). The effects of different treatments on seed germination of the *Cassia fistula* L. and *Cassia nodosa* Buch.-Ham. ex Roxb. in Kuwait. *African Journal of Agricultural Research*, **5**(3): 230-235.
- Anand, B.; Devagiri, G. M.; Maruti, G.; Vasudev, H. S. and Khaple, A. K. (2012). Effects of pre-sowing seed treatments on germination and seedling growth performance of *Melia dubia* Cav: An important multipurpose tree. *International Journal of Life Sciences*, **1**(3): 59-63.
- Ananthapadmanabha, H. S., Nagaveni, H. C. and Rai, S. N. (1991). Endogenous gibberellin in relation to flower induction in sandal. *My forest*, **24**: 32-24.
- Andriamparany, J. N. and Buerkert, A. (2019). Effect of ultrasonic dormancy breaking on seed germination and seedling growth of three wild yam species (*Dioscorea* spp.) from SW-Madagascar. *Genetic Resources and Crop Evolution*, **66**(6): 1167-1174.

- Azad, M. S.; Zedan-Al-Musa, M. and Matin, M. A. (2010). Effects of pre-sowing treatments on seed germination of *Melia azedarach*. *Journal of Forestry Research*, **21**(2): 193-196.
- Azad, S.; Manik, M. R.; Hasan, S. and Matin, A. (2011). Effect of different pre-sowing treatments on seed germination percentage and growth performance of *Acacia auriculiformis*. *Journal of Forestry Research*, **22**(2): 183.
- Bagchi, S. K. and Sharma, V. P. (1989). Biometrical studies on seed characters of *Santalum album* L. *Silvae genetica*, **38**(3-4): 152-153.
- Bajaniya V. G.; Karetha K. M.; Parmar L. S.; Purohit V. L. and Chotaliya B. M. (2018). Influence of pre-soaking treatment on seedling growth of Khirni (*Manilkara hexandra* Roxb) Seedling cv. Local. *International Journal of Pure and Applied Bioscience*, **6**(1): 1668-1672.
- Barman, T. S. and Sarma, C. M. (1985). Effect of ethrel (2-chloroethyl phosphonic acid) on germination and seedling growth of Tea *Camellia sinensis* (L.). O. KUNIZ. *Indian Journal of Physiology*, **28**(4): 413-417.
- Batabyal, S.; Dalal, T. and Tah, J. (2014). Effect of different seed-sources on germination parameters by means of artificial seed germination of *Santalum album* L. *International Journal of Pure and Applied Bioscience*, **2**(2): 149-152.
- Bhat, D. M.; Murali, K. S. and Ravindranath, N. H. (2001). Assessment of propagation techniques for forest species of the Western Ghat region of India. *Forests, Trees and Livelihoods*, **11**(3): 233-250.
- Caliskan, O.; Mavi, K. and Polat, A. (2012). Influences of pre-sowing treatments on the germination and emergence of fig seeds (*Ficus carica* L.). *Acta Scientiarum. Agronomy*, **34**(3): 293-297.
- Choudhury, B. I.; Khan, M. L. and Das, A. K. (2009). Seed dormancy and germination in *Gymnocladus assamicus*: An endemic legume tree from Northeast India. *Seed Science and Technology*, **37**(3): 582-588.

- Christidis, B. G. (1954). Seed vitality and other cotton characters as affected by the age of seed. *Plant physiology*, **29**(2): 124.
- Da Silva, J. A. T. and Dobranszki, J. (2015). Sonication (ultrasound) affects *in vitro* growth of hybrid *Cymbidium*. *Botanica Lithuanica*, **20**(2): 121-130.
- Das, S. C. and Tah, J. (2013). Effect of GA₃ on seed germination of Sandal (*Santalum album* L.). *International Journal of Current Science*, **8**: 79-84.
- Fattahi, M.; Nazeri, V.; Sefidkon, F.; Zamani, Z. and Palazon, J. (2011). The effect of pre-sowing treatments and light on seed germination of *Dracocephalum kotschy* Boiss: An endangered medicinal plant in Iran. *Horticulture, Environment, and Biotechnology*, **52**(6): 559-566.
- Gamage, Y. M. M.; Subasinghe, S. M. C. U. P. and Hettiarachchi, D. S. (2010). Change of seed germination rate with storage time of *Santalum album* L. (Indian sandalwood) seeds. In *Proceedings of the 15th International Forestry and Environment Symposium* (Vol. 26, p. 27).
- Gavit, R. R. (2018). Effect of pre-sowing seed treatment on germination and growth of khirni (*Manilkara hexandra* L.). (Doctoral dissertation, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist: Ratnagiri).
- Giri, D. and Tamta, S. (2012). Effect of pre-sowing treatments on seed germination in *Hedychium spicatum*: an important vulnerable medicinal plant of Indian Himalayan region. *Scientific Research and Essays*, **7**(19): 1835-1839.
- Gomez, K. A. and Gomez, A. A. (1984). Statistical procedures for agricultural research. John Wiley & Sons, New York. pp. 618.
- Ivanova, V. and Panchev, V. (2016). Effect of pre sowing treatment with ultrasound and stratification of *Laurocerasus officinalis* L. seeds on some growth behavior of seedlings. *Agro-knowledge Journal*, **17**(2): 173-181.

- Jayawardena, M. M. D.; Jayasuriya, K. M. G. G. and Walck, J. L. (2015). Confirmation of morphophysiological dormancy in sandalwood (*Santalum album* L., Santalaceae) seeds. *Journal of the National Science Foundation of Sri Lanka*, **3**(43): 211- 215.
- Karmakar, A.; Bhattacharyya, N. G. and Tah, J. (2018). Influence of treatments in winter season over the location: a simple bi-variate correlation study of *Santalum album* L. *International Journal of Research and Analytical Reviews*, **5**(4): 642-653.
- Khan, M. M.; Iqbal, M. J.; Abbas, M. and Usman, M. (2003). Effect of ageing on viability, vigour and chromosomal damage in pea (*Pisum sativum* L.) seeds. *Pakistan Journal of Agricultural Sciences*, **40**(1-2): 50-54.
- Liu, J.; Wang, Q.; Karagic, D.; Liu, X.; Cui, J.; Gui, J. and Gao, W. (2016). Effects of ultrasonication on increased germination and improved seedling growth of aged grass seeds of tall fescue and Russian wildrye. *Scientific reports*, **6**: 1-12.
- Lopez-Ribera, I. and Vicient, C. M. (2017). Use of ultrasonication to increase germination rates of Arabidopsis seeds. *Plant methods*, **13**(1): 1-6.
- Mane, S. B.; Naglot, U. M. and Parse, R. N. (2018). Effect of different pre-sowing treatments on shoot growth of custard apple (*Annona squamosa* L.). *Journal of Pharmacognosy and Phytochemistry*, **7**(5): 1945-1947.
- Miano, A. C.; Forti, V. A.; Abud, H. F.; Gomes-Junior, F. G.; Cicero, S. M. and Augusto, P. E. D. (2015). Effect of ultrasound technology on barley seed germination and vigour. *Seed Science and Technology*, **43**(2): 297-302.
- Mishra, B.; Chakraborty, S. and Viswanath, S. (2018). Sandalwood farming in India: problems and prospects. *Indian Journal of Tropical Biodiversity*, **26**(1): 1-12.
- Mohammadi, H.; Soltani, A.; Sadeghipour, H. R. and Zeinali, E. (2012). Effects of seed aging on subsequent seed reserve utilization and seedling growth in soybean. *International Journal of Plant Production*, **5**(1): 65-70.

- Muir, J. P. and Pitman, W. D. (1987). Improving germination rate of the Florida legume *Galactia elloittii*. *Rangeland Ecology and Management/Journal of Range Management Archives*, **40**(5): 452-454.
- Nikam, T. D. and Barmukh, R. B. (2009). GA₃ enhances *in vitro* seed germination in *Santalum album* L. *Seed Science and Technology*, **37**(2): 276-280.
- Oboho, E. G. and Igharo, B. (2017). Effect of pre-germination treatments on germination and watering regimes on the early growth of *Pycnanthus angolensis* (Welw) Warb. *Journal of Agriculture and Veterinary Science*, **10**(3): 62-68.
- Ogbu, J. U.; Okereke, O. P. and Oyeleye, A. D. (2016). Efficacy of pre-sowing soaking treatment of African mahogany (*Azelia africana* Sm.) seeds for enhanced germination. In *Proceedings of 50th Annual Conference of Agricultural Society of Nigeria (ASN)* (pp. 577-580).
- Okunlola, A. I.; Adebayo, R. A. and Orimogunje, A. D. (2011). Methods of breaking seed dormancy on germination and early seedling growth of African locust bean (*Parkia biglobosa*) (JACQ.) Benth. *Journal of Horticulture and Forestry*, **3**(1): 1-6.
- Opoku, J. A.; Amissah, J. N.; Essilfie, M. E. and Norman, J. C. (2018). Effect of pre-sowing treatments on seed germination and seedling growth of silver butterfly tree (*Bauhinia rufescens*). *Current Agriculture Research Journal*, **6**(3): 344-354.
- Palepad, K. B.; Bharad, S. G. and Bansode, G. S. (2017). Effect of seed treatments on germination, seedling vigour and growth rate of custard apple (*Annona squamosa* L.). *Journal of Pharmacognosy and Phytochemistry*, **6**(5): 20-23.
- Pamei, K., Larkin, A., & Kumar, H. (2017). Effect of different treatments on the germination parameters and seedling quality index of *Tectona grandis* (Teak) under nursery condition. *International journal for computer science*, **5**(5): 2418-2424.

- Pamungkas, D. and Nichols, J. D. (2019). The influence of scarification and media containing vesicular arbuscular mycorrhiza on germination of sandalwood (*Santalum album* L.) seeds. In *IOP Conference Series: Earth and Environmental Science* (Vol. 394, No. 1, p. 012052). IOP Publishing.
- Parrish, D. J. and Leopold, A. C. (1978). On the mechanism of aging in soybean seeds. *Plant Physiology*, **61**(3): 365-368.
- Patel, H. S.; Tandel, M. B.; Prajapati, V. M.; Amlani, M. H. and Prajapati, D. H. (2018). Effect of different pre-sowing treatments on germination of red sanders (*Pterocarpus santalinus* L. f.) in net house condition. *International Journal of Chemical Studies*, **6**(2): 876-879.
- Patil, S. S. and Krishna, A. (2016). Influence of pre-sowing treatments on seed germination and seedling quality in canes. *International Journal of Pure and Applied Bioscience*, **4**(4): 185-192.
- Pradhan, B. K. and Badola, H. K. (2012). Effect of storage conditions and storage periods on seed germination in eleven populations of *Swertia chirayita*: a critically endangered medicinal herb in Himalaya. *The Scientific World Journal*, **2012**: 1-9.
- Rai, S. N. and Sarma, C. R. (1990). Depleting sandalwood production and rising prices. *Indian Forester* **116**: 348-355.
- Redding Jr, B. K. (2016). Continuous ultrasonic treatment of seeds. *U.S. Patent Application No. 13/986,757* pp. 1-26.
- Rehman, S. and Park, I. H. (2000). Effect of scarification, GA₃ and chilling on the germination of goldenrain-tree (*Koelreuteria paniculata* Laxm.) seeds. *Scientia Horticulturae*, **85**(4): 319- 324.
- Rice, K. J. and Dyer, A. R. (2001). Seed aging, delayed germination and reduced competitive ability in *Bromus tectorum*. *Plant Ecology*, **155**(2): 237-243.

- Rinaldelli, E. (2000). Effect of ultrasonic waves on seed germination of *Capparis spinosa* L. as related to exposure time, temperature and gibberellic acid. *Advances in Horticultural Science*, **14**(4): 182-188.
- Saied, A. S.; Gebauer, J. and Buerkert, A. (2008). Effects of different scarification methods on germination of *Ziziphus spina-christi* seeds. *Seed Science and Technology*, **36**(1): 201-205.
- Sandal plantation: High value Indian sandalwood plantation. (2017, June 22nd). Retrieved from <http://sandalplantation.com/>.
- Sandeep, R.; Sashikala, B. and Neelam, K. (2016). Impact of GA₃ seed pre-treatment on seedling growth in *Delonix Regia*. *Research Journal of Recent Sciences*, **5**(11): 47-49.
- Sarihan, E. O.; Ipek, A. R. I. F.; Khawar, K. M.; Atak, M. and Gurbuz, B. (2005). Role of GA₃ and KNO₃ in improving the frequency of seed germination in *Plantago lanceolata* L. *Pakistan Journal of Botany*, **37**(4): 883.
- Sebastian, A.; Vasudevan, S. N. and Macha, S. I. (2015). Seed quality as influenced by dormancy breaking treatments in foxtail millet genotypes. *International Journal of Agricultural Science and Research*, **5**(6): 177-182.
- Shankar, M. and Devakumar, A. S. (2018). Effect of pre-sowing treatments on seed germination and seedling qualities of sandalwood (*Santalum album* L.). *Mysore Journal of Agricultural Sciences*, **52**(4): 732-737.
- Sharififar, A.; Nazari, M. and Asghari, H. R. (2015). Effect of ultrasonic waves on seed germination of *Atriplex lentiformis*, *Cuminum cyminum* and *Zygophyllum eurypterum*. *Journal of Applied Research on Medicinal and Aromatic Plants*, **2**(3): 102-104.
- Shetty, R. H. (1977). Is sandal exotic? *Indian Forest*, **203**: 359-367
- Shim, S. I.; Moon, J. C.; Jang, C. S.; Raymer, P. and Kim, W. (2008). Effect of potassium nitrate priming on seed germination of seashore paspalum. *Hort Science*, **43**(7): 2259-2262.

- Srimathi, R. A.; Kulkarni, H. D. and Venkatesan, K. R. (1995). Recent advances in research and management of Sandal (*S. album* L.) in India. Associated Publishing Co., New Delhi, India pp. 416.
- Srinivasan, V. V.; Sivaramakrishnan, V. R.; Rangaswamy, C. R. and Ananthapadmanabha, H. S. (1992). Sandal, *Santalum album* Linn. *Indian Council of Forestry Research and Education*, Publsd. ICFRE, Bangalore, India.
- Subasinghe, S. M. C. U. P. (2014). Restoration of *Santalum album* L. resource in Sri Lanka: Distribution, seed storage, germination and establishment. *Journal for Department of Wildlife Conservation*, **2**: 155-164.
- Sujatha, V. N. and Manjappa, K. (2015). Effect of pre-sowing treatment on seed germination of *Melia azedarach* L. *Karnataka Journal of Agricultural Science*, **28**(2): 269-270.
- Sutheesh, V. K.; Jijeesh, C. M. and Divya, T. P. (2016). Evaluation of organic and inorganic pre-treatments for better seed germination and seedling vigour in *Santalum album* L. *Plant Archives*, **16**(1): 143-150.
- Talei, D., Valdiani, A.; Abdullah, M. P. and Hassan, S. A. (2012). A rapid and effective method for dormancy breakage and germination of King of Bitters (*Andrographis paniculata* Nees.) seeds. *Maydica*, **57**(2): 98-105.
- Tambat, B.; Vishwanath, K.; Chaithra, G. N. and Hareesh, T. S. (2006). Improved germination of *Gymnacranthera canarica* Warb. an endangered, endemic tree species of Myristica swamps, Western Ghats, India. *Seed Science and Technology*, **34**(3): 603-608.
- Thanuja, P. C.; Nadukeri, S. and Kolakar, S. S. (2019). Effect of pre sowing seed treatments on seed germination and seedling growth in Rakta Chandana (*Pterocarpus santalinus* L.): An endangered medicinal plant. *International Journal of Conservation Science*, **7**(3): 1577-1580.
- Thanuja, P. C.; Nadukeri, S.; Kolakar, S.; Hanumanthappa, M.; Ganapathi, M. and Vasudev, K. L. (2018). Enhancement of germination and seedling growth attributes of a medicinal tree species *Pterocarpus marsupium* Roxb. through pre

- sowing seed treatments. *Journal of Pharmacognosy and Phytochemistry*, 7(3): 165-169.
- Turagavuli, A. T. (2018). Techniques for improving germination of papua New Guinea sandalwood (*Santalum macgregorii*). Doctoral dissertation, University of Technology, 1-47.
- Vachhani, K. B.; Gohil, J. H.; Pandey, R. and Ray, N. R. (2014). Influence of chemicals, PGR's and cow-dung slurry as seed treatment on germiability, growth and development of Khirnee (*Manilkara hexandra Roxb*) under net house condition. *Trends in Biosciences*, 7(14): 1641-1643.
- Vasanth, P. T.; Vijendrakumar, R. C.; Guruprasad, T. R.; Mahadevamma, M. and Santhosh, K.V. (2014). Studies on effect of growth regulators and biofertilizers on seed germination and seedling growth of tamarind (*Tamarindus indica* L.). *Plant Archives*, 14(1): 155-160.
- Venkatesan, K. R.; Srimathi, R. A. and Kulkarni, H. D. (1995). Survey of sandal populations. In: recent advances in research and management of sandal (*Santalum album* L.) in India. Srimathi, R. A.; Kulkarni, H. D. and Venkatesan, K. R. (eds). Associated Publishing Company, New Delhi, pp. 3–52.
- Venkatesh, A.; Vanangamudi, M.; Vanangamudi, K.; Parthiban, K. T.; Ravichandran, V. and Rai, R. V. (2000). Effect of growth stimulants on seed germination and morpho-physiological attributes in pungam (*Pongamia pinnata*). *Journal of Tropical Forest Science*, 12(4): 643- 649.
- Vijendrkumar, R. C.; Sreeramu, B. S. and Halesh, G. K. (2014). Effect of pre-sowing growth regulator treatments on germination and seedling growth of garden rue (*Ruta graveolens* Linn.). *Asian Journal of Horticulture*, 9(1): 193-197.
- Vira, R. and Smith, A. (1996). *Santalum austrocaledonicum* seed germination study. *Sandalwood Research Newsletter*, 5: 2
- Weinberger, P. and Burton, C. (1981). The effect of sonication on the growth of some tree seeds. *Canadian Journal of Forest Research*, 11(4): 840-844.

Bibliography

- Yildiztugay, E. and Kucukoduk, M. (2012). Dormancy breaking and germination requirements for seeds of *Sphaerophysa kotschyana* Boiss. *Journal of Global Biosciences*, **1**: 20-27.
- Zaman, S.; Padmesh, S. and Tawfiq, H. (2009). Effect of pre-germination treatments on seed germination of *Helianthemum lippii* (L.) Dum. Cours. University of Arizona, *Desert Plants*, **25** (2): 18-23.

APPENDIX I

Weekly meteorological data (mean values) on maximum and minimum temperature, maximum and minimum relative humidity, rainfall and rainy days recorded during the sandalwood germination period (December 2019 – February 2020) at Junagadh Agricultural University, Junagadh

Month	Standard Week	Total Rainfall (mm)	Number of Rainy Days	Temperature (°C)		Relative Humidity (%)	
				Max.	Min.	Morning	Evening
December 2019	49	0.0	0	33.5	14.1	70	26
	50	0.0	0	32.3	15.0	72	28
	51	0.0	0	30.7	12.6	81	29
	52	0.0	0	31.9	11.7	74	23
January 2020	1	0.0	0	30.8	12.4	85	34
	2	0.0	0	27.3	10.2	61	23
	3	0.0	0	28.9	12.0	74	32
	4	0.0	0	31.5	13.6	72	31
	5	0.0	0	32.0	12.0	77	32
February 2020	6	0.0	0	37.5	16.4	76	21
	7	0.0	0	34.9	16.1	62	24
	8	0.0	0	36.6	17.3	67	23
	9	0.0	0	36.5	18.7	61	22