SEED SOURCE STUDIES ON *Santalum album* L. IN HIMACHAL PRADESH

Thesis

by

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FRONTISPIECE

***Santalum album* L.**

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CERTIFICATE - I

This is to certify that the thesis titled **"Seed source studies on *Santalum album* L. in Himachal Pradesh"** submitted in partial fulfillment of the requirements for the award of degree of **Master of Science (Forestry)** in the discipline of **Forest Genetic Resources** to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) - 173 230 is a bonafide research work carried out by **Ms Ruchi Thakur (F-2019-43-M)** daughter of Sh. Shiv Ram under my guidance and supervision and no part of this thesis has been submitted for any other degree or diploma.

This assistance and help received during the course of investigations has been fully acknowledged.

Dated:
Place: Nauni, Solan

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CERTIFICATE-II

This is to certify that the thesis entitled, "**Seed Source Studies on *Santalum album* L. in Himachal Pradesh"** submitted by **Ms Ruchi Thakur, (F-2019-43-M)** Daughter of Shri Shiv Ram to Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni), Solan (HP) 173230 India in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (FORESTRY)** in the discipline of **Forest Genetic Resources** has been approved by the Advisory Committee after an oral examination of the same in collaboration with the External Examiner.

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I solely claim the responsibility for all the errors and omissions.

Place: Nauni (Solan) **(Ruchi Thakur)**

CONTENTS

ABBREVIATIONS

ANOVA	:	Analysis of Variance
a msl	:	above mean sea level
°C	:	Degree Celsius
Cm	:	Centimeter
et al.	:	And others
etc.	:	Etcetera
FYM	:	Farm yard manure
Ft.	:	Feet
g	:	Gram
GA_3	:	Gibbrellic acid
HCl	:	Hydrochloric acid
HNO_3	:	Nitric acid
H P	:	Himachal Pradesh
H_2SO_4	:	Sulphuric acid
IAA	:	Indole - 3- acetic acid
i.e.	:	That is
Linn./L.	:	Linnaeus
ltr / L	:	Litre
m	:	Meter
mM	:	milli Molar
Mg	:	Milli gram
mm	:	Millimetre
RBD	:	Randomized Block Design
Rs	:	Rupees
sp.	:	Species
SE:	:	Standard error
TTC	:	2,3,5- Triphenyl Tetrazolium chloride
TTIG	:	Time taken to initiate germination
TTCG	:	Time taken to complete germination
VAM	:	Vesicular Arbuscular Mycorrhizal
viz.	:	Videlicet
Wt.	:	Weight
%	:	Per cent
@	:	at the rate

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Chapter-1

INTRODUCTION

Santalum album Linn. is one of the most valuable timber species, with fragrant heartwood that has enticed the timber trade since antiquity. It is well known as Royal tree because of its limited range, high valuable oil and presence of santalol (Jeeva *et al*., 1997).

It is evergreen tree of moderate size with a girth of 1-2.4 m and height up to 12- 15 m (Sen - Sarma,1982). It belongs to Santalaceae family and well distributed in 9600 km^2 with 600-1600 mm of annual rainfall (Troup, 1921) mostly in the deciduous forests of Deccan region of peninsular India from which about 8200 km^2 area falls under two states namely Karnataka and Tamil Nadu which are known to be its natural habitats (Srinivasan *et al*., 1992). In Himachal Pradesh the species finds sporadic distribution in Bilaspur, Hamirpur and Kangra districts varying soil conditions.

This species blooms and bears fruit twice a year during March to April and September to October. Seed production is good in September to December season. Some trees only bloom once a year while some do not bloom on regular basis. The flowers are bisexual, axillary cymes, straw yellow coloured at initial stages but perianth turns to deep reddish brown color later. The tree begins to bloom at a young age of 2 to 3 years. Flowering and fruiting seasons differ according to the altitude. Flowering begins about a month earlier in trees growing at lower altitudes than in trees growing at higher altitudes. The fruit is drupe with diameter of 6.32 to 7.00 mm and purplish black colour. At maturity, the colour of the fruit changes from green to purplish black. The fruit has a single seed with a relatively hard brown endocarp. Leaves are small, normally opposite with a rounded or pointed tip and reticulate venation. The bark of younger tree is tight, dark brown or nearly black and of older tree is rough with deep vertical cracks.

Santalum album is one of India's most valuable commercial but threatened tree species. Sandalwood is valued for its fragrant heartwood and existing strong international demand is projected to continue for the next 30 years (Thomson, 2020). The most economic parts of sandal tree are roots and stem. The fragrant heartwood is found in these parts which is converted in to chips and steam distilled to extract oil. Santanol is responsible for Sandalwood's aroma. Sandalwood oil is commonly used in the perfumery industries and

pharmaceutical uses in medicines for the treatment of fever, general fatigue, cold, skin disorders, urinary tract infections, and other ailments. The chips of sapwood are white which are used for making incense sticks(Arunkumar *et al*., 2012). Because of its sweet scent, longevity aroma and fixative property, sandalwood oil is highly demanded by perfumery industries.

Sandalwood is a partial root parasite as it makes connection with the host species which is required for growth and development of young tress as well as adult tress and host plant also provide required light for healthy growth of seedlings. It has been revealed that without the primary host, growth of sandal is poor so primary host is essential for growth and development of species.

Natural regeneration generally occurs by seeds and birds usually disperse seeds, which take 4 to 8 weeks to germinate (Venkatesan, 1995). Seeds are dibbled in a pit or different containers and sown on mounds to achieve artificial regeneration. Plantation of seedling through nursery operations, vegetatively and tissue culture are also in practice.

The indigenous geographical region from which seeds or other propagules are derived is referred to as the seed source (Zobel and Talbert, 1984). Seed source trials are the first step in forest tree species restoration, ensuring that germplasm is correctly stored, preserved, and conserved. It provides basic knowledge of both genetic and environmental variations, allowing comparison among seed sources on the basis of different characters. It is considered a preliminary phase of survey, screening and selection for carrying out breeding programmes.

Sandalwood possesses both medicinal and aromatic qualities. Sandalwood is mostly used to keep things cold. It is used as a genitourinary and bronchial tract disinfectant, as well as a diuretic, expectorant, and stimulant. It has both sedative and astringent properties. It is used for blood purification and memory enhancement. It is also used to treat masses that are coughing, urticaria, eye infections and vomiting. It is mostly used as a beauty material because sandalwood essential oil is used to treat skin conditions such as pimples, skin eruptions, itching, swelling and rashes.

Due to the changes in land use patterns, habitat degradation, illegal felling and plantation theft, natural sandalwood plantations are steadily declining in India. Sandalwood seeds have highest levels of dormancy which do not allow seeds to germinate. Sandalwood

seeds are water and oxygen resistant, which prevents the seed from germinating. Seed dormancy is also caused by impermeable seed coats, mechanically resistant seed coats, rudimentary, morphologically mature but physiologically immature embryos (Das and Tah, 2013). Breaking the seed dormancy through various pre-sowing seed treatments will improve seed germination. The seeds are treated with GA_3 to enhance germination. Treatments of sandal seeds with GA_3 have been found most important and successful practice from different pre sowing treatments (Nagaveni and Srimathi 1985).

Keeping in view the economical and pharmaceutical importance of the species and the bright prospects of tree framing entrepreneurship, present research work on seed source evaluation has been planned with following objectives-

i) To study phenotypic variations of the species
ii) To study seed characteristics and patterns of variations among different seed sources
iii) Nursery growth performance of half sibs from selected seed sources

Chapter-2

REVIEW OF LITERATURE

Seed source evaluation studies are important for improvement and multiplication of forest tree species. The primary goal of seed source testing is to establish the quality of available seeds in a given geographic area and to determine the seed producing capability of tree species under investigation**.** The goal of present study was to assess the differences in phenotypic and morphological characteristics of *Santalum album* L., seed qualities, seedling growth performances of various seed sources. A brief resume of the relevant research work already completed on *Santalum album* and other species in relation to seed source variations has been compiled and organised under the following headings:

2.1 PHENOTYPIC STUDIES AND USES

Dutt (2000) studied present status, nursery and plantation technology of sandalwood (*Santalum album* L.) in low hills of Himachal Pradesh under laboratory and field conditions. Phenotypic studies were carried out in two districts of Himachal Pradesh viz., Bilaspur and Jwalamukhi. For Bilaspur, maximum tree height and tree diameter was recorded i.e,15.50 m and 22.50 cm and for Jwalamukhi maximum tree height and tree diameter was recorded 14.25 m and 20.25 cm. The studies on germinability of seeds under nursery conditions showed that seeds collected during September to October and sown in April gave maximum percentage of germination (52.00%) and germination energy (26.00%) in minimum duration (23.00 days). Generally in lab conditions (75%) germination energy is higher than the field conditions.

Studies conducted by Dey (2001) revealed that sandalwood (heartwood) was resistant to termites and wood borers, making it one of the best woods for carving, second only to

ivory. Because of its smoothness, uniform fibres, straight near grains, it lends itself to intricate work.

Sindhu *et al.* (2010) studied morphology of sandalwood. This research also includes phytochemical investigation and pharmacological studies which involve anti- ulcerogenic activity, antipyretic effects, effects on central nervous system, effects on blood pressure, anti-inflammatory effect of sandalwood oil.

Das and Tah (2013) conducted a study on the growth pattern of *Santalum album* L. and its expected yield. The height and girth of standing sandalwood trees and 51 felled trees were taken in Hirbundh Beat of Khatra range of Bankura (South) Division, West Bengal. It was found that a sandalwood tree attained an average height of 10.20 m and girth of 83.00 cm at the age of 35 years. The study also revealed that the average yield per tree was recorded as 214.51 kg and the average price per tree was Rs 1,90,000.00 while the maximum yield recorded from one tree was 415 kg which fetched an avenue of Rs 4,35,000.00 in 2010.

A study on naturally grown sandalwood tree was conducted in Himachal Pradesh by Sharma and Lekha (2014) and their studies revealed that better growth performance is exhibited by naturally grown sandalwood tress. They observed the presence of oil in the heartwood of sandalwood which indicated that the sandalwood tree can be planted on a large scale in the sub-montane zone of Himachal Pradesh.

Santha and Dwivedi (2015) studied anticancer effects of *Santalum album*. α -Santlol, a sesquiterpene derived from Sandalwood, has anti-inflammatory, anti-oxidant, anti-viral, and anti-bacterial properties. The current review examined anticancer role of sandalwood oil and α -santalol in carcinogenesis.

East Indian Sandalwood oil is highly demanded for its sweet fragrance, tenacious aroma, spicy, warm and fixative properties. Sandalwood is used for number of items including medicine, perfumes, agarbathis, handicrafts, carvings, religious purposes and in timber industries. Divakara *et al*.(2018).

Page *et al*. (2020) studied morphological, heartwood and essential oil characters in 126 *Santalum macgregorii* trees of 5 population in Papua New Guinea. Results of this study revealed that the average percentage of heartwood in the basal region was 15.8%, with no significant differences among sites. There was significant tree-to-tree variation in heartwood

proportion (0–61%) and positive correlation between stem and heartwood diameter (r = 0.39). Significant variation in leaf morphology was found between sample sites and the leaves in Rigo were found to be significantly ($P < 0.05$) shorter in length. Maximum tree diameter was recorded in Kuriva i.e, 19.4 cm and minimum in Malalaua i.e, 11.7 cm. Maximum tree height was recorded for Kuriva i.e, 13.8 m and minimum for Malalaua i.e, 8.2. Maximum bole height was recorded for Kuriva i.e, 4.8m and minimum for Rigo i.e 2.6m.

2.2 LEAF MORPHOMETRIC AND FLORAL CHARACTERSTICS

Bhasker (1992) studied Pollination biology and fertilization in *Santalum album* L. (Santalaceae). Flowers of *Santalum album* were found to be self-incompatible and specifically adapted for insect pollination, according to studies. Flies (*Phytomia argyrocephala, Eristalinus arvorum, Dolichomerus crassa*) and bees (*Apis florea, A. cerana, A. dorsata*) were the most common pollinators, visiting the flowers for the nectar in a cup-like disc.

Prehaten and Ratnaningrum (2005) studied about visitors which were active at different stages of flowering of *Santalum album* at different times . Their studies revealed that visitors from three orders i.e Diptera, Hymenoptera, and Lepidoptera visited hermaphrodite, self-compatible, protandrous single flowers with papillate stigma and four anthers with less-sticky pollen. Visitors were found to be arrived at various times and periods of flowering.

Fiani and Yulaih (2011) studied foliage morphological variations of various provenances of *Santalum album*. Leaves samples were collected in Watusipat, Gunung Kidul from an ex-situ conservation plot of *Santalum album*. A total of 14 sandalwood provenances were studied, with five individual trees were selected from each provenance. The results revealed that there was difference between foliage morphology among provenances and the measurements showed that leaf size varies with lengths ranging from 5.184 to 7.798 cm and widths ranging from 2.182 to 3.524 cm. Karang Mojo had the smallest leaf size measuring 5.184 cm in length and 2.182 cm in width, while Waisika had the largest leaf size measuring 7.798 cm in length and 3.524 cm in width.

Baskorowati (2011) studied patterns of flowering and flower visiting insects of *Santalum album* L. at ex – situ conservation plot, Watusipat, Gumung Kidul and Yogyakarta. *Santalum album* L. flowers twice a year and shows maximum flowering during June and

November at this site. Study showed that various insects were found to visit on *Santalum* flower; commonly found insects were honey bees and ants. *Santalum album* L. was mainly cross pollinated by insects although in an open pollination low number of fruit set found. Low number of fruit production was influenced by degree of self – incompatibility and variation of flowering intensity.

The study was conducted in Wanagama Forest Research Station, Yogyakarta Province, Indonesia by Ratnaningrum and Indrioko (2014) and was focused on genetic diversity and flowering characterstics of seven sandalwood provenanaces those were planted on ex-situ gene conservation in Wanagama and its effects on pollination. The availability of attractants given by ten marked individuals of each provenance was used to investigate pollination mechanisms. Plant pollinator interactions were then assessed daily including stigmatic touch, pollen load, interplant movement, feeding activity, and visitation rate by using Ghazoul and Jones and Little methods. Results showed that provenances from the same location had identical genotypes and flowering characteristics and heterostyly and protandry were found in all the provenances. The size and colour of perigonium varied between provenances and over time. Moths, butterflies (Lepidoptera), flies (Diptera), ants, bees and wasps were among the insect species that visited flowers (*Hymenoptera*). In terms of primary (pollen and nectar) and secondary (perigonium colour and mature anthers) attractants, the type of insect and visitation rate were dependent on flowering phases.

In a study conducted by Ratnaningrum and Indrioko (2015), climatic factors like temperature and rainfall controls flowering and seed production of sandal. Extreme rainfall resulted in late floral initiation, shorter span of stigma receptivity, bigger size of reproductive organs and increment in temperature resulted to shorter flowering period, decrease in flower and fruit abundance.

Keshavanarayan *et al*. (2015) studied floral ecology and reproductive biology of *Pterospermum reticulatum* at Pilikula reserve forest, Mangalore, Karnataka during 2012-2013. Anthesis occurred in the evening between 18:30 and 22:30 hours and peak flowering was observed in February and April. Some of the ants and grass hoppers were seen feeding on the sepals, petals and flower buds and the TTC test revealed that 94.23 percent of pollen had maximum viability under 0.5 percent concentration of sucrose on the first day of anthesis.

Silva *et al.* (2016) studied hemi-parasitic nature, basic biological mechanism, advanced in vitro technologies of *Santalum album* L. which gave base to scientist for execution of sustainable programs of research and transformation of genes.

Ratnanigrum *et al*. (2016) conducted a study in Gunung Sewu Geopark, Indonesia in 2013 to 2014 flowering seasons of *Santalum album*. Following adapted methods of Owens *et al* and Ghazoul, they observed flowering phenology in terms of floral initiation, stages and cycles and assessed Pollination Effectiveness and Reproductive Success. Observation showed that flowering and seed production was influenced by variations in rainfall, temperature, and soil moisture, as well as altitude and climatic conditions. Sites with lower altitude, lower rainfall, high temperature, low relative humidity and low soil moisture yielded flowers earlier and for a shorter period of time. Flowering frequency and reproductive outputs were found affected by both decrease in temperature and rise in temperature.

A detailed study on phenology, reproductive biology, breeding system, seed collection, processing and nursery techniques, growth yield and economics, population status and conservation of *Santalum album* L. has been conducted by Arunkumar *et al*. (2016).

Krishnakumar and Parthiban (2017) studied phenology of flowering and seed production of *Santalum album* L. during its flowering season in year 2015 at Forest College and Research Institute, Mettupalayam, Tamil-Nadu to know about bud, flower, fruit and morphology of seeds for quality and quantity of seed production. Sandal plantation at site commenced to first flower on July and to second flower during December. Seed setting (20.52%) and seed germination percentage (51.84%) is less in first season as compared to second season i.e seed setting was 35.01% and seed germination was 60.40%). Bud, flower, fruit and morphology of seed is directly related in seed setting and seed germination percentage which showed that seeds collected from flowering of second season (December) produced good quality seedling.

Ratnaningrum *et al*. (2018) compared the effects of flowering and pollination on reproductive yields of *Santalum album* during flowering periods of dry and rainy seasons of year 2016. Results showed that the rate of flowering and pollination varied greatly between seasons, but was comparable between locations. Reproductive yield on the other hand varied greatly between locations, but comparable between seasons. Both the abundance and pollination of flowers showed negative correlation with reproductive parameters. Populations

could gain more flowers and visits, but there were considerably lower reproductive production. Infact, more flowers increased geitonogamy in colonialized and lower heterozygosity populations, which may contribute to inbreeding depression.

The study was carried out in five different flowering seasons at Forest College and Research Institute, Tamil Nadu to identify the pollinators for the production of good quality seeds of Sandalwood by Krishnakumar *et al.* (2018a). This study revealed that Sandalwood is a cross pollinating spp. and the pollinators those facilitate the pollination were *Monomorium destructor, Camponotus spp.* and *Apis cerana indica.* Two types of pollinators i.e. *Monomorium destructor* and *Apis cerana indica* were found as frequently visitors. Results of this study showed that identification of pollinators is essential for production of good quality seeds.

Fatin and Ratnaningrum (2018) studied differences in structure of three floral variants i.e. YSF (Yellow big flower), RBF (Red big flower) and RSF (Red small flower) of sandalwood landraces for visitors diversity in Gunung Sewu Geopark, Indonesia. During 2016 flowering season, they investigated these variant differences and their implications for visitor diversity and visitation rate in the Bleberan group which was one of the most genetically diverse populations in Gunung Sewu Geopark. Their results revealed that coleopterans and hemipterans were more common at YBF, while hymenopterans were more common at RBF and RSF. Dipterans and lepidopterans were equally attracted to yellow and red flowers. RBF and YBF got more visits than RSF because their flowers were larger.

2.3 SEED TRAIT AND INVITRO GERMINATION STUDIES

Manonmani and Vanangamudi (2002) found that big sized seeds of *Santalum album* should be selected to obtain maximum percentage of germination and increased seedling vigour. Maximum 100 fruit weight (76.32 g), 100 seed weight (18.48 g), more seed length and seed breadth (7.69 cm and 6.66 cm) were observed at Coimbatore than other locations (Harur, Siruvani, Mettupalayam).

Dhania *et al.* (2003) conducted provenance variation studies in pod and seed characteristics of *Albizia chinensis* where they collected seed from wide range of natural distribution in Himachal Pradesh. Results revealed that seed length varied from 5.60 mm to 6.53 mm in Kundz and Manan provenance, respectively. Seed width varied from 4.19 mm to

5.08 mm in Kundz and Manan provenance respectively. They found that seeds which contain more food reserves showed higher germination per cent than smaller ones which helps in providing more energy for germination.

Nayak *et al.* (2004) studied seed source variation in *Albizia lebbeck* in Karnataka and their studies reported that among five provenances, mean daily germination ranged from 0.728 (Chickmagalur) to 1.382 (Mandya). Mandya provenance showed highest germination value (2.806) and least (1.37) was in Dharwad provenance. Such variation in germination may be attributed by dormancy of seed caused by impermeability of hard seed coat or may be dormancy in embryo.

Dutt and Verma (2005) observed effect of time of collection, various pre sowing treatments i.e. T_1 (0.1% of GA_3), T_2 (0.05% of GA_3), T_3 (0.025% of GA_3), T_4 (Depletion of mesocarp), T_5 (Cracking of mesocarp), T_6 (control) and time of sowing on germination of seeds of sandal under nursery conditions and found that seeds collected during months of September and October showed better performance than seeds collected during March to April. Results also revealed that seeds collected during September to October and sown in April registered maximum germination percentage (48.50%) and germination energy (35.00%) with presowing treatment T_4 (depleting of mesocarp) and minimum germination energy (6.00%) and germination energy (4.00%) was recorded with pre-sowing treatment T_6 (control). Germination percentage (41.50%) and germination energy (21.50%) was recorded with T_2 when seeds were collected during October to November and sown in April.

Annapurna *et al.*(2005b) conducted a study in Tree Improvement and Propagation Division, Institute of Wood Science and Technology, Bangalore, India on impact of clones in a clonal seed orchard on the variation of seed traits, germination and seedling growth in *Santalum album* L. Their study revealed that over the years, there was a lot of variation in seed size, weight, germination, vigour and seedling growth among different clones and there were positive correlation between the seed weight, seed length and width but, seed size had no impact on germination and days to germinate or early seedling development.

Ginwal *et al*. 2005 studied seed source variation in morphology, hermination and seedling growth of *Jatropha curcus* Linn. in Central India. Results of their studies revealed that a significant seed source variation was observed in seed morphology (color, size and wight), seed germination (viability, germination percent, germination energy and germination

value) and seedling growth parameters. The phenotypic and genotypic variance, coefficient of variability and broad sense heritability showed variability. High percentage of heritability with moderate genetic gain was observed for seed germination traits which showed that germination is under genetic control.

Nikam and Burmukh (2009) studied that in - vitro seed germination enhanced due to GA_3 in *Santalum album* L. Under aseptic conditions, the endocarp was removed and the seeds were pre-treated with 2, 4, 6 and 8 mM gibberellic acid (GA_3) for 12 hours before being inoculated on Murashige and Skoog's (MS) medium. Results of this study revealed that final germination was improved with imbibition of seeds in 4 mM GA_3 in 30 days as compared to 46% germination in non-treated seeds.

The study was conducted on effects of GA_3 on seed germination of sandal (*Santalum album* Linn.) in West Bengal by Das and Tah (2013). Seeds were treated with cold water, hot water and GA_3. Results showed that soaking the seeds of *Santalum album* L. in hot and cold water does not improve the germination percentage, but soaking the seeds in 0.05% GA_3 for 16 to 24 hours gave good rate of germination.

Zhou *et al*.(2014) studied effects of smoke water and karrikin on the seed germination of 13 tree species from southern tropical and subtropical monsoon climate regions of South China using laboratory and pot trials. Results of this study revealed that only *Aristolochia debilis*, when diluted 1:10, showed a strong positive response to commercial SW among the 13 species examined. 1–100 nM 3-methyl-2H-furo [2, 3-c] pyran-2-one (karrikin 1 or KAR1) and 10–1000 nM gibberellic acid (GA_3) also stimulated seed germination in *Acacia debilis*. GA_3 induced *Santalum album* seed germination and greatly elongated the radicles of *A. debilis*, while SW did not.

Subasinghe (2014) studied current distribution of *Santalum album* L. in Sri Lanka, as well as efforts to improve seedling germination and initial growth rates via seed treatments, seed viability loss and the impact of different host species at the seedling level. Their studies revealed that the best seed treatment was 0.05 percent Gibberellic acid and seed viability decreased rapidly with storage time. The best host species for the seedling stage of *S. album* were found to be *Desmodium triflorum, Mimosa pudica* and *Clitoria ternatea.*

Sutheesh *et al.* (2016) studied evaluation of organic and inorganic pretreatments for better seed germination and seedling vigour in *Santalum album* L. They collected mature seeds of sandal from Marayoor Nachivayal forests of Idduki district, Kerala. Sixteen pretreatments were given to the seeds which include acid scarification, soaking in tap & cold water, GA_3, cow dung, cow dung slurry and cow urine in different concentration and duration. The results showed that highest germination percentage and germination index was seen soaking seeds in 500 mg/ ltr GA_3 for 24 hours and lowest in Soaking the seeds in H_2SO_4 for 5 minutes.

Shanker and Devakumar (2018) investigated effects of pre - sowing treatments on germination of seeds and seedling qualities of *Santalum album* at College of Agriculture, UAS, GKVK, Bengaluru. Seeds were treated with GA_3 (with two different concentrations i.e. 100 ppm and 500 ppm). Results showed that seeds treated with 500 ppm for 24 hours showed highest seed germination (67%).

Silva *et al*.(2019) studied pollination biology, importance and seed germination of Red sandalwood (*Pterocarpus santalinus* L.).Their studies revealed that *Apis dorsata, A. cerana indica* and A. *florea* were commonly visited pollinaters and seeds treated with 500mg/L gibberelic acid for 24 hours gave 66.7% seed germination which also improved plant growth and survival of seedling as compared to other treatments as soaking with tap water, luke warm water, H_2SO_4 or HCl.

Polaiah *et al.* (2020) studied the effects of pre - sowing treatments (GA_3, cow dung slurry, cow urine, HNO_3, H_2SO_4, Thiourea) on germination of seeds of *Santalum album* L. and found that treatment of seeds of sandalwood with GA_3 (1500 ppm) for 24 hours results to higher percentage of germination and superior growth of sandalwood seedling.

Kaur *et al*.(2020) studied enhancement of seed germination through breaking seed dormancy of various species like *Acacia spp., Albizia lebbeck, Cassia spp., Santalum album, Terminalia arjuna* etc. through scarification, stratification, chemical, Biological and irradiation methods. Their studies revealed that Gibberellins, IAA, Kinetin and other growth hormones were mainly associated with seed germination and seedling physiology and in most species GA_3 was the most widely used growth regulator for germination enhancement at 100-200 ppm for 1 -2 h.

2.4 NURSERY STAGE GROWTH PERFORMANCE

Sandalwood is affected by *Fusarium oxysporum* seedling mortality at different stages, causing damping off, collar rot, stem and root infection. The disease has been documented in Karnataka and Tamil Nadu as well as all of Kerala, including high-altitude areas like Marayur (Remadevi *et al*. 2005).

Annapurna *et al.*(2005a) observed that root trainers (270 cc) gave better growth of seedling of *Santalum album* L. having media soil, compost, cocopeat, burnt rice husk and charcoal (Ratio- 25:15:50: 5:5), sieved with 6 × 6 holes / square inch as compared to the polybags because in polybags there was a risk of root coiling.

Annapurna *et al*. (2006) investigated production of quality seedling of *Santalum album* L. and stage at which it requires host. *S. album* required primary host at its nursery stages and secondary host in field. The study on primary host stage showed that by providing host after transplanting at two leaf stage was optimal stage for better growth of seedling. This study revealed that among six leguminous hosts *Mimosa pudica* proved best host for better growth of *S. album* and among five non leguminous host species *Alternanthera sessile* (L.) proved the best host. Observation showed that there were remarkable effects of host spp. on haustorial number, size and content of chlorophyll.

Jagdish *et al.* (2007) studied about seed sources and collection time that have a major impact on germination parameters in sandal. They discovered that out of the three maturity collection periods (15 days interval), the mid collection of seeds were the most suitable, followed by the early and late collections.

Rathod *et al*. (2014) studied the effect of soil type on the growth and survival of seedling of *Santalum album* L. Collected seeds were treated with 0.05% GA_3 for 16 hours and treated seeds were sown in sand bed in nursery at Dungara, Surat and Gujarat. After 35-40 days, seedling were transferred in polybags with medium having FYM, sand, soil, Mancozeb, Phorate, VAM, chicken excretion. All the constituents remain same whereas soil used either red or yellow as the two distinct treatments. The results showed that there was not much difference found in height and collar diameter among two treatments.

Batabyal *et al.* (2014) studied effect of seed sources on germination parameters through artificial seed germination of *Santalum album* L. at West Bengal, India. For this

experiment the seeds were collected during October to November 2012 from three locations viz., Bankura, Burdwan and Bangalore. After the dormancy period of seed of 60 days the seeds were washed, depulped and dried for easy germination. Pre - sowing treatment of 0.05% of GA_3 was given to seeds for enhancing the germination of seeds and treated seeds were sown in germination bed. Different seed germination parameters like germination percentage, germination speed, time taken for completion of germination, peak value of germination and germination value were found to be significant at 1% level of significance. This study revealed that the Burdwan district showed best result on germination percentage & TTIG and Bankura district showed best results for TTCG.

Patel *et al*. (2018) investigated different pre-sowing treatments and their effects on germination of *Pterocarpus santalinus* . Their studies revealed that seeds treated with GA_3 @ 500 ppm for 1 day registered best results for maximum plant parameters namely higher germination percentage (66.67), collar diameter(5.65 mm), plant height (41.20 cm), number of leaves per plant (20.44), root length (30.57 cm), fresh weight of plant 931.58g / plant), dry weight of plant (24.77g / plant).

Mohanpatra *et al*. (2018) studied about the effect of potting mixture on the growth and quality of Sandalwood (*Santalum album* L.) seedlings with the aim of improving the quality of planting material in a short period of time at College of Forestry, Orissa University of Agriculture and Technology (O.U.A.T) Bhubaneswar, India during 2014 – 2015. In June 2014, 19 different combinations of potting mixtures with sand, red soil, FYM, perlite, vermin compost, neem cake and karanj cake were prepared and filled into 9”x5” size black polythene bags. Results of their study revealed that at 270 DAS, the potting mixture of sand + red soil + vermin compost in a 1:1:1 ratio had substantially higher height (43.53cm), collar diameter (4.06mm), number of leaves per plant (51.43), branch number (4.71), shoot biomass (12.50 g), root biomass (2.95 g), total biomass (15.45 g) and quality index (1.03).

Krishnakumar *et al.* (2018b) studied growth performance of superior progenies of *Santalum album* L. under nursery conditions in TNAU, Coimbatore. The results showed that from 30 progenies, 2 progenies i.e. FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) recorded superior plant height, collar diameter, number of leaves and volume index. Integration of these 2 superior progenies would results into better production of wood.

Mohanpatra *et al*. (2019) studied nursery media and sowing time for germination of Sandalwood (*Santalum album* L.) at College of Forestry/College of Agriculture Orissa

University of Agriculture and Technology Bhubaneswar, Orissa, India. This study was carried out in a nursery using a split plot design. Seeds with and without seed coats were used in the experiment. Freshly collected sandalwood seeds were treated with 0.05% Gibberellic acid and pretreated seeds with eight treatments i.e T_1 (sand), T_2 (sand: perlite in 1:1), T_3 (perlite), T_4 (sand: red soil in 1:1), T_5 (perlite: red soil in 1:1), T_6 (sand: red soil: FYM in 1:1:1), T_7 (sand: perlite: red soil) and T_8 (sand: perlite: red soil) were sown in the months of April, May and June. The results of their study showed that in sand ($S_2T_2M_1$), seeds sown without seed coat in the month of May had significantly maximum germination percentage (55%), germination potential (70%), and germination energy (41.50 percent).

Hemalatha and Chaudhari (2021) conducted experiment under greenhouse during 2019-20 to study pre sowing treatment's effects on seed germination and its parameters in *Santalum album*. Their study revealed that out of seven pre sowing treatments, seeds with GA_3 with 300 ppm (T_2) recorded maximum germination percentage (34.66), collar diameter (2.23 mm) and speed of germination (0.64).

2.5 CORRELATION AND GENETIC ESTIMATES

Singh *et al*.(2006) studied variation in seeds and seedling traits of *Celtis australis*. Seeds collection of *Celtis australis* were collected from 13 different locations in India's Central Himalaya, ranging in altitude from 550 to 1980 metres. The results of their studies revealed that seed traits showed significant ($p = 0.05$) differences between provenances and seed weight varied between provenances, ranging from 47.8 to 83.1 g/1000 seed with a mean of 66.9 10.7 g/1000 seed. A significant ($p = 0.01$) positive correlation was found between morphological characteristics of seeds, such as seed weight and seed source elevational range. There was a significant ($p= 0.01$) positive association between seedling growth success and seed source altitude.

Krishnakumar *et al*. (2017) studied genetic variability among different progenies of *Santalum album* Linn. Their studies revealed that out of 30 progenies, FCRISA 18 performed better in terms of growth characteristics which indicated that it could be used for many improvement programme. The diameter at breast height (DBH) had maximum heritability, while the number of branches had lowest; however, volume had highest heritability. Volume had greatest genetic progress as a percentage of the mean, followed by clear bole height,

crown height, and diameter at breast height (DBH), showing that there is still scope for genetic improvement.

Yadav *et al*. (2019) studied correlation coefficient of white sandal from three locations in Nepal. Bi-variate correlation co-efficient analysis was used on observations after a year. Results showed that in the first set of experiments the r -values for each treatment range from 0.149 to 0.839, in the second set of experiments it ranges from 0.383 to 0.882 and in third experiment r values range from 0.086 to 0.867 which are all suitable from a biometrical standpoint.

Yadav *et al.* (2019) studied the performance of twenty phenotypically superior trees in the natural distribution zones of Uttar Pradesh. Their study revealed that for all of the morphological and biomass traits, the phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV), indicating that the traits were susceptible to environmental variability. Hybridization between *Melia dubia* genotypes with more diverse genotypes may result in genotypes with high heterotic vigour.

Chapter-3

MATERIALS AND METHODS

The present research work entitled “Seed source studies *on Santalum album* L. in Himachal Pradesh” was carried out in the department of Tree Improvement and Genetic Resources, College of Forestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during 2020-2021. Present study was conducted in three Forest Divisions from state Forest Department of Himachal Pradesh. Three seed sources were selected from Bilaspur Forest Divison viz., Changer (S_1), Kosariyan (S_2) and Samoh (S_3) district Bilaspur, one from Hamirpur Forest Divison i.e, Hiranagar (S_4) district Hamirpur and two from Dehra Forest Divisions viz., Jwalamukhi (S_5) and Sadwan (S_6) district Kangra. Each seed source was represented by selected ten trees to record phenotypic characters, seed studies and nursery raising. Tree selection the basis of diameter class ranges between 11.22-16.88 cm.

Experimental sites

Location : Laboratory and nursery experiments was conducted at Nauni located at 30° 51' 44.7444" N latitude and 77° 10' 9.1488" E longitude, at 1200m above mean sea level.

Climate : The Nauni falls under subtropical to sub temperate climate with an average annual rainfall of about 1250 mm. Generally May and June are the hottest months and December to Feburary are the coldest. Bilaspur, Hamirpur and Kangra are in the subtropical sub montane low hill zone.

The details related to material and methodology used to carried out the research work is given under following headings:

3.1 Phenotypic Characters

3.1.1 Tree height (m)

3.1.2 Crown spread (m)

3.1.3 Crown shape

3.1.4 Bark characteristics

3.1.5 Clear bole height (m)

3.2 Morphological characteristics

3.2.1 Leaf length (cm)

3.2.2 Leaf width (cm)

3.2.3 Leaf shape

3.2.4 Leaf color

3.2.5 Leaf area (cm^2)

3.3 Floral characteristics

3.3.1 Flower type

3.3.2 Pollen vectors

3.3.3 Vector visitation

3.3.4 Pollen collection and storage

3.3.5 Pollen viability

3.4 Seed studies

3.4.1 Seed weight (g)

3.4.2 Seed diameter (mm)

3.4.3 Seed color

3.4.4 Seed treatment

3.4.5 Seed germination (%)

3.4.6 Germination energy index

3.4.7 In vitro germination of seeds

3.5 Nursery growth performance of seedling

3.5.1 Seedling height (cm)

3.5.2 Collar diameter (mm)

3.5.3 Number of leaves/ seedling

3.5.4 Inter nodal length (cm)

3.5.5 Leaf length (cm)

3.5.6 Leaf width (cm)

3. 5.7 Leaf color

3.6 Statistical analysis, genetic estimate and simple correlation

The above mentioned parameters of present study have been explained in details as under-

3.1 PHENOTYPIC STUDIES

The selected mother trees were studied on the basis of main phenotypic characters; tree height, crown characteristics, leaf and bark features.

Table-1: Selected study seed source for phenotypic, morphological, seed studies and nursery performance of *Santalum album* L.

Sr. No	Seed sources	Forest Range	Forest divisons	Altitude (amsl)	Latitude	Longitude
1	Changer(S_1)	Sadar	Bilaspur	375 m	31.43176°N	76.50654°E
2	Kosariyan S_2	Sadar	Bilaspur	384 m	31.56245 °N	76.52427°E
3	Samoh (S_3)	Jhandutta	Bilaspur	370 m	31.39466°N	76.68760°E
4	Hiranagar (S_4)	Hamirpur	Hamirpur	780 m	31.87588 °N	76.51284°E
5	Jwalamukhi (S_5)	Jwalamukhi	Dehra	558 m	31.87598 °N	76.32437°E
6	Sadwan (S_6)	Dehra	Dehra	503 m	32.79705 °N	76.22740°E

3.1.1 Tree height (m)

Total height of tree is straight line distance from tip of leading shoot to ground level. Height of marked trees were taken by with the help of Ravi's multimeter.

3.1.2 Crown spread (m)

Crown spread was measured in two directions viz., North – South and East – West by using plum bob, perpendicular staff and measuring tape. The perpendicular staff was fixed on ground in two directions according to the last branch of crown by the use of plum bob. The measuring tape was used to measure the distance (crown spread) between last branches in both the directions. This process was firstly used to measure the crown spread in N-S direction and the same process was repeated to measure the crown spread in E-W direction.

3.1.3 Crown shape

The crown shape varies mostly with the associated tree canopies and also on exposed isolated sites. The shape was accordingly recorded as spreading broad, columnar etc. depending on branch angle.

3.1.4 Clear Bole height

It was measured from ground level to first branch of tree with the help of Ravi's multimeter.

3.2 MORPHOLOGICAL AND FLORAL CHARACTERISTICS

3.2.1 Leaf characteristics

Fifteen leaf samples from each sources were taken for studying the morphological variations pertaining to the tree foliage. The leaf characteristics include:

3.2.1.1 Leaf length (cm)

The leaf length was measured with the help of scale .The length of the leaf was measured from tip of the apex to the base.

3.2.1.1 Leaf width (cm)

Leaf width was measured with the help of scale at its broadest expand.

3.2.1.2 Leaf shape

Leaf shape was observed by following the Standard Cyclopedia of Horticulture (Bailey, 1963) and the leaf dimensions were compared to conclude the shapes of leaves on accessible lower part of crown randomly.

3.2.1.3 Leaf colour

Colour chart of Royal Horticulture Society, London was used to determine the surface colour of leaves. It was observed when the leaves were at the best of its growth.

3.2.1.4 Leaf area (cm^2)

Leaf area was measured with the help of digital leaf area meter (LICOR-model 3100 A).

3.3 FLORAL BIOLOGY

Floral biology has important practical applications as well as scientific significance and it covers wide range of topics including floral parts studies, pollination by various pollen vectors, floral reward pollen and plant reproductive performance. Floral biology was studied during August - December in Nauni Campus.

3.3.1 Flower type

Flower type was observed by examining the parts of the flower with the help of sharp blade and microscope. Flowers were observed hermaphrodite, perianth is simple. Stamens

were observed 4-5 and opposite to the perianth lobes. Ovary is inferior, 1 celled and placentation is free-central.

3.3.2 Pollen vectors

Activity of pollen vectors was observed and identification of pollen vectors was done through imaging, scientific expertise avaibility.

3.3.3 Vector visitation

The pollination biodynamics of main pollinators from morning till evening was observed, twice a day; morning hours; 9-11 am and evening hours; 5-7 pm and their visitation time was recorded with the help of stop watch.

3.3.4 Pollen collection and storage

Pollens were collected in isolation to prevent contamination and collected pollens were stored in glass vials and kept in refrigerator in two temperature i.e. -20°C and 4°C.

3.3.5 Pollen viability(%)

Pollen viability of freshly collected flowers (Pale green and reddish color) and dull green buds were studied by preparing slides in 1 per cent acetocarmin solution and observed under microscope. Deeply stained and normal looking pollen grains was counted under three replications as viable pollens, whereas shrivelled and weekly stained were recorded as non-viable and expressed in percentage. The pollen viability was calculated separately for pollens of green flowers, red flowers and buds.

3.4 SEED STUDIES

Six seed sources were studied representing three forest divisions of Himachal Pradesh along with various factors were studied.

3.4.1 100 Seed weight (g)

100 seed weight was recorded from each seed source by using electronic balance as per ISTA 1996 regulations.

3.4.2 Seed diameter (mm)

A random samples of fifteen seeds per seed source were taken and seed diameter was measured in mm with the help of Vernier Digital Calliper.

3.4.3 Seed color

Seed color plays an important role in seed quality and seed growth ability. Seed color was observed on the sources basis with the help of Colour chart of Royal Horticulture Society, London.

3.4.4 Seed treatment

Seeds were treated with GA_3 (500ppm for 24 hours) for better germination of seeds.

3.4.5 Germination percentage (%)

The seeds from each seed source were sown in the polybags during the months of April and May in three replications under glass house conditions and germination was recorded and expressed as % germination.

3.4.6 Germination energy index (%)

This was computed as per Grouse and Zimmer (1958).

$$GEI = A_1 + (A_1+A_2) + (A_1+A_2+A_3)+.....(A_1+A_2+A_3.....An) \times \frac{100}{N+n}$$

Where, A_1, A_2, A_3 and A_n are the number of seeds newly germinated on nth day respectively, N is total number of seeds used for experiment and n is the number of days of observation.

3.4.7 *In vitro* germination

The experiment was conducted during last week of March. The seed coat was removed under aseptic conditions and the seeds were pre- treated with 4mM gibberellic acid for 12 hours. After pre sowing treatments, all treated seeds were washed with Tee - pole under running water and treated with 2% Bavestin before washed with autoclave distilled water for 2- 3 times, then cultured on MS media and autoclaved sand. Seeds cultured in autoclaved sand were placed in germinator for 30 days with temperature 25°C and humidity 75-85 %.

Treatment details

Sowing media (s) : 2

s_1: MS Media

s_2: Autoclaved Sand

3.4.7.1 Time taken for germination of seeds

The observation on emergence of radicle were recorded when the first radicle emerged.

3.4.7.2 Germination percentage

Germination percentage was calculated by number of seeds in a given sample that actually germinated divided by total number of seeds and expressed in percentage.

3.5 NURSERY STAGE GROWTH PERFORMANCE OF SEEDLINGS

The seeds were treated with GA_3 sown with proper tags bearing the codes assigned to each seed source. The seedlings of six seed sources were raised during April and May in the polybags maintained under glasshouse conditions.

Treatment details-

Sowing dates (d) : 2

d_1 - Date of sowing (20-04-2020)

d_2 - Date of sowing (20-05-2020)

Various growth parameters were measured at 3, 6, 9 and 12 months of age.

3.5.1 Seedling height (cm)

Height was measured from the collar region up to the apex of the leading shoot.

3.5.2 Collar diameter (mm)

Collar diameter was measured using digital Vernier Calliper at an interval of three months.

3.5.3 Number of leaves

Total number of leaves per seedlings was recorded. However, too young leaves were ignored. The observation was recorded at an interval of three months.

3.5.4 Internodal length (cm)

It was measured as the distance between two consecutive leaves on the main axis.

3.5.5 Leaf length (cm)

The leaf length was measured with the help of scale. The length of the leaf was measured from tip of the apex to the base.

3.5.6 Leaf width (cm)

Leaf width was measured with the help of scale at its broadest expand.

3.5.6 Leaf color

Color chart of Royal Horticulture society, London was used to determine the surface color of leaves.

3.6 STATISTICAL ANALYSIS

Statistical analysis is an important tool for data evaluation and interpretation of the results. The data on phenotypic characters was analysed using RBD (Randomized Block Design) and the seed studies along with data on growth performance of the progeny were analysed using CRD (Completely Randomized Design).

Genetic estimation and correlation

The data thus obtained was subjected to statistical analysis as described by Panse and Sukhtame (1967). The design used was Completely Randomized Design and Randomized Block Design. The Statistical analysis for each parameter was carried out on mean values and the analysis of variance (ANOVA).

Table 2: ANOVA table for Randomized Block Design (RBD)

Source of Variation	Degree of freedom	Mean Sum of Square	Variance Ratio
Replication(r)	r-1	MSR	$\frac{MSR}{MSE}$
Seed Source(s)	s -1	M_t = MSS	$\frac{MSS}{MSE}$
Error	(r-1) (s-1)	M_e = MSE	

Table 3: ANOVA table for completely Randomized Design (CRD)

Source of Variation	Degree of freedom	Mean Sum of Square	Variance Ratio
Seed Source	s -1	M_t = MSS	$\frac{MSS}{MSE}$
Error	s(r – 1)	M_e = MSE	

Here,

r = number of replications

s = number of seed source

MSR = Mean Sum of Square due to replication

MSS = Mean Sum of Square due to seed sources

MSE = Mean Sum of Square due to error

The critical difference (CD) was calculated as:

$CD = SE_d \times t_{0.05}$

where,

$SE_d = \frac{\sqrt{2MSE}}{r}$ and $t_{0.05}$ is the table value at error degree of freedom at 5 % level of significance.

Genetic parameters were worked out with regard to estimate of heritability (broad sense). Genotypic, phenotypic and environmental variance were calculated as follows:

$V_e = Me$

$V_g = \frac{Mt-Me}{r}$

$V_p = V_g + V_e$

Where;

Ve = environmental variance

V_g = genotypic variance

V_p = phenotypic variance

Coefficients of variability

Coefficients of variability were worked out by the formulae suggested by Burton and De- Vane (1953):

$PCV\ (\%) = \frac{\sqrt{V_p}}{\bar{X}} \times 100$

$GCV\ (\%) = \frac{\sqrt{V_g}}{\bar{X}} \times 100$

Where,

PCV(%) = Phenotypic coefficient of variability

GCV(%) = Genotypic coefficient of variability

X□ = population mean

Repeatability

The repeatability coefficient, may be considered as the top limit of the genetic-phenotypic variance relationship (Falconer and Mackey 1996) as these coefficients also show the proportion of within-population variation that contributes to total variance and the proportion of between-tree variation that contributes to total population variation.

$$\text{Mother tree repeatability}(\sigma_m^2) = \frac{\sigma_m^2}{\sigma_m^2 + \sigma_{w(m)}^2}$$

Where, σ_m^2 = Mother tree variance

$\sigma_{w(m)}^2$ = With in mother tree variance

Heritability(%)

Heritability in percentage was calculated by formula suggested by Burton and De-Vane (1953) and Johnson *et al.* (1955):

$$h = \frac{Vg}{Vp}$$

Where,

h = heritability (broad sense)

V_p = phenotypic variance

V_g = genotypic variance

Genetic advance

The expected genetic advance at five percent selection intensity was calculated by the formula suggested by Lush (1940) and further used by Burton and De - Vane (1953) and Johnson *et al.* (1955):

$$\text{Genetic advance} = \frac{Vg}{Vp} \times \sqrt{Vp} \times k$$

Where;

k = Selection differential at five percent selection intensity.

The value of k = 2.06 (Allard, 1960)

Genetic gain

Genetic gain was worked out to be the genetic advance as per cent of population mean ($\bar{X}$) following the method suggested by Johnson *et al.* (1955) as under:

$$\text{Genetic gain (\%)} = \frac{\text{Genetic advance}}{\bar{X}} \times 100$$

Chapter-4

RESULTS AND DISCUSSION

The present research was conducted in the department of Tree Improvement and Genetic Resources at Dr.Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan by selecting trees of *Santalum album* L. from subtropical ranges of Himachal Pradesh comprising of six seed sources viz. Changer (S_1), Kosariyan (S_2) and Samoh (S_3) district Bilaspur, Hiranagar (S_4) district Hamirpur, Jwalamukhi (S_5) and Sadwan (S_6) district Kangra , which are situated at significant distance from each other and falling across three Forest Division viz. Bilaspur, Hamirpur and Dehra. Ten trees were selected on the basis of phenotypic superiority from each of seed sources. The study parameters consisted of samples of leaves to study the variations in morphological characteristics among seed sources. The floral characters, pollination vectors and pollen viability were studied from the tree growing in Nauni campus area. Seeds were collected from trees of different seed sources and grown in the glasshouse conditions during the months of April and May to study variations in nursery growth parameters viz., height, collar diameter, leaf length, leaf width, internodal length, number of leaves and number of nodes per plant.The findings of the investigations have been presented under the headings as given below:

4.1 Phenotypic characteristics

4.2 Morphometric characteristics

4.3 Floral characteristics

4.4 Seed studies

4.5 Nursery stage growth performance of seedling

4.6 Genetic estimates

4.7 Correlation studies

4.1 Phenotypic characteristics

Various phenotypic characters of selected tree viz; Tree height(m), diameter(cm), clear bole height(m), crown spread(cm), crown shape, bark characteristics were studied at all seed sources i.eChanger (S_1), Kosariyan (S_2),Samoh (S_3), Hiranagar (S_4), Jwalamukhi (S_5) and Sadwan (S_6).

Table 4 : Variation in phenotypic characters among different seed sources

Seed Sources	Tree height (m)	Clear bole height (m)	Crown spread (m)		Crown shape	Bark characteristics
			N-S	W-E		
Changer(S_1)	12.16	4.71	3.19	3.13	Oval	Greyish with vertical cracks
Kosariyan(S_2)	8.79	4.08	3.06	3.15	Oval and irregular	Greyish brown with vertical cracks
Samoh(S_3)	10.96	5.26	3.24	3.32	Oval and irregular	Greyish with vertical cracks
Hiranagar(S_4)	9.38	4.46	3.03	3.00	Irregular	Greyish with vertical cracks
Jawalamukhi(S_5)	7.21	3.32	2.88	2.81	Oval	Greyish with vertical cracks
Sadwan(S_6)	13.71	5.03	3.48	3.53	Round, oval and irregular	Reddish brown with vertical cracks
Mean	10.37	4.48	3.14	3.16		
$CD_{0.05}$	1.44	0.97	NS	NS		

4.1.1 Tree height (m)

The average height of the treein natural stands of six sources were found to range between 7.21 m to 13.71 m. Maximum tree height was found inSadwan (S_6) with value (13.71 m) and minimum was in Jwalamukhi (S_5) with value (7.21 m). Present findings are consistent with the findings of Page *et al.*(2020) in *Santalummacgregorii* where tree height varied between 8.2 m to 13.8 m. In present study there is consistent changes among tree height of mother trees representing different seed sources. Average tree height was recorded for source Sadwan of value 13.71 m. (Table 4)

4.1.2 Clear bole height

It is clear from the table 4 that maximum clear bole height was observed in S_3 with value 5.26 m followed by Sadwan (S_6) with 5.03 m and Changer (S_1) with value 4.71 m. Minimum clear bole height was observed in Jwalamukhi (S_5) with value 3.32 m. These findings are also consistent with findings of Page *et al*. 2020. where the minimum and maximum clear bole height ranged between 2.6 to 4.4 m.

a) Greyish with vertical cracks (S_1)

b) Greyish with prominent reddish vertical cracks (S_6)

c) Greyish brown with vertical cracks (S_2)

Plate 1: Variations in bark characteristics

4.1.3 Crown spread (m)

Crown spread (N-S) was found maximum in Sadwan (S_6) of value 3.48 m and minimum in Jwalamukhi (S_5) of value 2.88 m. Crown spread (E-W) was found maximum in Sadwan (S_6) with value 3.53 m and minimum in Jwalamukhi (S_5) with value 2.81m.

4.1.4 Crown shape

The crown shape of this species was found quite variable and was observed oval, round and irregular in different seed sources. In Changer (S_1), crowns of all selected ten trees were found oval. In Kosariyan (S_2) out of 10 trees, 7 trees were having oval crowns and rest had irregular type of crown. In Samoh (S_3), oval and irregular types of crown were observed. Six trees had oval type of crown and 4 trees had irregular type of crown. Irregular type of crowns were observed in Hiraganagar (S_4). In Jwalamukhi(S_5) only oval types of crown were observed. In Sadwan (S_6) round, oval and irregular types of crown were observed . Five trees were having oval, 3 trees were having round and rest two had irregular types of crowns. These variations in crown type among different seed sources might be due to crown competition, locality factors and environmental conditions.

4.1.5 Bark characteristics

The bark colour of selected individual trees in different seed sources was noticed to vary between grey brown with vertical cracks, grey with vertical cracks and greyish bark with prominent reddish vertical cracks. In S_1, S_3, $S_4$and S_5 greyish colored bark with vertical cracks were observed. In S_2, greyish brown colored bark with vertical cracks were observed. In S_6, greyish bark with prominent reddish vertical cracks were observed (Table 4).

4.2 MORPHOMETRIC CHARACTERISTICS

Different morphometric characteristics of leaves were studied from different seeds sources to observe the variations in leaf length, leaf width, leaf colour, leaf area and leaf shape (Plate 2) and are presented in Table 5.

4.2.1 Leaf length (cm)

It is clear from the table 5 that leaf length varied from 6.18 -7.36 cm. Maximum leaf length was observed in Jwalamukhi (S_5) of value 7.36 cm which is statistically at par with

Kosariyan (S_2) with value 7.06 cm. Minimum leaf length was observed in S_4 of value 6.18 cm. In the present study there is uniform variability in the leaf length of mother trees of different seed sources. These finding were similar with findings of Fiani and Yuliah (2011) and Page *et al.* 2021.

Table 5: Variation in morphometric characters among different seed sources

Seed Sources	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Leaf color	Leaf shape
Changer (S_1)	6.95	2.87	19.72	Yellow green group (147A)	Oval, Lanceolate
Kosariyan (S_2)	7.06	2.79	22.91	Yellow green group (146B)	Oval, Lanceolate
Samoh (S_3)	6.74	2.81	19.06	Yellow green group (146A)	Oval, Lanceolate
Hiranagar (S_4)	6.18	2.51	19.13	Yellow green group (146B)	Oval Lanceolate
Jawalamukhi (S_5)	7.36	2.67	21.70	Green group (137A)	Oval, Lanceolate
Sadwan (S_6)	6.92	3.03	21.76	Yellow green group (146A)	Oval, Lanceolate
Mean	6.87	2.78	20.71		
$CD_{0.05}$	0.31	NS	NS		

4.2.2 Leaf width(cm)

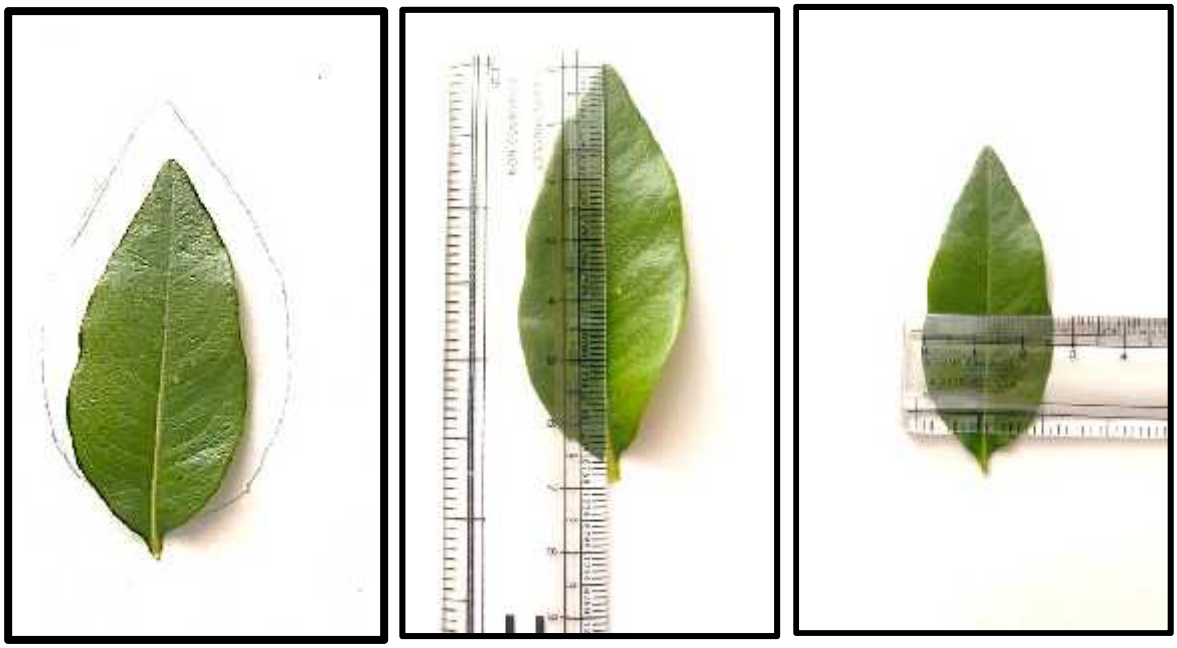
The results for the leaf width were found non-significant irrespective of the variations in leaf shape. The values for leaf width ranged between 2.51cm (S_4) to 3.03 cm (S_6) among different seed sources.

4.2.3 Leaf area (cm^2)

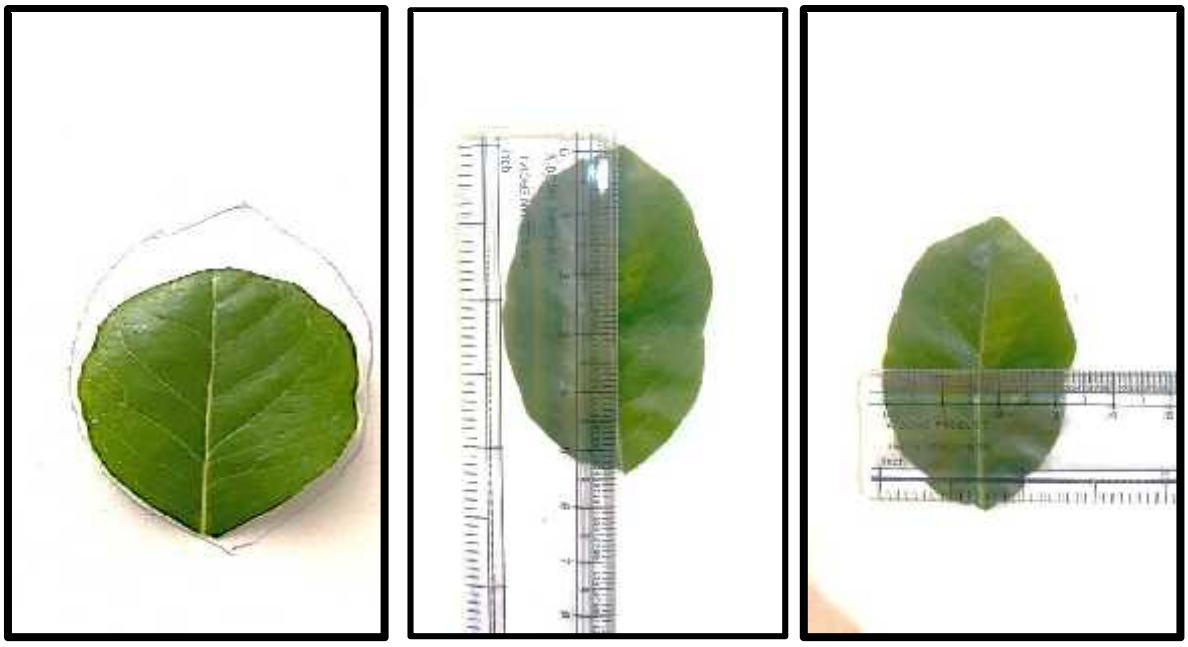
Regarding the leaf area, the non-significant variations were found between different seed sources but higher values were recorded from Kosariyan (S_2) with value of 22.91cm^2 and in Samoh (S_3)with value of 19.06 cm^2.

4.2.4 Leaf color

The leaf color was observed with Yellow green group (147 A, 146 B, 146 A) and green group (137 A). In seed source namely Jwalamukhi, leaves with green group (137 A) was observed whereas remaining seed sources shows leaf color of yellow green group (Table 5).



a) Lanceolate



b) Ovate

Plate 2: Leaf characteristics

4.2.5 Leaf shape

Oval and lanceolate type of leaves were observed within trees among different seed sources. Observation showed that form of leaves varies between flat and wavy. This might be due to environmental reasons, seasonal changes and shade from other trees. These findings were similar with the findings of Fiani and Yuliah (2011) in which variations were observed both among leaves within each individual and between individuals within provenances.

4.3 FLORAL CHARACTERISTICS

The salient features on floral and reproductive biology were studied among three mother trees (m_1, m_2 and m_3) at Nauni campus.

4.3.1 Flower size

All flowers observed were about 4-6 mm across, reddish purple, in axillary and terminal paniculate cymes. Perianth was observed simple and very rarely doubled. The tube wholly or partially adnate to the ovary and confluent with pedicel. Stamens were observed as many as perianth - lobes and opposite to them, inserted at the base or within the free part of them. Inferior type of ovary was observed.

4.3.2 Flower type

Hermaphrodite flowers were observed for different three mother trees.

4.3.3 Pollen vectors

The main primary pollinators identified were honey bee, dragon fly, beetle, Dipetran fly, black ants. In *Santalum album* L. Pollinators namely red ant, black ant, Indian honey bee, blue bottle fly, painted lady fly were reported by Baskorowati (2011) and Krishnakumar*et al*. (2018).

4.3.4 Vector visitation

Visitation timing of pollen vectors were observed for ten days during last week of August 2020 to first week of September 2020 in morning (9 am – 11am) and evening (5 pm - 7 pm). During these days insect visiting time was found to vary with different pollinators. Italian honey bee,dragon fly, blue bottle fly visited the flower only in morning time. Black ant and beetle visited the flowers in both morning or evening time. (Table 6) These observation are similar with the observations of Krishnakumar*et al*.(2018a).

Table 6: Pollinators visiting time in *Santalum album* L. at UHF conditions

Visiting days	Pollen vectors									
	Black ant		Italian honey bee		Blue bottle fly		Dragon fly		Beetle	
	Morning (9 am – 11am)	Evening (5 pm - 7pm)	Morning (9 am - 11am)	Evening (5 pm - 7pm)	Morning (9 am - 11am)	Evening (5 pm - 7 pm)	Morning (9 am - 11am)	Evening (5 pm - 7pm)	Morning (9 am - 11am)	Evening (5 pm - 7pm)
Day1	√	-	√	-	√	-	√	-	-	
Day2	√	-	√	-	√	-	√	-	√	
Day3	-	-	√	-	√	-	-	-	-	
Day4	√	-	√	-	-	-	-	-	-	
Day5	√	-	√	-	-	-	-	-	-	
Day6	√	-	√	-	-	-	-	-	-	
Day7	√	-	√	-	-	-	-	-	-	
Day8	√	-	√	-	√	-	-	-	-	√
Day9	√	-	√	-	-	-	√	-	-	√
Day10	√	√	√	-	-	-	-	-	-	
Morning(%)	80		100		40		30		10	
Evening (%)	10		-		-		-		20	
No visit (%)	10		100		60		70		70	

4.3.5 Pollinator studies

Observation on time spend (range) on flower is presented in Table 7 and showed that beetle spend more time on the flower (30-40 seconds) as compared to rest of the pollinators and dragon fly spend least time on the flower (0-5 seconds).

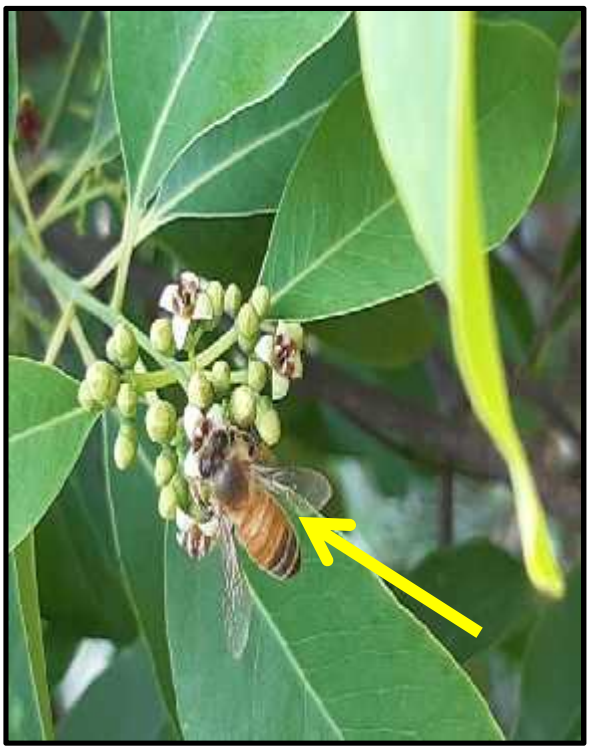
Table 7: Variation for pollinators time spent / flower in *Santalum album* L. at different days of flowering

Visiting time	Pollinators time spend on flower (seconds)				
	Black ant	Italian honey bee	Blue bottle fly	Dragon fly	Beetle
Day1	5-20	10-20	10-20	5-10	-
Day2	15-20	5-15	5-10	0-5	30-40
Day3	-	10-15	10 -15	-	-
Day4	10-15	15-20	-	-	-
Day5	15-25	10-15	-	-	-
Day6	10- 20	5-15	-	-	-
Day7	15-20	0-15	-	-	-
Day8	20-30	20-30	5-15	-	25-35
Day9	15-20	5-20	-	10-15	25-40
Day10	5-15	10-20	-	-	-

d) Beetle

e) Blue bottle fly

Plate 3: Pollinators on *Santalum album*



a) Italian honey bee

b) Dragon fly

c) Black ant

Plate 3 (Contd.) : Pollinators on *Santalum album*

4.3.6 Pollen viability %

There were no significant differences recorded in mother trees, floral bud color and their interactions for pollen viability %. Among mother trees, percent of pollen viability varied from 93.02 to 94.71 percent. Among floral bud color, pollen viability percent varied from 93.19 to 94.75 percent. In interaction between mother trees and floral bud color, pollen viability ranged between 92.62 to 95.93 percent.

Table 8 :Pollen viability percentage in *Santalum album* L. flowers

Mother tree	Pollen viability %			
	$Stage_1$ (%)	**$Stage_2$ (%)**	**$Stage_3$ (%)**	**Mean**
m_1	92.62 (9.62)	93.72 (9.68)	93.02 (9.64)	93.12 (9.65)
m_2	93.62 (9.68)	95.93 (9.79)	93.39 (9.66)	94.31 (9.71)
m_3	94.06 (9.70)	94.58 (9.73)	93.16 (9.65)	93.93 (9.69)
Mean	93.43 (9.67)	94.75 (9.73)	93.19 (9.65)	

	$CD_{0.05}$
m	NS
f	NS
m x f	NS

m: Mother tree ,f: Floral bud colour , T: Temperature , $Stage_1$: Dull green, $Stage_2$: Pale green , $Stage_3$: Reddish

The values in parenthesis are square root transformed values.

4.3.6 Pollen collection and storage

Pollens were extracted from dull green buds, pale green flower and reddish flowers during its flowering months of September – December and stored in desiccators at different temperatures viz. 4°C and - 20°C. Pollen viability were studied in 1 percent acetocarmin solution for 3 months after storage in the interval of 1 month.

4.3.6.1 Pollen viability % from different floral stages after 1 month of storage at different temperature

It is clear from the table 9 that there were no significant differences in pollen viability among different mother tree andfloral bud color. Viability percent for mother trees ranges between 93.42 to 94.40 percent whereas amongfloral bud color, viability percent ranges

Table:**9 Pollen viability (%) from different floral stages after 1 month storage at different temperatures**

Mother tree number	Temperature								$Stage_1$	$Stage_2$	$Stage_3$	Overall Mean
	(4°C)				(-20°C)							
	$Stage_1$	$Stage_2$	$Stage_3$	Mean	$Stage_1$	$Stage_2$	$Stage_3$	Mean				
m_1	93.33 (9.66)	92.75 (9.63)	93.51 (9.67)	93.20 (9.65)	94.59 (9.73)	95.42 (9.77)	93.85 (9.69)	94.62 (9.73)	93.96 (9.69)	94.08 (9.70)	93.68 (9.68)	93.91 (9.69)
m_2	92.41 (9.61)	95.02 (9.75)	92.83 (9.63)	93.42 (9.67)	93.62 (9.68)	93.15 (9.65)	93.48 (9.67)	93.42 (9.67)	93.02 (9.64)	94.09 (9.70)	93.15 (9.65)	93.42 (**9.67**)
m_3	94.84 (9.74)	94.65 (9.73)	92.51 (9.62)	94.00 (9.70)	95.60 (9.78)	94.58 (9.73)	94.18 (9.70)	94.79 (9.74)	95.22 (9.76)	94.61 (9.73)	93.35 (9.66)	94.40 (**9.72**)
Mean	93.53 (9.67)	94.14 (9.70)	92.95 (9.64)	93.54 (9.67)	94.60 (9.73)	94.38 (9.71)	93.84 (9.69)	94.28 (9.71)	94.07 (9.70)	94.26 (9.71)	93.39 (9.66)	

$CD_{0.05}$	
m	NS
f	NS
T	0.04
m x f	NS
m×T	NS
f×T	NS
m×f×T	NS

m: Mother tree ,f: Floral bud colour , T: Temperature , Stage $_1$: Dull green, Stage $_2$: Pale green , $Stage_3$: Reddish
The values in parenthesis are square root transformed values.

1. Immature bud **2. Pale green flower** **3. Reddish color flower**

Plate 4: Stages of flower development in *Santalum album*

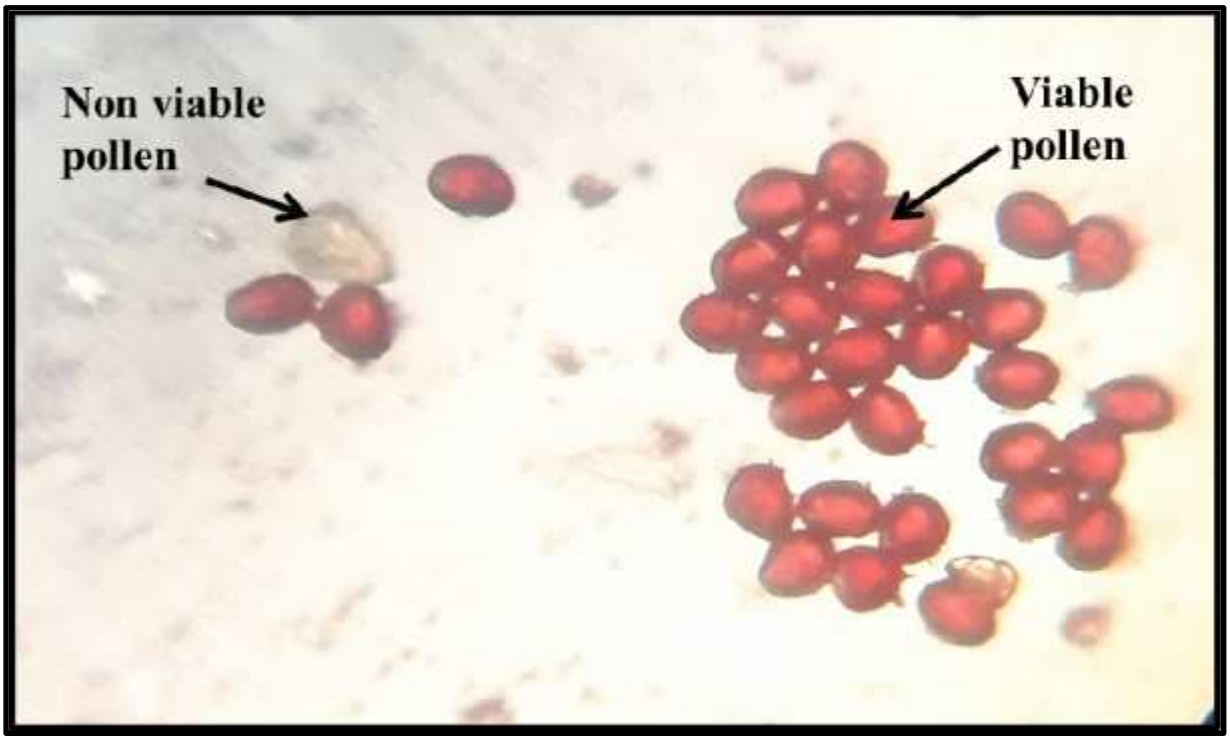


Plate 5: Pollen viability in *Santalum album*

between 93.39 to 94.07 percent. In case of temperature, significant difference was found. Higher viability percent was recorded for T_2(- 20°C) with 94.28% as compared to T_1(4°C) with 93.54 %. In case of m x f interaction, m × T, f × T and m × f × T interaction, no significant difference were observed for pollen viability. Viability percent for m × f interaction ranges between 93.02 to 95.22 percent whereas viability percent for m × temperature for 4 °C viability percent ranges between 93.20 to 94.00 percent and for -20 °C viability percent ranges between 93.42 to 93.47 percent. Viability percent for f× T interaction for 4°C ranges between 92.95 to 94.14 percent and for -20 °C viability percent ranges between 93.84 to 94.60 percent. In m × f × T interaction viability percent for 4° C ranges between 92.41 to 95.02 percent and for - 20° C ranges between 93.15 to 95.60 percent.

4.3.6.2 Pollen viability % from different floral stages after 2 month of storage at different temperature

It is clear from the table 10 that there were no significant differences in pollen viability among different mother trees. Viability percent for mother trees ranges between 88.97 percent to 94.40 percent whereas amongfloral bud color, maximum viability percent was recorded for $stage_3$ (90.23 %)and minimum was recorded for $stage_2$(88.05%), however the results for pollen viability were significant for floral bud color and storage temperature. Among two temperatures viz., 4°C and -20°C, viability percent varied from 89.50 to 90.48 percent. Viability percent for m × f interaction, ranges between 87.01 to 90.59 percent whereas viability percent for m × T for 4 °C viability percent ranges between 89.13 to 90.20 percent and for -20 °C viability percent ranges between 87.75 to 89.17 percent. In case of f × T interaction for 4°C, maximum percent of pollen viability was recorded for $stage_1$× T_1(90.42 %) and minimum was recorded for $stage_2$ × T_1(88.10%) whereas for -20 °C, maximum percent of pollen viability was recorded for $stage_3$ × T_2 (90.48 %) and minimum was recorded for $stage_1$ × T_2 (87.38%). In f × m × T interaction viability percent for 4° C ranges between percent 85.64 to 91.90 and for - 20° C ranges between 85.48 to 90.20 percent.

4.3.6.3 Pollen viability % from different floral stages after 3 month of storage at different temperature

There was no significant differences in pollen viability among different mother trees and floral bud color (Table 11). Viability percent for mother tree ranges between 81.48 to 86.63 percent whereas amongfloral bud color, viability percent ranges between 83.92 to

Table:10 Pollen viability (%) from different floral stages after 2 months storage at different temperatures

Mother tree number	Temperature								$Stage_1$	$Stage_2$	$Stage_3$	Overall Mean
	(4°C)				(-20°C)							
	$Stage_1$	$Stage_2$	$Stage_3$	Mean	$Stage_1$	$Stage_2$	$Stage_3$	Mean				
m_1	91.90 (9.59)	85.64 (9.25)	89.97 (9.49)	89.17 (9.44)	88.48 (9.41)	88.38 (9.40)	90.65 (9.52)	89.17 (9.44)	90.19 (9.50)	87.01 (9.33)	90.31 (9.50)	89.17 (9.44)
m_2	89.38 (9.48)	89.28 (9.45)	88.73 (9.42)	89.13 (9.44)	88.23 (9.39)	87.80 (9.37)	90.82 (9.53)	88.95 (9.43)	88.81 (9.42)	88.54 (9.41)	89.78 (9.47)	89.04 (9.44)
m_3	89.98 (9.48)	89.39 (9.45)	91.21 (9.55)	90.20 (9.50)	85.43 (9.24)	87.84 (9.37)	89.96 (9.48)	87.75 (9.37)	87.71 (9.36)	88.62 (9.41)	90.59 (9.52)	88.97 (9.43)
Mean	90.42 (9.51)	88.10 (9.39)	89.97 (9.49)	89.50 (9.49)	87.38 (9.35)	88.01 (9.38)	90.48 (9.51)	88.62 (9.41)	88.90 (9.43)	88.05 (9.38)	90.23 (9.50)	

	$CD_{0.05}$
m	NS
f	0.08
T	NS
m x f	NS
m×T	NS
f×T	0.11
m×f×T	NS

m: Mother tree ,f: Floral bud colour , T: Temperature , Stage $_1$: Dull green, Stage $_2$: Pale green , $Stage_3$: Reddish
The values in parenthesis are square root transformed values.

Table:11 Pollen viability (%) from different floral stages after 3 months storage at different temperatures

Mother tree number	Temperature								$Stage_1$	$Stage_2$	$Stage_3$	Overall Mean
	(4°C)				(-20°C)							
	$Stage_1$	$Stage_2$	$Stage_3$	Mean	$Stage_1$	$Stage_2$	$Stage_3$	Mean				
m_1	85.04 (9.66)	86.14 (9.63)	84.37 (9.67)	85.18 (9.65)	85.89 (9.73)	84.56 (9.77)	82.95 (9.69)	84.46 (9.73)	85.46 (9.69)	85.35 (9.7)	83.66 (9.68)	84.82 (9.69)
m_2	86.68 (9.61)	89.75 (9.75)	88.10 (9.63)	88.18 (9.67)	80.79 (9.68)	84.30 (9.65)	85.15 (9.67)	83.41 (9.67)	83.73 (9.64)	87.03 (9.7)	86.63 (9.65)	85.80 (9.67)
m_3	83.95 (9.74)	87.08 (9.73)	85.62 (9.62)	85.55 (9.7)	85.57 (9.78)	85.70 (9.73)	77.35 (9.7)	82.87 (9.74)	84.76 (9.76)	86.39 (9.73)	81.48 (9.66)	84.21 (9.72)
Mean	85.22 (9.67)	87.66 (9.7)	86.03 (9.64)	86.30 (9.67)	84.08 (9.73)	84.85 (9.71)	81.82 (9.69)	83.58 (9.71)	84.65 (9.7)	86.25 (9.71)	83.92 (9.66)	

$CD_{0.05}$	
m	NS
f	NS
T	0.04
m x f	NS
m×T	NS
f×T	NS
m×f×T	NS

m: Mother tree ,f: Floral bud colour , T: Temperature , Stage $_1$: Dull green, Stage $_2$: Pale green , $Stage_3$: Reddish
The values in parenthesis are square root transformed values.

86.25 percent. In case of temperature, significant difference was found. Maximum viability percent was recorded for T_1 (4°C) with 86.30 % as compared to T_2 (-20 °C) with 83.58 %. In case of m x f, m × T, f × T and m × f × T interaction, no significant difference were observed for pollen viability percent. Viability percent for m × f interaction ranges between 81.48 to 87.03 percent whereas viability percent for m × T for 4 °C viability percent ranges between 85.22 to 87.66 percent and for -20 °C viability percent ranges between 81.82 to 84.85 percent. Viability percent for f × T interaction for 4°C ranges between 85.18 to 88.18 percent and for -20 °C viability percent ranges between 77.35 to 85.15 percent. In f × m ×T interaction viability percent for 4° C ranges between 83.95 to 89.75 percent and for - 20° C ranges between 77.35 to 85.89 percent.

4.4 SEED PARAMETERS

4.4.1 Seed weight (g)

From each seed source weight of 100 seeds were taken. It is clear from the table 12 that there is a significant differences among different seeds sources. Maximum seed weight was recorded in Kosariyan (14.58 g) which are statistically at par with Hiranagar (14.32 g) and Changer (14.14 g). Minimum seed weight was recorded in Jwalamukhi (10.56 g). These findings were found similar with the findings of Manonmani and Vanangamudi (2003) &Batabyal*et al*. (2014).

4.4.2 Seed diameter (mm)

Seed diameter (mm) was found significantly different for seed sources. Maximum seed diameter was recorded in Kosariyan (S_2) with mean value of 6.99 mm which was statistically at par with S_6, S_4 and S_1 with mean value of diameter as 6.80 mm, 6.77 mm and 6.76 mm respectively. Minimum seed diameter was recorded in Jwalamukhi (S_5) with value of 6.32 mm which was statistically at par with Samoh (S_3) with mean value of 6.38 mm. (Table 12).

4.4.3 Seed color

Seed color was observed with Brown group (200C and 200D) and Grey brown group (N199C and N 199D). In sources namely Changer (S_1), Kosariyan (S_2) and Samoh (S_3) seeds

with brown group were observed, whereas remaining seeds sources showed seed color of Grey brown group.

4.4.4 Seed treatment - Seeds were treated with GA_3@500ppm for better germination of seeds.

Table 12: Variation in seed characters among different seed sources

Seed source	Seed weight(g)	Seed diameter(mm)	Seed color
Changer (S_1)	14.14	6.76	Brown group (200C)
Kosariyan (S_2)	14.58	6.99	Brown group (200D)
Samoh (S_3)	13.16	6.38	Brown group (200C)
Hiranagar (S_4)	14.32	6.77	Grey brown group (N199D)
Jawalamukhi (S_5)	10.56	6.32	Grey brown group (N199C)
Sadwan (S_6)	13.16	6.80	Grey brown group (N199C)
Mean	13.32	6.67	
$CD_{0.05}$	0.73	0.26	

4.4.5 Seed germination (%)

Seeds of *Santalum album* L. were depulped, cleaned, graded, pre-treated with GA_3@ 500 ppm for 24 hours and sown in polybags during the month of April and May in three replications under glass house conditions. Among seed sources, maximum germination percentage was recorded for Changer (S_1) with the mean value of 72.22 % which was statistically at par with Samoh (S_3) with mean value of 67.78 % and Kosariyan (S_2) with mean value of 65.56 %. Minimum germination percentage was recorded for Hiranagar (S_4) with mean value of 25.00 % which was statistically at par with Jwalamukhi (S_5) with mean values of 28.33 %. Among two sowing dates, no significant differences were observed and more germination percentage (51.85 %) was recorded for d_2 and less was for d_1(48.33%). In interaction between seed source x sowing dates, seed germination percent ranged between 23.33 to 75.56 % . These findings were similar with the findings of Das and Tah (2013), Batabyal*et al*. (2014) and Jagdish*et al*. (2008).

4.4.6 Germination energy index(%)

It is clear from the Table 13 that in different seed sources maximum germination energy was found for Sadwan (S_6) with mean value of 34.42 % and minimum was found for

Hiranagar (S_4) with the mean value of 19.25 %. Among two sowing dates, d_1(35.00 %) had more germination energy as compared to d_2(14.11%). In interaction between seed sources x sowing dates, no significant difference was found.

Table 13:Variation in Germination parameters among different seed sources

Seed sources	Germination percentage (%)			Germination energy(%)		
	d_1	**d_2**	**Mean**	**d_1**	**d_2**	**Mean**
Changer(S_1)	68.89 (56.39)	75.56 (60.51)	72.22 (58.45)	38.10	18.42	28.26
Kosariyan(S_2)	68.89 (56.11)	62.22 (52.41)	65.56 (54.26)	33.81	10.53	22.17
Samoh(S_3)	62.22 (52.07)	73.33 (59.00)	67.78 (55.54	31.43	9.21	20.32
Hiranagar(S_4)	26.67 (30.28)	23.33 (28.07)	25.00 (29.17)	26.67	11.84	19.25
Jawalamukhi(S_5)	26.67 (30.78)	30.00 (32.99)	28.33 (31.88)	35.71	16.23	25.97
Sadwan(S_6)	36.67 (36.92)	46.67 (42.98)	41.67 (39.95)	44.29	24.56	34.42
Mean	48.33 (43.76)	51.85 (45.99)		35.00	14.11	
$CD_{0.05}$						
Seed source(S)		9.28			5.68	
Sowing date(d)		NS			3.28	
S x d		NS			NS	

S: Seed sources, d: Sowing dates, d_1: First date of sowing, d_2: Second date of sowing.
The values in parenthesis are arc signed transformed values.

4.4.7 In vitro germination of seeds

The seed coat was removed under aseptic conditions and the seeds was pre- treated with 4mMgibberellic acid for 12 hours. After pre sowing treatments, all treated seeds were washed with Tee - pole under running water and treated with 2% Bavestin before washed with autoclave distilled water for 2- 3 times, then cultured on MS media and autoclaved sand during the month of March 2021. Seeds cultured in autoclaved sand were placed in germinator for 30 days with temperature 25^{o}C and humidity 75-85 %.

Plate 6: Seed color variation among different seed sources

In vitro germination of seeds in MS media

In vitro germination of seeds in autoclaved sand

Plate 7: In vitro seed germination of *Santalum album*

Table 14: In vitro germination of seeds among different seed sources in two sowing media

Seed sources	Time taken for Germination(days)			Germination percentage (%)		
	MS media (S_1)	Sand (S_2)	Mean	MS media (S)	Sand (S_2)	Mean
Changer (S_1)	20.00	17.50	18.75	38.89 (38.49)	77.77 (62.15)	58.33 (50.32)
Kosariyan (S_2)	14.17	14.83	14.50	38.89 (38.49)	27.77 (31.53)	33.33 (35.01)
Samoh (S_3)	17.78	19.50	18.64	44.44 (41.74)	61.11 (51.47)	52.78 (46.60)
Hiranagar (S_4)	22.60	16.50	19.55	55.55 (48.22)	55.55 (48.22)	55.55 (48.22)
Jawalamukhi (S_5)	16.33	21.50	18.92	66.66 (54.71)	66.66 (54.71)	66.66 (54.71)
Sadwan (S_6)	11.17	14.50	12.83	33.33 (35.25)	44.44 (41.74)	38.89 (38.49)
Mean	17.01	17.39		46.29 (42.82)	55.55 (48.30)	

$CD_{0.05}$

Seed sources (S)	0.90	8.39
Sowing media (s)	NS	4.84
S x s	NS	11.86

S: Seed sources, s: Sowing media, s_1: MS media, s_2: sand
The value in parenthesis are arc signed transformed values.

4.4.7.1 Time taken for germination

It is clear from the table 14 that among seed sources, maximum time taken for germination was recorded in Hiranagar (19.55 days) which was statistically at par with Jwalamukhi and Changer with mean value of 18.92 and 18.75 days. Minimum time recorded for germination in Samoh (S_3) with mean value of 12.83 days. Among sowing media, there was no significant difference recorded. In interaction between sources x sowing media, maximum time taken for germination was recorded in S_4s_1 with the mean value of 22.60 days and minimum was recorded in $S_6s_1$with the mean value of 11.17 days.

4.4.7.2 Seed germination(%)

Among seed sources, maximum germination percentage was recorded for Jwalamukhi (S_5) with mean value of 66.66 % which was statistically at par with S_1 (58.33%) and S_4(55.55

%). Minimum germination percentage was recorded for Kosariyan (S_2) with mean value of 38.49 %. Between two sowing media, s_2 (autoclaved sand) had more germination percentage (55.55%) as compared to s_1(46.29 %). In interaction between seed source x sowing media, maximum germination percentage was found for $S_1s_2$with the mean value of 77.77 % and minimum percentage was found for S_2s_2 with the mean value of 27.77 %.

4.5 NURSERY STAGE GROWTH PERFORMANCE OF SEEDLING

The seedlings of six seed sources were raised during the months of April and May, 2020 in polybags maintained under glasshouse conditions. Nursery growth performance of seedling were studied for seedling height, collar diameter, leaf length, leaf width, leaf color, number of leaves and nodes per seedling. The data was recorded after three months, six months, nine months and one year of age to record variation between different seed sources.

4.5.1 Seedling height(m)

4.5.1.1 Seedling height at the age of 3 months

It is evident from the table 15 that there was no significant differences recorded among seed sources, sowing dates and interaction between seed sources and sowing dates. Among seed sources, seedling height ranged between 9.47 to 10.53 cm whereas among two sowing dates $d_1$showed seedling height as 10.11 cm and d_2 as 9.35 cm. In interaction between seed sources × sowing date interaction, seedling height ranged between 8.48 to 11.32 cm.

4.5.1.2 Seedling height at the age of 6 months

A perusal of data presented in table 15 indicated that significant difference was recorded between sowing dates. Among seed sources, seedling height varied from 12.07 to 13.01 cm. More mean seedling height was recorded in $d_1$with the value of 13.85 cm as compared to d_2(10.90 cm). In source x sowing date interaction, seedling height varied from 9.89 to 14.29 cm.

4.5.1.3 Seedling height at the age of 9 months

It is clear from the table that there was significant differences between the seed sources and sowing dates. Mean values among seed sources revealed that Jwalamukhi (S_5) seed source had maximum seedling height with 16.04 cm which is statistically at par with

Table :15 Seedling height (cm) of *Santalum album*seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer (S_1)	10.00	9.01	9.51	13.03	11.81	12.42	15.83	14.03	14.93	18.22	16.83	17.53
Kosariyan (S_2)	10.47	8.48	9.47	14.13	10.38	12.26	15.46	12.13	13.79	18.63	15.57	17.10
Samoh (S_3)	9.75	11.32	10.53	14.29	11.73	13.01	17.36	12.93	15.15	20.12	15.98	18.05
Hiranagar (S_4)	9.89	9.06	9.49	13.96	9.89	11.93	16.17	11.24	13.71	18.41	14.96	16.68
Jawalamukhi (S_5)	9.88	9.70	9.79	13.95	11.19	12.57	16.85	15.22	16.04	19.20	15.59	17.40
Sadwan (S_6)	10.66	8.56	9.61	13.77	10.36	12.07	15.93	11.72	13.82	18.51	24.73	21.62
Mean	10.11	9.35		13.85	10.90		16.27	12.88		18.85	17.28	

$CD_{0.05}$				
Source (S)	NS	NS	1.70	2.28
Date (d)	NS	0.96	0.98	1.32
S×d	NS	NS	NS	3.23

S: Seed source, d: Date of sowing, d_1: First date of sowing (April), d_2: Second date of sowing (May)

Samoh with height 15.15 cm and Changer (14.93 cm). Hiranagar (S_4) had minimum seedling height with the mean value of 13.71cm which is statistically at par with Kosariyan and Sadwan with height 13.79 and 13.82 cm. Among two sowing dates, more seedling height was found in d_1 with value of 16.27 cm as compared to d_2 with value of 12.88 cm. In seed source x sowing date interaction seedling height varied from 11.24 to 17.36 cm.

4.5.1.4 Seedling height at the age of one year

It is clear from the table that there was significant difference found between seed sources, sowing dates and their interactions. Mean values among seed sources revealed that Sadwan (S_6) seed source had maximum seedling height as 21.62 cm followed by Samoh and Changer with height 18.05 cm and 17.53 cm respectively.Hiranagar (S_4) had minimum seedling height with the mean value of 16.68 cm which are statistically at par with Kosariyan and Jwalamukhi with 17.10 and 17.40 cm. Among two sowing dates, more seedling height was found in d_1(18.85 cm) as compared to d_2(17.28 cm) . In seed source x sowing date interaction, maximum seedling height was recorded for S_3d_1 with the mean value of 20.12 cm and minimum was recorded for S_4d_2 with the mean value of 14.96 cm.The results of the study are consistent with the findings of Krishnakumar*et al*. (2018 a) who studied seedling growth parameters in different seed sources of *Santalum album* L.

4.5.2 Collar diameter (mm)

Seedling raised in the glass house during two sowing dates were observed to record the diameter attained by them for 3 months, 6 months, 9 months and at the age of 1 year.

4.5.2.1 Collar diameter at the age of 3 months

It is clear from the table 16 that there was significant differences recorded between seed sources, sowing dates and interaction between seed sources and sowing dates. Among seed sources maximum collar diameter was recorded for Sadwan (S_3) with the value of 1.51 mm which was statistically at par with Kosariyan (1.47 mm) and Sadwan(1.44 mm). Minimum collar diameter was recorded for Changer (S_1) with the value of 1.18 mm. More collar diameter was recorded in $d_1$with the value of 1.51 mm as compare to d_2(1.26 mm). In seed source x sowing date interaction, maximum seedling height was recorded in S_2d_1 with the value of 1.71 mm and minimum was recorded for S_1d_2 with the value of 0.97 mm.

Table:16 Collar diameter (mm) of *Santalum album* seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer(S_1)	1.40	0.97	1.18	2.07	1.15	1.61	2.69	2.41	2.55	3.33	3.08	3.20
Kosariyan(S_2)	1.71	1.23	1.47	2.19	2.53	2.36	2.75	1.56	2.16	3.18	2.49	2.84
Samoh(S_3)	1.70	1.32	1.51	2.39	1.16	1.77	2.76	1.52	2.14	3.33	2.69	3.01
Hiranagar(S_4)	1.54	1.22	1.38	2.07	0.86	1.46	2.37	1.46	1.92	2.87	2.53	2.70
Jawalamukhi(S_5)	1.35	1.29	1.32	1.72	1.14	1.43	2.59	2.24	2.42	3.36	2.85	3.11
Sadwan(S_6)	1.35	1.53	1.44	1.83	1.13	1.48	2.38	2.08	2.23	3.19	2.70	2.95
Mean	1.51	1.26		2.05	1.33		2.59	1.88		3.21	2.72	

$CD_{0.05}$				
Source (S)	0.18	NS	0.30	0.32
Date (d)	0.10	0.52	0.17	0.19
S×d	0.25	NS	0.42	NS

S: Seed source, d: Date of sowing, d_1: First date of sowing (April), d_2: Second date of sowing (May)

4.5.2.2 Collar diameter at the age of 6 months

Table showed that seed sources had non-significant differences for collar diameter however, maximum collar diameter was recorded for Sadwan (S_3) with the value of 2.36 mm and minimum collar diameter was recorded for Changer (S_5) with the value of 1.43 mm. More collar diameter was recorded in $d_1$with the value of 2.05 mm as compared to d_2(1.33 mm). In source x sowing date interaction, collar diameter ranges between 0.86 mm to 2.53 mm.The results of the study are consistent with the findings of Krishnakumar*et al*. (2018).

4.5.2.3 Collar diameter at the age of 9 months

Mean values among seed sources revealed thatChanger (S_1) had maximum seedling height with 2.55 mm and statistically at par with Jwalamukhi (S_5) with 2.42 mm.Hiranagar had minimum seedling height with the mean value of 1.92 mm. Among two sowing dates, maximum collar diameter was found in $d_1$with the value of 2.59 mm as compared to $d_2$with the value of 1.88 mm. In seed source x sowing date interaction, maximum collar diameter was recorded for S_3d_1 with mean value of 2.76 mm and minimum was recorded for S_4d_2 with mean value of 1.46 mm.

4.5.2.4 Collar diameter at an age of 1 year

Mean values among seed sources revealed thatChanger (S_3) had maximum collar diameter with 3.01 mm and statistically at par with Jwalamukhi with 2.95 mm.Hiranagar (S_4) had minimum collar diameter with mean value of 2.70 mm. Among two sowing dates, more collar diameter was found in d_1(3.21 mm) as compare to d_2(2.72 mm). In source x sowing date interaction, collar diameter ranged between 2.49 to 3.36 mm and no significant differences were recorded.

4.5.3 Number of leaves

Number of leaves per seedling were recorded and observations were taken for 3 months, 6 months, 9 months and at the age of 1 year (Table 17).

4.5.3.1 Number of leaves at the age of 3 months

It is clear from the table 17 that there was no significant differences found among seed sources, sowing dates and their interactions. Number of leaves ranged between 8.81 to 9.88 among seed sources. d_1 had number of leaves 9.86 and d_2(9.03). In seed source x sowing date interactions number of leaves ranged between 8.29 to 11.18.

Table:17 Number of leaves (cm) of *Santalum album*seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer(S_1)	9.84	8.56	9.20	12.98	10.72	11.85	9.93	10.40	10.16	16.22	18.23	17.23
Kosariyan(S_2)	10.19	9.57	9.88	12.61	6.67	9.64	10.73	9.17	9.95	17.06	16.78	16.92
Samoh(S_3)	8.91	9.92	9.41	11.72	6.58	9.15	9.30	8.11	8.71	17.43	17.33	17.38
Hiranagar(S_4)	8.86	8.75	8.81	11.07	6.72	8.90	10.65	7.06	8.85	18.32	22.25	20.29
Jawalamukhi(S_5)	10.17	9.10	9.63	12.31	8.85	10.58	9.90	8.08	8.99	16.93	16.07	16.50
Sadwan(S_6)	11.18	8.29	9.74	10.72	9.46	10.09	10.74	8.76	9.75	23.14	16.38	19.76
Mean	9.86	9.03		11.90	8.17		10.21	8.59		18.18	17.84	

$CD_{0.05}$				
Source (S)	NS	1.83	NS	NS
Date (d)	NS	1.06	NS	NS
S×d	NS	NS	NS	4.18

S: Seed source, d: Date of sowing, d_1: First date of sowing (April), d_2: Second date of sowing (May)

4.5.3.2 Number of leaves at the age of 6 months

There was significant differences found between seed sources and sowing dates. Maximum number of leaves were recorded for Changer (S_1) with the mean value of 11.85 and minimum was recorded for Hiranagar (S_4) with mean value of 8.90 among seed sources. In d_1 more number of leaves were recorded with mean value of 11.90 as compared to d_2(8.17). In source x sowing date interaction, number of leaves ranged between 6.58 to 12.98.

4.5.3.3 Number of leaves at the age of 9 months

There was no significant differences found between seed sources, sowing dates and their interaction. Number of leaves ranged between 8.71 to 10.16 among seed sources. Number of leaves in $d_1$was 10.21 and in $d_2$was 8.59. In seed source x sowing date interactions number of leaves ranged between 8.59 to 10.21.

4.5.3.4 Number of leaves at an age of one year

It is clear from the table that there was no significant differences found among seed sources and sowing dates.Number of leaves ranged between 16.50 to 20.29 among seed sources. d_1 had number of leaves 18.18 and value for d_2 was 17.84. In the interaction between seed sources and sowing dates, maximum number of leaves were recorded for S_4d_2 with the mean value of 22.25 and minimum number of leaves were recorded for S_5d_2 with the value of 16.38. The results of the study are consistent with the findings of Krishnakumar*et al*. (2018).

4.5.4 Number of nodes

Total number of nodes per seedling were recorded and observations were taken for 3 months, 6 months, 9 months and at the age of 1 year (Table 18).

4.5.4.1 Number of nodes at the age of 3 months

It is evident from the table 18 that there was no significant differences was found among seed sources , sowing dates and their interactions. Number of nodes ranged between 4.60 to 5.14 among seed sources. d_1 had number of nodes 5.04 and d_2 had 4.71 number of nodes. In seed source x sowing date interactions, number of nodes ranged between 4.19 to 5.56.

Seedling germination

Seedling growth at 3 months

Seedling growth at 6 months

Seedling growth at 9 months

Seedling growth at one year

Plate 8: Seedling growth from germination to one year age

Table:18 Number of nodes of *Santalum album* seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer(S_1)	5.17	4.19	4.68	7.31	5.97	6.64	9.23	7.37	8.30	11.05	9.31	10.18
Kosariyan(S_2)	4.79	4.42	4.60	7.78	5.33	6.56	9.04	6.94	7.99	11.92	9.72	10.82
Samoh(S_3)	5.12	5.08	5.10	7.82	6.42	7.12	9.58	7.61	8.60	11.67	11.17	11.42
Hiranagar(S_4)	4.63	5.42	5.02	7.68	4.64	6.16	8.95	6.61	7.78	11.95	9.11	10.53
Jawalamukhi(S_5)	4.96	4.41	4.69	7.37	6.92	7.14	9.83	8.53	9.18	12.22	12.03	12.13
Sadwan(S_6)	5.56	4.71	5.14	7.24	6.47	6.85	8.76	7.78	8.27	10.88	11.16	11.02
Mean	5.04	4.71		7.53	5.96		9.23	7.47		11.62	10.42	

$CD_{0.05}$				
Source (S)	NS	NS	NS	NS
Date (d)	NS	4.25	0.67	0.93
S×d	NS	NS	NS	NS

S: Seed source, d: Date of sowing, d_1: First date of sowing (April), d_2: Second date of sowing (May)

4.5.4.2 Number of nodes at the age of 6 months

Data presented in table 18 showed that among seed sources, number of nodes ranged between 6.16 to 7.14. Among two sowing dates, more nodes per seedling were recorded in d_1 (7.53) as compared to d_2 (5.96).In source x sowing date interactions no significant differences were found, howevernumber of nodes ranged between 4.64 to 7.82.

4.5.4.3 Number of nodes at the age of 9 months

Data presented in table that there was no significant difference was found between seed sources. Number of nodes ranged between 7.78 to 9.18 among seed sources. Number of nodes for d_1 was found maximum with the mean value of 9.23 as compared to d_2 with the value of 7.47. In source x sowing date interaction, number of nodes ranged between 6.94 to 9.83.

4.5.4.4 Number of nodes at an age of 1 year

It is evident from the table that there was no significant differences found between seed sources and interaction between seed sources and sowing date and number of nodes ranged between 10.18 to 12.13 among seed sources. Number of nodes for d_1 was more with the mean value of 11.62 as compared to d_2 with the value of 10.42. In source x sowing date interaction, number of nodes ranged between 9.11 to 12.22.

4.5.5 Internodal length(cm)

Internodal length per seedling were recorded and observations were taken upto 1 year at an interval of three months (Table 19).

4.5.5.1 Internodal length at an age of 3 months

It is evident from the table 19 that there was no significant differences found among seed sources, sowing dates and their interactions. Internodal length ranged between 1.27 cm to 1.42 cm among seed sources. d_1 had internodal length (1.35 cm) and d_2 had internodal length 1.32 cm. In seed source x sowing date interaction internodal length ranged between 1.23 cm to 1.42 cm.

Table:19 Internodal length (cm)of *Santalum album* seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer(S_1)	1.31	1.35	1.33	1.39	1.25	1.32	2.08	1.41	1.74	1.96	2.06	2.01
Kosariyan(S_2)	1.34	1.28	1.31	1.32	1.40	1.36	1.30	1.52	1.41	1.79	2.08	1.94
Samoh(S_3)	1.41	1.43	**1.42**	1.31	1.18	1.24	1.31	1.36	1.34	1.85	1.86	1.86
Hiranagar(S_4)	1.30	1.22	**1.27**	1.31	1.20	1.26	1.42	1.46	1.44	1.87	2.04	1.96
Jawalamukhi(S_5)	1.35	1.42	1.39	1.41	1.22	1.32	1.33	1.31	1.32	1.84	1.91	1.87
Sadwan(S_6)	1.36	1.23	1.29	1.42	1.09	1.25	1.42	1.34	1.38	2.01	1.98	2.00
Mean	1.35	1.32		1.36	1.23		1.48	1.40		1.89	1.99	

$CD_{0.05}$				
Source (S)	NS	0.04	0.13	NS
Date (d)	NS	NS	0.07	NS
S×d	NS	0.02	0.18	0.24

S: Seed source, d: Date of sowing, d_1: First date of sowing (April), d_2: Second date of sowing(May)

4.5.5.2 Internodal length at the age of 6 months

Maximum mean value of internodal length was recorded for Kosariyan (S_2) with the value of 1.36 cm followed by Changer and Jwalamukhi with mean value of 1.32 cm and 1.32 cm. Minimum internodal length was recorded for Samoh (S_3) with the mean value of 1.24 cm which was statistically at par with Sadwan with mean value of 1.25 cm.d_1 had more internodal length (1.36 cm) as compared to d_2 (1.23 cm). In source x sowing date interaction, maximum number of leaves were recorded in S_6d_1 with the value of 1.42 cm and minimum was recorded for S_3d_2 with the value of 1.18 cm.

4.5.5.3 Internodal length at the age of 9 months

There was significant differences was found between seed sources, sowing dates and their interactions. Maximum internodal length was recorded for Changer(S_1) with the mean value of 1.74 cm and minimum was recorded for Jwalamukhi (S_5) with the mean value of 1.32 among seed sources. In d_1 more internodal length was recorded with the mean value of 1.48 cm as compared to d_2(1.40 cm). In seed source x sowing date interaction, maximum number of leaves were recorded in S_1d_1 with the value of 2.08 cm and minimum was recorded for S_2d_1 with the value of 1.30 cm.

4.5.5.4 Internodal length at the age of 1 year

There was no significant differences found between seed sources. Among seed sources internodal length varied between 1.86 cm to 2.01 cm whereas in two sowing dates $d_2$had 1.99 cm and d_1 had 1.89 cm internodal length. In seed source x sowing date interaction, internodal length varied between 1.79 cm to 2.08 cm.

4.5.6 Leaf length (cm)

Length of leaves of seedlings were recorded and observations were taken for 1 year at the interval of 3 months (Table 20).

4.5.6.1 Leaf length at the age of 3 months

In different seed sources, leaf length varied between 4.94 to 5.95 cm. Between two sowing dates,significant difference was found in sowing dates. More leaf length was recorded in d_2 (5.65 cm) as compared to d_1(5.10 cm). In interaction between seed source and sowing date leaf length ranged between 4.66 to 6.65 cm (Table 20).

Table:20 Leaf length (cm) of *Santalum album* seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer(S_1)	4.66	5.23	4.94	5.37	5.51	5.44	5.12	5.51	5.31	5.18	6.32	5.75
Kosariyan(S_2)	5.15	5.73	5.44	5.68	5.11	5.39	5.13	4.96	5.04	5.56	5.71	5.63
Samoh(S_3)	5.25	6.65	5.95	5.54	5.52	5.53	5.53	6.00	5.77	5.43	5.96	5.70
Hiranagar(S_4)	4.92	5.78	5.35	5.67	5.32	5.49	5.60	5.43	5.51	6.14	5.99	6.06
Jawalamukhi(S_5)	5.50	5.63	5.56	5.51	5.41	5.46	5.56	5.45	5.50	6.41	6.09	6.25
Sadwan(S_6)	5.16	4.90	5.03	5.26	5.40	5.33	5.39	6.28	5.83	6.33	5.92	6.13
Mean	5.10	5.65		5.50	5.38		5.39	5.61		5.84	6.00	

$CD_{0.05}$				
Source (S)	NS	NS	0.37	0.44
Date (d)	0.43	NS	0.22	NS
S×d	NS	NS	0.53	0.63

S: Seed source, d: Date of sowing, d_1: First date of sowing(April), d_2: Second date of sowing(May)

4.5.6.2 Leaf length at the age of 6 months

It is clear from the table 20 that there was no significant differences was found between seed sources, sowing dates and interaction between seed sources and sowing dates. Among seed sources, leaf length varied from 5.33 to 5.53 cm. d_1 had leaf length (5.50 cm) and d_2 had 5.38 cm. In interactions between seed sources and sowing date, leaf length varied between 5.11 cm to 5. 68 cm.

4.5.6.3 Leaf length at an age of 9 months

In different seed sources, maximum leaf length was recorded in Sadwan (S_6) with the mean value of 5.83 cm and statistically at par with S_3 and S_5 with the value of 5.77 and 5.50 cm. Minimum leaf length was recorded for Kosariyan (S_2) with the mean value of 5.04 cm followed by Changer and Hiranagar with 5.31 and 5.51. Among two sowing dates, in d_2 more leaf length was recorded with the value of 5.61 cm as compared to d_1(5.39). In interaction between seed source and sowing date, maximum leaf length recorded in S_6d_2 with the value of 6.28 cm and minimum was recorded for S_2d_2 with the value of 4.96 cm.

4.5.6.4 Leaf length at the age of 1 year

Data presented in table 20 revealed that among different seed sources mean value of jwalamukhi (S_5) had maximum leaf length (6.25 cm) which was statistically at par with Sadwan (S_6) and Hiranagar (S_4) with the value of 6.13 and 6.06 cm. Minimum leaf length was recorded for Kosariyan (S_2) with mean value of 5.63 cm which was statistically at par with Samoh (S_3) and Changer (S_1) with the value of 5.70 and 5.75 cm. Among two different sowing dates, second date of sowing (d_2) had leaf length (6.00 cm) and d_1(5.84 cm). In the interaction between seed sources and sowing dates, maximumleaf length was recorded for S_5d_1 with the mean value of 6.41 cm and minimum recorded for S_1d_1 with the value of 5.18 cm.

4.5.7 Leaf width (cm)

Width of leaves of seedlings were recorded and observations were taken upto 1 year at an interval of 3 months. (Table :21).

Table:21 Leaf width (cm) of *Santalum album* seedling at different age interval

Seed sources	Age of seedling (Months)											
	3 months			6 months			9 months			One year		
	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean	d_1	d_2	Mean
Changer(S_1)	1.20	1.35	1.28	1.39	1.32	1.35	1.24	1.35	1.30	2.24	1.97	2.11
Kosariyan(S_2)	1.26	1.33	1.29	1.36	1.27	1.31	1.36	1.29	1.33	2.36	1.83	2.10
Samoh(S_3)	1.22	1.38	1.30	1.30	1.27	1.28	1.27	1.25	1.26	2.20	1.88	2.04
Hiranagar(S_4)	1.22	1.18	1.20	1.23	1.41	1.32	1.28	1.44	1.36	2.20	2.03	2.12
Jawalamukhi(S_5)	1.48	1.19	1.34	1.27	1.39	1.33	1.33	1.89	1.61	2.51	2.10	2.30
Sadwan(S_6)	1.21	1.24	1.22	1.22	1.25	1.24	1.44	1.34	1.39	2.19	1.94	2.06
Mean	1.27	1.28		1.30	1.32		1.32	1.43		2.28	1.96	

$CD_{0.05}$				
Source (S)	NS	NS	0.18	NS
Date (d)	NS	NS	0.10	0.13
S×d	NS	NS	0.26	NS

S: Seed source, d: Date of sowing, d_1: First date of sowing (April), d_2: Second date of sowing (May)

4.5.7.1 Leaf width at the age of 3 months

Data presented in table 21 indicated that there was no significant differences found in seed sources, sowing dates and interaction between them. Leaf width ranged between 1.22 to 1.34 cm among seed sources. d_2 had leaf width (1.28 cm) and d_1 had 1.27 cm. In seed source x sowing date interactions leaf width ranged between 1.18 cm to 1.48 cm.

4.5.7.2 Leaf width at the age of 6 months

Data presented in table 21 indicated that there was no significant differences found in seed sources, sowing dates and interaction between them. Leaf width ranged between 1.24 to 1.35 cm among seed sources. d_2 had leaf width (1.32 cm) and d_1 had 1.30 cm. In seed source x sowing date interactions leaf width ranged between 1.22 cm to 1.41 cm.

4.5.7.3 Leaf width at the age of 9 months

Table indicated that significant differences found in seed sources, sowing dates and their interactions. Maximum leaf width was recorded for Jwalamukhi (S_5) with the mean value of 1.61 cm and minimum was recorded for Samoh (S_3) with the mean value of 1.26 cm in seed sources. Leaf width for d_2 was found more with the mean value of 1.43 cm as compared to d_1 with the value of 1.32 cm. In source x sowing date interaction, maximum leaf width was recorded in S_1d_1 with the value of 1.24 cm and minimum was recorded for S_5d_2 with the value of 1.89 cm.

4.5.7.4 Leaf width at the age of 1 year

Among different seed sources, leaf width ranged between 2.04 to 2.30 cm. Among two sowing dates, first date of sowing (d_1) had more leaf width (2.28 cm) as compared to d_1(1.96 cm). In the interaction between seed sources and sowing dates, leaf width ranges between 1.83 to 2.51 cm.

4.5.8 Leaf color

4.5.8.1 Leaf color at the age of 3 months

The leaf color was observed with Green group (143C) and Yellow green group (N144 A, N144 C, 144 B and 144 C). In sources namely Changer (S_6) leaves with Green group were observed whereas remaining seeds sources showed leaf color of Yellow green group.

4.5.8.2 Leaf color at the age of 6 months

The leaf color was observed with Green group and Yellow green group. In sources namely Changer (S_1) and Kosariyan (S_2) jwalamukhi (S_5) and Sadwan (S_6), leaves with Yellow green group (144A) were observed. Whereas in seed source S_4 (Samoh) and Hiranagar (S_3) leaves with Green green group (142 A and 142 B) were observed.

4.5.8.3 Leaf color at the age of 9 months

In seed sources namely Kosariyan (S_1) leaves with Yellow green group (N144C) were observed whereas remaining seeds sources S_2, S_3, S_4, S_5,S_6 showed leaf color of Yellow green group (144D, 144 A, 144B, 144 C).

4.5.8.4 Leaf color at the age of 1 year

In sources S_1 and S_2 leaves with green group 143 were observed (143 B and 143 A). In sources S_3, S_5 and S_6 leaves with Green group 141 were observed (141 B , 141C) and in S_4, leaves with Yellow green group 144 were observed (144 C).

4.6 GENETIC ESTIMATES

After statistical analysis, genetic estimate is a useful technique for analysing data collected from mother trees of different genotypes and half sib progenies. The major genetic parameters in tree improvement work are heritability, genetic gain, and genetic progress. Genetic parameters in *Santalum album* L. have been estimated and presented in table 22.

4.6.1 Genetic estimates for different characters

i) **Genotypic coefficient of variability (GCV%)** – Maximum value for GCV was estimated for tree height (22.43 %) whereas minimum was estimated for crown spread (N-S) with value 4.53 %.

ii) **Phenotypic coefficient of variability (PCV%)** - Maximum value for PCV was estimated for tree height (24.24%) whereas minimum was estimated for seed diameter (5.76%)

iii) **Repeatability coefficient** – The highest repeatability was found for seed weight (0.92) and minimum was found for crown spread (N-S) with value 0.18.

iv) **Genetic advance** – Maximum genetic advance was recorded for tree height (4.43) and minimum was recorded for crown spread (N-S) with value 0.13.

v) **Genetic gain** - Maximum genetic gain was recorded for tree height (42.74) and minimum for crown spread (N-S) with value 4.06.

Table: 22 Genetic parameter and repeatability coefficient for various characters

Phenotypic characters		GCV%	PCV%	Repeatability coefficient	Genetic advance	Genetic gain
Tree height		22.43	24.24	0.85	4.43	42.74
Tree diameter		14.12	17.66	0.63	3.38	23.26
Crown spread	N-S	4.53	10.42	0.18	0.13	4.06
	E-W	5.42	10.75	0.29	0.18	5.63
Bole height		13.98	20.02	0.48	0.9	20.11
Morphological characters						
Leaf length		6.37	9.67	0.43	0.45	8.66
Leaf width		7.04	10.97	0.15	0.19	9.3
Seed character						
Seed weight		14.6	15.2	0.92	2.89	28.9
Seed diameter		4.93	5.76	0.74	0.43	8.7

Table: 23 Genetic estimates for nursery stage performance of progenies from different Seed sources

Nursery Parameters	GCV%	PCV%	Heritability	Genetic advance	Genetic gain
Seedling height	13.47	17.15	0.62	3.94	21.8
Number of leaves	10.03	17.04	0.35	2.19	12.17
Collar diameter	9.39	13.07	0.52	0.41	13.9
Nodes per seedling	6.79	14.03	0.23	0.75	6.78
Leaf length	5.37	8.27	0.42	0.43	7.18
Leaf width	7.82	12.08	0.42	0.22	10.43
Internodal length	2.49	7.88	0.1	0.03	1.62

4.6.2 Genetic estimate for nursery stage performance of progenies from different seed sources

i) **Genotypic coefficient of variability (GCV%)** – Maximum value for GCV was estimated for seedling height (13.47 %) whereas minimum was estimated for internodal length (2.49%).

ii) **Phenotypic coefficient of variability (PCV%)** - Maximum value for PCV was estimated for seedling height (17.15 %) whereas minimum was estimated for internodal length (7.88)

iii) **Heritability**– The highest heritability was found for seedling height (0.62) and minimum was found for internodal length (0.10)

iv) **Genetic advance** –Maximum value for genetic advance was estimated for seedling height (3.94) whereas minimum was estimated for internodal length (0.03).

v) **Genetic gain** - Maximum value for genetic gain was estimated for seedling height (21.80) whereas minimum was estimated for internodal length (1.62).

In phenotypic, seedling growth characters and morphological characters, higher value of phenotypic coefficient of variability (PCV) as compared to genotypic coefficient of variability (GCV) indicates thatfield environment has a significant impact on these characters. These findings are similar with the findings reported by Yadav*et al*. 2014 in *Meliadubia*. High heritability and genetic gain was recorded in seed weight and tree height so these characters are useful for the selections. The concept of GCV with high heritability can be achieved best through selection was given by Burton and De Vane (1953).

The maximum repeatability coefficient of mother tree parameters was registered for tree height (0.85). For morphological characters maximum repeatability coefficient was found in leaf length (0.48). In seed traits maximum repeatability coefficient was recorded for seed weight (0.92) and in nursery traits maximum heritability was observed for seedling height (0.62). Heritability mean value from 0-0.3 is low, 0.3-0.6 is moderate and 0.6 and above is high (Robinson *et al.*,1949).

4.7 CORRELATION STUDIES

Simple correlation is a useful tool for determining the level of relationship between various characters and it plays an important role in any tree improvement program as it aids in identifying the relationships between distinct character whether one is linked with the other or not. Table 24 revealed correlation coefficient among different characters.

Tree height has been found to influence seedling characters at one year age as depicted highly positive values like internodal length (r= 0.64), seedling height (r= 0.74) while number of leaves at one year age were also found to show considerable positive

Table 24: Simple correlation coefficient for various characters

Traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	0.84**	1.00												
3	-0.20	-0.49*	1.00											
4	0.77**	0.50*	0.43	1.00										
5	-0.22	-0.52*	0.68**	0.32	1.00									
6	0.38	0.51*	-0.59*	0.06	-0.19	1.00								
7	0.30	0.15	-0.25	0.20	0.34	0.81**	1.00							
8	0.37	0.45	0.23	0.53*	-0.03	0.44	0.21	1.00						
9	0.55*	0.09	0.46	0.75**	0.48*	-0.31	0.11	-0.12	1.00					
10	0.74**	0.47*	0.16	0.80**	0.25	-0.13	0.09	-0.03	0.87**	1.00				
11	0.19	-0.05	0.68**	0.46	-0.02	-0.47*	-0.47*	0.42	0.34	0.13	1.00			
12	0.44	0.43	-0.77**	-0.08	-0.30	0.36	0.36	-0.51*	0.18	0.39	-0.64**	1.00		
13	-0.49*	-0.45	0.53*	-0.09	0.29	-0.89**	-0.77**	-0.36	0.13	0.09	0.22	-0.39	1.00	
14	0.64**	0.30	-0.23	0.38	0.05	0.58*	0.77**	0.10	0.44	0.34	-0.06	0.50*	-0.81**	

Keys to characters :

1. Tree height
2. Clear bole height
3. Leaf length
4. Leaf width
5. Leaf area
6. Seed weight
7. Seed diameter
8. Germination percent
9. Germination energy index
10. Seedling height
11. Collar diameter
12. Number of leaves
13. Number of nodes
14. Internodal length

* = Highly significant at 1% level
* = Significant at the 5% level

correlation with number of leaves of seedling (r=0.44). Number of nodes of seedling have significant negative correlation with internodal length (r = -0.81) of seedling at one year age.

Clear bole height of mother tree was found to express positive significant correlation with leaf width (r= 0.50), seed weight (r=0.51) and seedling height (r= 0.47) whereas significant negative correlation with leaf length (r= -0.49), leaf area (r= -0.52. Positive but non-significant correlation was found with seed diameter (r= 0.45), germination percent (r= 0.37) and number of leaves (r= 0.43) whereas non-significant negative correlation was found in collar diameter (r= -0.05) and number of nodes (r= -0.45).

Leaf length of selected mother trees shows highly significant positive correlation with leaf area (r= 0.68) and seedling parameter i.e, collar diameter (r=0.68) whereas highly significant negative correlation with number of leaves (r= -0.77) and seed weight (r= -0.59). Non-significant positive correlation was found with leaf width (r= 0.43), germination percent (r= 0.23), germination energy index (r= 0.46) and seedling height diameter (r= 0.16) whereas non-significant negative correlation was found in seed diameter (r= -0.25) and internodal length (r= -0.23)

Leaf width of selected mother trees found to be highly significant positive correlated with collar diameter (r= 0.80) of seedling and germination percent (r= 0.59). Non-significant positive correlation was found in leaf area (r= 0.32), seed weight (r= 0.06), seed diameter (r= 0.20), collar diameter (r= 0.46) and internodal length (r= 0.38) whereas non-significant negative correlation was with number of leaves and number of nodes.

Leaf area of selected trees shows significant positive correlation with germination energy index (r= 0.48) whereas non-significant positive correlation was found for seed diameter (r= 0.34), seedling height (r= 0.25), number of nodes (r= 0.29) of seedling. Leaf area of mother tree is found to be negative correlated with seed weight (r= -0.19), germination percent (r= -0.03), collar diameter (r= -0.02) and number of leaves (r= -0.30).

As the seed weight forms the basis of healthy seedling, so was found for *Santalum*seedling where highly significant positive correlation was found with seed weight, seed diameter leading towards good correlation for seed characters namelyseed diameter (r= 0.81) ,collar diameter (r=0.68) and internodal length (r=0.58). Significant negative correlation

have been found to exist with number of nodes (r= -0.89**) and collar diameter (r= - 0.47*). Seed diameter shows highly significant positive correlation with internodal length (r= 0.77) whereas significant but negative correlation was found in collar diameter (r = -0.47). Non-significant positive correlation was found with germination percent (r= 0.21), germination energy index (r= 0.11), seedling height (r= 0.09) and number of leaves (r= 0.36). These findings were similar with the findings of Singh *et al*. 2006 in which significant positive correlation was found between morphological characteristics of seeds, such as seed weight in *Celtisaustralis*.

Germination percent shows significant negative correlation with number of leaves (r= -0.51). Non-significant positive correlation was found with collar diameter (r= 0.34) and internodal length (r= 0.44) of seedling whereas non-significant negative correlation was found with germination energy index (r= -0.12), seedling height (r= -0.03) and number of nodes (r = - 0.36). Germination energy index shows highly significant relation with seedling height (r= 0.87) whereas non-significant positive correlation was in collar diameter (r= 0.34), number of leaves (r= 0.18), number of nodes (r= 0.13) and internodal length (r= 0.44) of seedling.

Seedling characters viz., seedling height and collar diameter showed non-significant positive correlation with other parameters. Seedling height was found non-significant positive correlation with collar diameter (r= 0.13), number of leaves (r= 0.39), number of nodes (r= 0.09) and internodal length (r= 0.34). Collar diameter of seedling was found highly significant correlation with number of leaves (r= -0.64). Non-significant positive correlation was with number of nodes (r= 0.22) and non-significant negative correlation was in internodal length (r= - 0.06).

Number of leaves of seedling was found to exhibit significant positive correlation with internodal length (r= 0.50) and non-significant negative correlation was found in number of nodes of seedling (r = -0.39).

Chapter-5

SUMMARY AND CONCLUSIONS

The present research work entitled "**Seed source studies *on Santalum album* L. in Himachal Pradesh**" was carried out in the department of Tree Improvement and Genetic Resources, College of Forestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during 2020-2021. In the present study three Forest Divisions were selected randomly from state Forest Divisions of Himachal Pradesh and six seed sources were selected among three Forest Divisions. Three seed sources were selected from Bilaspur Forest Divison viz., Changer (S_1), Kosariyan (S_2) and Samoh (S_3) district Bilaspur, one from Hamirpur Forest Divison i.e. Hiranagar (S_4) district Hamirpur and two from Dehra Forest Divisionsviz., Jwalamukhi (S_5) and Sadwan (S_6) district Kangra. The investigations included variations among seed sources on various parameters pertaining to phenotypicparameters, seed traits and nursery growth performance of half sibs, representing the ten seed trees from each source.

MAJOR FINDINGS

The results obtained from present research work are summarized as below:

Ten phenotypically superior trees of approximately same age and diameter class were selected from different seed sources for present research and the observations were recorded on phenotypic characters, leaf morphological and floral characteristics, seed traits and nursery stage growth parameters.

Phenotypic characters studied among different seed sources were of great significance and it revealed greater variability in tree height and clear bole height among seed sources. Maximum tree height was found in S_6(Sadwan) with value (13.71 m) and minimum was in S_5(Jwalamukhi) with value (7.21 m) whereas mean clear bole height was found maximum in S_3 with value 5.26 m followed by Sadwan (S_6) with 5.03 m and Changer (S_1) with value 4.71 m and Minimum clear bole height was observed in Jwalamukhi (S_5) with 3.32 m.

Regarding leaf morphological parameters, maximum leaf length was observed in Jwalamukhi (S_5) of value 7.36 cm which is statistically at par with S_2(Kosariyan) with value 7.06 cm and minimum leaf length was observed in S_4 of value 6.18 cm.

Main primary pollinators viz., honey bee, dragon fly, beetle, Dipetran fly, black ants were identified and their time spent on flower was observed. Observation showed that beetle spend more time on the flower (30-40 seconds) as compared to rest of the pollinators and dragon fly spend least time on the flower (0-5 seconds).

In case of seed traits seed weight and seed diameter showed significant variations among seed sources. Maximum seed weight was recorded in Kosariyan (14.58 g) which is statistically at par with Hiranagar (14.32 g) and Changer (14.14 g). Minimum seed weight was recorded in Jwalamukhi (10.56 g). Maximum seed diameter was recorded in S_2 with mean value of 6.99 mm and minimum seed diameter was recorded in S_5 with value of 6.32 mm.

Under nursery conditions , more germination percent was recorded for second sowing date (d_2) with value 51.85 percent as compare to d_1 with value 48.33 percent. Among seed sources significant differences were found. Maximum germination percentage was recorded for S_1 (Changer) with the mean value of 72.22 % and minimum germination percentage was recorded for S_4 (Hiranagar) with mean value of 25.00 %. In case of germination energy, maximum germination energy was found for S_6 (Sadwan) and minimum was found for S_4 (Hiranagar) with the mean value of 19.25 %. Among two sowing dates, d_1(35.00 %) had maximum germination energy as compared to d_2(14.11%).

Under laboratory conditions germination percent varied significantly among seed sources, sowing dates and their interactions. Among seed sources, maximum germination percentage was recorded for S_5 (Jwalamukhi) with mean value of 66.66 % and minimum germination percentage was recorded for S_2 (Kosariyan) with mean value of 38.49 %. Among two sowing media, M_2 (sand) had maximum germination percentage (55.55%) as compared to M_1(46.29 %). In interaction between seed source x sowing media, maximum germination percentage was found for $S_1M_2$with the mean value of 77.77 % and minimum percentage was found for S_2M_2 with the mean value of 27.77 %.

In case of one year seedling growth, maximum seedling height was recorded for Sadwan (S_6) where mean seedling height was found to be 21.62 cm and collar diameter was recorded maximum for Samoh (S_3) with mean value 3.01 mm among different seed sources. In case of two sowing dates, d_1 had more seedling height (18.85 cm) and collar diameter (3.21 mm) and d_2 had smaller seedling height (17.28 cm) and collar diameter (2.72 mm). In case of

interaction between seed source × sowing dates, maximum seedling height was found for S_3d_1 with the mean value of 20.12 cm and minimum was recorded for S_4d_2 with the mean value of 14.96 cm. Maximum leaf length was recorded for Jwalamukhi (6.25 cm) and minimum was for Kosariyan (5.71 cm).

Among two sowing dates first date of sowing (d_1) was found better for nursery growth parameters viz., seedling height (18.85 cm), collar diameter 3.21 mm, number of leaves (18.18) , number of nodes (11.62), leaf width (2.28 cm) and d_2 was found better for number of nodes (11.62), internodal length (1.99 cm) and leaf length (6.00 cm).

In case of nursery parameters high heritability and genetic advance was recorded for seedling height so this character is important for selection. In case of phenotypic characters, morphological and seed characters maximum GCV % (22.43), PCV % (24.24), genetic advance (4.43) and genetic gain (42.74) was estimated for tree height and maximum repeatability coefficient was estimated for seed weight (0.92).

The simple correlation revealed that tree height showed highly significant positive correlation with clear bole height, leaf width and internodal length. Leaf length shows highly significant positive correlation in leaf area and collar diameter whereas leaf area showed highly significant positive correlation with germination energy index. However seed weight showed highly significant positive correlation with seed diameter and collar diameter. Collar diameter was found highly significant correlation with number of leaves.

CONCLUSIONS

The present research was carried out in Himachal Pradesh for evaluation of *Santalum album* L. seed sources selected from three Forest Divisions and the following conclusions have been drawn.

1. Sadwan (S_6) performed well for phenotypic characters of mother trees. Maximum tree height (13.71 m), crown spread in both direction viz., East to West (3.48 m) and North to South (3.53 m) was recorded for S_6.

2. High heritability (0.62) and genetic advance (3.94) was recorded for seedling height so this character is important for selection. In case of phenotypic characters, morphological and seed characters maximum GCV % (22.43), PCV % (24.24),

genetic advance (4.43) and genetic gain (42.74) was estimated for tree height and maximum repeatability coefficient was estimated for seed weight (0.92).

3. In case of nursery growth performance of progenies from different seed sources, maximum GCV %, PCV % , heritability (0.62), genetic advance (3.94) and genetic gain (21.80) was estimated for seedling height.
4. Jwalamukhi (S_5) performed better for leaf morphological characters. Maximum leaf length was reported for S_5 (7.36 cm).
5. Maximum seed weight and seed diameter was recorded in Kosariyan of district Bilaspur i.e. 14.48 g and 6.99 mm.
6. Seed germination percent was recorded better in s_2 (55.55 %) as compared to s_1 (46.29%).
7. The seed sowing time was found to influence the seedling growth and April sowing proved better for seedling height (18.85 cm), collar diameter (3.21 mm) number of leaves (18.18) and number of nodes (11.62) leaf width (2.28 cm) at one year of age.
8. Maximum germination percent in field conditions was recorded for seed sowing (55.85 %) during the month of May 2020.
9. Maximum germination percent was recorded for second sowing media, M_2 (55.85 %) in in vitro seed germination.
10. The nursery growth stage performance of half sibs from S_6d_2have shown better mean seedling height of 24.73 cm. Half sib from Sadwan (district Kangra) performed best for seedling height as compared to rest of the half sib seedling from other seed sources.

The present research on seed source variations concluded that seed sources viz., Sadwan, Jwalamukhi in Dehra Forest Divisionsand Kosariyan in Bilaspur Forest Divisions performed best for phenotypic and morphological characters, seed traits and seedling growth potentials with promising genetic estimates for achieving the goals of selection for superiority.

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APPENDIX – I

Composition of modified Murashige and Skoog (1962) basal medium (MS medium)

Constituents	g/L
Inorganic constituents	
STOCK I {Major constituents (50 ml/l)}	
NH_4NO_3	33.00
KNO_3	38.00
$CaCl_2.2H_2O$	8.86
$MgSO_4.7H_2O$	7.40
KH_2PO_4	3.40
STOCK II {Minor constituents (1ml/l)}	
H_3BO_3	6.20
$MnSO_4.4H_2O$	22.30
$ZnSO_4.7H_2O$	8.65
KI	0.80
$Na_2MoO_4.2H_2O$	0.25
$CuSO_4.5H_2O$	0.025
$CoCl_2.6H_2O$	0.025
STOCK III (5ml/l)	
Na_2EDTA	7.46
$FeSO_4.7H2O$	5.56
STOCK IV {Organic constituents (5ml/l)}	
Pyridoxine	0.020
Glycine	0.080
Thiamine	0.040
Nicotinic acid	0.020

APPENDIX – II

Analysis of variance (ANOVA)

1. ANOVA for variation in phenotypic characteristics of *Santalum album* Linn.

Source of variation	Degree of freedom	MSS				
		Tree height	Tree diameter	Clear bole height	Crown spread	
					N-S	E-W
Replication	3	1.543457	3.134436	5.99792	0.29270	0.26563
Seed source	5	22.53278	19.16803	1.977522	0.16835	0.24547
Error	15	0.91179	2.369043	0.411401	0.08708	0.09135
Total	23					

2. ANOVA for Variation in morphological characters among different seed sources

Source of variation	Degree of freedom	MSS		
		Leaf length	Leaf width	Leaf area
Mother tree	5	0.46365	0.05469	8.05192
Error	12	0.14025	0.03486	9.97341
Total	17			

3. ANOVA for Pollen viability percentage in *Santalum album* L. flowers

Source of variation	Degree of freedom	MSS
Replication	8	2.94516
Mother tree	2	3.33893
Stages	2	6.31039
Tree×stages	4	1.06566
Total	18	3.29959

4. ANOVA for Pollen viability % from different floral stages at different temperature

Source of variation	Degree of freedom	MSS		
		1 month	2 month	3 month
Replication	17			
Mother tree (m)	2	0.01135	0.00052	0.03567
Floral bud color (f)	2	0.00985	0.06081	0.07682
Temperature (T)	1	0.01952	0.02933	0.29937
m x f	4	0.00540	0.02141	0.05700
m x T	2	0.00608	0.02386	0.05406
f x T	2	0.00224	0.04551	0.03193
m x f x T	4	0.00846	0.01325	0.05220
Error	36	0.00458	0.01264	0.04343
Total	53			

5. ANOVA for Variation in seed characters among different seed sources

		MSS	
Source of variation	**Degree of freedom**	**Seed weight**	**Seed diameter**
Genotypes	5	6.57100	0.20869
Error	12	0.17936	0.02166
Total	17		

6. ANOVA for seed germination parameters of *Santalum album*

Source of variation	**Degree of freedom**	**MSS**			
		Field seed germination parameters		**In vitro seed germination parameters**	
		Germination %	**Germination energy**	**Germination %**	**Time taken to initiate germination**
Seed source	5	990.865	195.9307	329.631	47.158
Sowing dates	1	44.979	3552.787	328.011	1.311
Seed source x sowing dates	5	28.555	12.84798	180.562	25.142
Error	24	60.005	22.71759	49.070	0.568
Total	35				

7. ANOVA for variation in seedling height (cm) of *Santalum album* seedling at different age interval

Source of variation	**Degree of freedom**	**MSS**			
		3 months	**6 months**	**9 months**	**1 year**
Treatments	11	2.17188	8.30008	13.1881	21.43272
Seed source (S)	5	1.01441	0.90507	5.42099	19.47052
Sowing date (d)	1	5.13060	78.83377	103.3777	22.30465
S x d	5	2.73761	1.58834	2.91729	23.22053
Error	24	1.63942	1.95722	2.04357	3.66978
Total	32	2.17188	8.30008	13.1881	21.43272

8. ANOVA for variation in collar diameter (mm) of *Santalum album* seedling at different age interval

Source of variation	**Degree of freedom**	**MSS**			
		3 months	**6 months**	**9 months**	**1 year**
Treatments	11	0.13284	0.99122	0.69326	0.30544
Seed source (S)	5	0.08512	0.74847	0.29778	0.20001
Sowing date (d)	1	0.55215	4.64788	4.56731	2.14602
S x d	5	0.09670	0.50264	0.31393	0.04275
Error	24	0.02220	0.57116	0.06177	0.072724
Total	32				

9. ANOVA for variation in number of leaves of *Santalum album* seedling at different age interval

Source of variation	Degree of freedom	MSS			
		3 months	6 months	9 months	1 year
Treatments	11	2.14415	16.71653	4.36361	0.44232
Seed source (S)	5	0.93703	6.98181	2.34070	0.40310
Sowing date (d)	1	6.18585	125.59560	23.39704	0.22552
S x d	5	2.54294	4.67543	2.57983	0.52491
Error	24	3.50851	2.35229	3.45313	0.13896
Total	32				

10. ANOVA for variation in number of nodes of *Santalum album* seedling at different age interval

Source of variation	Degree of freedom	MSS			
		3 months	6 months	9 months	1 year
Treatments	11	0.53181	3.07940	0.69326	0.30544
Seed source (S)	5	0.34354	0.83686	0.29778	0.20001
Sowing date (d)	1	1.00933	22.31966	4.56731	2.14602
S x d	5	0.62456	1.47388	0.31393	0.04275
Error	24	0.57870	0.67799	0.06177	0.07272
Total	32				

11. ANOVA for variation in internodal length (cm) of *Santalum album* seedling at different age interval

Source of variation	Degree of freedom	MSS			
		3 months	6 months	9 months	1 year
Treatments	11	0.01364	0.03260	0.13567	0.02800
Seed source (S)	5	0.01968	0.01385	0.14557	0.02341
Sowing date (d)	1	0.00548	0.16374	0.05255	0.09339
S x d	5	0.00923	0.02513	0.14239	0.01951
Error	24	0.02392	0.00670	0.01129	0.02100
Total	32				

12. ANOVA for variation in leaf length (cm) of *Santalum album* seedling at different age interval

Source of variation	Degree of freedom	MSS			
		3 months	6 months	9 months	1 year
Treatments	11	0.83648	0.08100	0.40150	0.442329
Seed source (S)	5	0.81071	0.02855	0.51072	0.403101
Sowing date (d)	1	2.69609	0.14753	0.43038	0.22552
S x d	5	0.49033	0.12015	0.28650	0.52491
Error	24	0.38229	0.09313	0.09811	0.13896
Total	32				

13. ANOVA for variation in leaf width (cm) of *Santalum album* seedling at different age interval

Source of variation	Degree of freedom	MSS			
		3 months	6 months	9 months	1 year
Treatments	11	0.02606	0.01274	0.09328	0.12071
Seed source (S)	5	0.01564	0.01033	0.09435	0.05254
Sowing date (d)	1	0.00098	0.00441	0.10309	0.93905
S x d	5	0.04148	0.01682	0.09024	0.02522
Error	24	0.01795	0.00732	0.02335	0.03815
Total	32				

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Title of Thesis	:	**"Seed source studies on *Santalum album* L. in Himachal Pradesh''**
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ABSTRACT

The present study entitled "Seed source studies on *Santalum album* L. in Himachal Pradesh was conducted in the Department of Tree Improvement and Genetic Resources of Dr. Y.S Parmar University of Horticulture and Forestry Nauni, Solan (H.P) during 2020-21. Trees of *Santalum album* L. were selected from subtropical ranges of Himachal Pradesh comprising of six seed sources viz. Changer (S_1), Kosariyan (S_2) and Samoh (S_3) district Bilaspur, Hiranagar (S_4) district Hamirpur, Jwalamukhi (S_5) and Sadwan (S_6) district Kangra , which are situated at significant distance from each other and falling across three Forest Division viz. Bilaspur, Hamirpur and Dehra with the aim to evaluate seed sources on the basis of various parameters viz., phenotypic, morphological , floral characteristics, seed traits, invitro germination and nursery growth performance of half sibs. Maximum tree height was found in S_6 (Sadwan) with value (13.71m) whereas mean clear bole height was found maximum in S_3 (5.26 m). Maximum seed weight and seed diameter was recorded in Kosariyan of district Bilaspuri.e, 14.48 g and 6.99 mm. Half sib from Sadwan (district Kangra) performed best for seedling height (21.62 cm) as compared to rest of half sibs among seed sources. Maximum leaf length was recorded for Jwalamukhi (6.25 cm). Primary pollinators viz., honey bee, dragon fly, beetle, Dipetran fly, black ants etc. were mostly visited on flower. Among seed sources, sowing media and their interactions, maximum invitro germination percent was recorded for S_5 (66.66%), s_2 (55.55 %) and S_1s_2 (77.77%). Among seed sources, maximum germination percent was recorded for S_1 (72.22%) in field studies. Highly significant correlation was found between tree height, clear bole height, collar diameter, seedling height, leaf length, leaf width, seed weight and seed diameter. Maximum GCV % (22.43). PCV % (24.24), genetic advance (4.43) and genetic gain (42.74) was estimated for tree height and maximum repeatability coefficient was estimated for seed weight (0.92 %). High heritability and genetic gain was recorded for seed weight and tree height so these characters are useful for selection.

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