

**MORPHOMETRIC AND CHEMICAL VARIABILITY IN
SOAPNUT (*Sapindus mukorossi* GAERTN.) IN
HIMACHAL PRADESH**

Thesis

by

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*Submitted in partial fulfilment of the requirements
for the degree of*

**MASTER OF SCIENCE
(FORESTRY)**

FOREST GENETIC RESOURCES



**COLLEGE OF FORESTRY
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FRONTISPIECE



SOAPNUT TREE (*Sapindus mukorossi* GAERTN.)
FAMILY- SAPINDACEAE



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CERTIFICATE-I

This is to certify that the thesis entitled, “**Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh**”, submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY) FOREST GENETIC RESOURCES** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is a record of bonafide research work carried out by **Mr. Vinod Kumar Kairon (F-2011-18-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation has been fully acknowledged.

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ABBREVIATIONS

ANOVA	:	Analysis of Variance
C.D.	:	Critical difference
cm	:	centimetre
CV	:	Coefficient of Variation
D.B.H.	:	Diameter at breast height
ECV	:	Environmental Coefficient of Variation
g	:	grams
GCV	:	Genotypic Coefficient of Variation
m	:	metre
mm	:	millimetre
masl	:	metres above sea level
PCV	:	Phenotypic Coefficient of Variation
S.D	:	Standard Deviation
UHF	:	Dr. Yaswant Singh Parmar University of Horticulture and Forestry
Ve	:	Environmental variance
Vg	:	Genotypic variance
Vp	:	Phenotypic variance

Chapter-1

INTRODUCTION

Sapindus mukorossi or Soapnut tree (Ritha) is an important multipurpose tree of North India, belonging to family Sapindaceae. The tree is native to China and Japan and much cultivated in North India, in moister tracts along the foot hills of Himalayas from Ravi eastward up to 1500 m elevation. The tree is also found wild in the valleys of North Western Himalayas, Assam and West Bengal. It is also planted in avenues. In Nagaland, it is cultivated extensively for use in small scale industries. The tree is cultivated in many parts of India as ornamental and for saponaceous fruits. In *Sapindus mukorossi*, the seed have mechanical dormancy due to hard seed coat (Troup, 1921).

The dried fruits of ‘Ritha’ are most valuable part of the plant. Its fleshy portion contains saponin, which is used in preparation of washing soap and as such is used for preparation of quality shampoos. The fruit is of considerable importance for its medical value as well. As per Ayurveda, Unani and Tibetan system of medication, it is useful in treating in number of human maladies like bad cold, facial pimples, irregularities in salivation, chlorosis, epilepsy, constipation, nausea, etc. It is also used as expectorant and antihelminthic in small doses. The Central Drug Research Institute, Lucknow, has recently developed a contraceptive cream out of ritha fruit. The same is marketed under the trade name “Consap” (Bahar and Singh, 2007).

Saponin chemically extracted from *Sapindus mukorossi* has properties such as micellar concentration, emulsification and hemolytic activities. Emulsification activity for water-kerosene and various plant oils are excellent in comparison with synthetic surfactant like sodium dodecyl sulfate (SDS). Hence crude Ritha is used as an economical bio-surfactant (Ghagi *et al*, 2011). Extraction of saponins from the pericarp of *Sapindus mukorossi* is used as compatibilizer in nanocomposites. Saponin increase mechanical properties and decrease roughness of nanofibrels (Cherian *et al.*, 2012).

Due to the continuous depletion of fossil fuels, considerable attention has been given to biodiesel production as an alternative to petrodiesel. The use of edible vegetable oil and animal fat for biodiesel production has recently been of great concern because, they compete with food materials. Furthermore the demand of vegetable oils for food has increased tremendously in recent years, thus it is impossible to justify the use of these oil of fuels. Hence, the contribution of non-edible oil such as Karanj (*Pongamia pinatta*), Jatropha (*Jatropha curcas*), Soapnut (*Sapindus mukorossi*), Neem (*Azadirachta indica*), Mahua (*Maduca indica*) etc. can be significant as a non-edible plant oil sources as biodiesel production. However Government of India does not want the new bio-fuel feedstock crops to compete with food crops for scarce agriculture land. Hence the focus is to encourage the use of wastelands and other unproductive land for cultivation of these relatively hardy bio-fuel crops. In view of economic, environmental and health benefits associated with biodiesel, planners have decided to develop biofuel programme in the country and the targets are fixed to replace 5 per cent to 10 per cent of petrodiesel by biodiesel in the year 2010 and 2015, respectively (Katwal and Soni,2003). Soapnut (*Sapindus mukorossi*) and Jatropha (*Jatropha curcas*) are newer sources of oil for biodiesel production. Experimental analysis showed that both oils have great potential to be used as feedstock for biodiesel production. Soapnut oil was found to have average of 9.1 per cent free fatty acid, 84.43 per cent triglycerides, 4.88 per cent sterol and 1.59 per cent others (Chhetri *et al.*,2008.)

The genus *Sapindus* comprises about twenty species of fairly large tree distributed throughout the tropical and subtropical regions of the world. Three species of the genus, viz. *Sapindus emarginatus*, *Sapindus mukorossi* and *Sapindus danura* are found in India. The first two are large tree species more common and commercially important as source of soapnut, while the last one is a small tree occurring only in West Bengal and Andaman Islands. Ritha is a large leaved deciduous handsome tree, better known as soapnut tree in inter-continental trade. It is also called doani or dodan or doda in local Indian dialects. The species flourishes well in deep clayey loam soils and does best in areas experiencing nearly 150 to 200 cm of annual rainfall. The bole of Ritha is straight and

cylindrical, reaching a height of about 20 to 25 m. The canopy comprising side branches and foliage constitutes an umbrella like hemispherical top measuring 4 to 6 m in diameter. The bark of ritha is shining grey and fairly smooth when the plant is young. It is dark grey when the plant approaches maturity. Ritha leaves are alternate and peripennate compound. The rachis is nearly 30 to 40 cm long and bears 5 to 10 pairs of leaflets. An individual's leaflet is about 7 to 15 cm long and 2 to 5 cm wide. It is acuminate and lanciolate in shape. The size of leaflets towards the tip of the rachis is smaller. Ritha flowers during May-June. The flowers are small and greenish white, polygamous and mostly bisexual in terminal thyrses or compound cymose panicles. These are sub-sessile; numerous in number and at time occur in loose panicles at the end of branches. The fruit of ritha appear in July-August and ripen by November-December. These are solitary globose, i.e., round nuts of 2 to 2.5 cm diameter, fleshy and saponaceous. The seed is enclosed in a black smooth and hard globose endocarp. The fruit is collected during winter month for seed and are sold in the market as soapnut. The trees are leafless from December – January to March – April, when the new leaves appear (Troup, 1921).

Oil content in *Sapindus mukorossi* seeds kernels on an average is 51.8 per cent. The oil from soapnut has been considered a non-edible oil having significant potential for biodiesel production from the material which otherwise is a waste material. Hence, the use of soapnut seeds as a biodiesel source becomes the Waste-to-Energy scheme. Furthermore, planting soapnut trees in community forestry and in barren land provide sink for carbon sequestration as well as feed stock for biodiesel production (Ucciani *et al.*, 1994). Soapnut oil is feasible for biodiesel production. Soapnut oil methyl esters (SNME) had satisfactory fuel properties, and the predominant components were methyl oleate at 55.2 weight percentage and methyl eicosanoate at 23.9 weight percentage. Oxidation stability of the SNME satisfied the requirements of the biodiesel specifications. Furthermore, the SNME is used as blending material with diesel at various volumetric percentages (Chen *et al.*, 2013).

Considering vast semi-wild distribution of soapnut, it is expected to have considerable genetic variation. Sufficient information on such aspect is lacking in

this species despite of its many uses. Environmental factors in combination with genetic and physiological factors play an important role in determination of plant potential for seed quality. These characters appear to be under strong genetic control (Roy *et al.* 2004).

Among various factors responsible for successful plantation programme, use of quality seeds in terms of genetic and physical attributes is of paramount importance. The seed size have been found to have a marked bearing on the quality of the nursery stock in numerous species and *Sapindus mukorossi* need not necessarily provide an exception to this. It is therefore, worthwhile to determine the optimum seed size for improving the physical quality of the seedlings/growing stock.

Sapindus mukorossi importance lies in the sale of fruits, which are mainly sold in the local market. A number of farmers are earning livelihood by marketing and selling the fruits from their planted trees. As the domestication and cultivation started the demand for quality seedling during planting time is very high. But low, delayed and uneven germination has created problem in raising seedling in nursery. Thus, there is strong need to produce genetically superior planting stock of Ritha.

So far, only few records of seed source variation of soapnut exist where an attempt was made to examine and identify the superior seed source for production of quality seedling (Bahar and Singh, 2007). Although, the plant is cultivated extensively for small scale industries in some part of country, however, commercial plantation for seed production is relatively a new concept. Thus, there is a strong need to work for its germplasm collection, evaluation, standardization of the propagation methods and oil content variation. Keeping in view all these facts, and potentials of this valuable plant bio resource, present investigation entitled, “Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh” was undertaken with the following objectives

- To study extent of variation in morphometric traits.
- To study variation in chemical characteristics.
- To study extent of variation in progeny performance traits.

Chapter-2

REVIEW OF LITERATURE

Keeping in view the potentials of this valuable bio resource, the present literature is reviewed under following broad headings:

- 2.1 Variation in morphometric traits
- 2.2 Variation in oil content and physico-chemical traits
- 2.3 Variation in germination parameters and progeny performance traits

2.1 VARIATION IN MORPHOMETRIC TRAITS

Variability studies are the prerequisite for the genetic improvement of any tree species under various climatic conditions. Seed sources testing for a particular species are desirable to screen the available variation for higher productivity and future breeding work. Selection of best seed source of desired species for a given site of region is necessary for achieving maximum productivity both in plantation forestry and agroforestry systems (Sharma *et al.*, 1994). The significance of variation studies and seed sources testing in forest tree improvement has been very well realized (Mehta and Sen, 1995).

Munthali *et al.*, (2012) worked on *Adansonia digitata* to determine within and between provenance variability in fruit and seed characteristics of five populations selected from four silvicultural zones and resulted mean fruit weight ranged from 125.8 ± 3.25 to 162.9 ± 3.25 gm, seed weight ranged from 38.6 ± 2.5 to 66 ± 2.01 gm and pulp weight ranged from 28.7 ± 1.33 to 41.4 ± 1.33 gm.

Mir (2011) studied the variation on seed source for fruit, seed morphological characteristics, seed viability and germination parameters under laboratory condition in *Sapindus mukorossi*. Fruit and seed were collected from different seed sources of Himachal Pradesh. The seed source of Chuwari (Chamba) was found to be the best source in comparison to other seed sources. Among fruit-seed and germination variables, the percent germination showed significant correlation with seed size and weight.

Singh and Sexena (2009) while studying seed size variation and its effect on germination and seedling growth of *Jatropha curcas* concluded that seed size and weight affects the germination percent and other parameters of germination. Larger seed germinated faster than smaller seeds in laboratory as well as under nursery condition. Germination value increased with the increase in seed size. The higher germination value for medium and large seeds indicates more rapid and complete germination in these seeds than in small seeds. While Suri (1984) reported that teak seeds from moist locality were bigger in size and weight as compared to that of dry zone and it was also reported that germination and plant percent are the function of quality of seed rather than size and weight of seed.

Luna *et al.*, (2008) studied seed sources variation in morphological traits of seed and oil content in *Jatropha curcas* and were studied among twenty four seed sources of *Jatropha curcas* and estimated broad sense heritability and genetic advance for various traits showed moderate to high value for number of traits and the maximum genetic gain was registered for girth followed by weight of 100 seed kernel, number of branches and weight of 100 seeds. The maximum variation was observed for weight of 100 seed kernels (12.45-44.55: 257.83 per cent).

Bahar and Singh (2007) conducted studies on seed source variation of *Sapindus mukorossi* by collecting seeds from thirteen localities of Himachal Pradesh, India and observed significant variation in fruit diameter, fruit weight, seed diameter and seed weight among all seed sources.

Bahar (2007) collected bulk seed samples of *Azadirachta indica* from 14 seed sources in southern and western Haryana, India and the composite seed samples were evaluated for variation in seed and germination characteristics. The experimental results of the study revealed significant variation in seed length, seed width, seed weight and per cent germination among all seed sources.

Ghildiyal and Sharma (2005) studied effect of seed size and temperature treatments on germination of various seed sources of *Pinus wallichiana* and *Pinus roxburghii* from Garhwal Himalaya and reported that the large sized seeds in *Pinus wallichiana* (mean germination percentage, 54.66%) and medium sized

seeds in *Pinus roxburgii* (mean germination percentage, 93.33%) have been recorded favourable for getting increased seed germination under laboratory conditions.

Ginwal *et al.*, (2005), while studying seed source variation in *Jatropha curcas* for seed germination parameters reported that the variation in seed viability, germination percentage, germination energy and germination value was significant among different seed sources with coefficient of variation of 6.67, 10.03, 11.27 and 27.41 per cent, respectively. Almost a similar trend was noticed in nursery germination percentage, germination energy and germination value with coefficient of variation of 9.26, 9.92 and 21.12%, respectively.

Luna and Kumar (2005) studied evaluation of seed sources variation in Aonla (*Embllica officinalis* Gaertn.) and reported that the germination per cent, germination energy and seed viability were observed highest in the January collection.

Radhakrishanan and Vanangamudi (2004) collected the seed samples of *Albizzia lebbek* from thirty seed sources throughout the country. The seed quality parameters of samples were evaluated using image analyser. Significant variation was observed among seed sources for seed quality parameters. On the basis of overall performance, Mettupalayan followed by Bhagwala and Gadag sources expressed superiority for seed traits.

Todaria *et al.* (2004) while conducting studies on seed source variation on seed germination parameters of *Acacia catechu* reported that variation in seed germination parameters of 20 seed sources collected between 120 to 1300 m sl altitude in Garhwal Himalaya and Siwaliks showed non significant relation with altitude of seed origin. The experiment also concluded that among all temperature regimes, 30/20 °C alternative temperature was found most suitable for the seed germination of *Acacia catechu*.

Effect of altitude variation in seed morphology of *Grewia optiva* population. Four populations of *Grewia optiva* (Nauni, Palampur, Kandaghat and Tattapani) geographically separated from each other, were selected. Results showed that the fruits from Kandaghat population had the maximum seed length (6.17 mm), seed weight

(10.65 gm) and seed viability (63.78%) while Tattapani populations had the least values for the observed seed characteristics (Gupta *et al.*, 2000).

Mature fruits of *Salvadora oleoides* collected from eight selected trees in natural population and studied for different fruit and seed characters, the study revealed that there were large variations in fruit colour, 100 fruit weight and 100 seed weight (Jindal *et al.*, 1999).

Devagiri *et al.*, (1998) studied seed source variation in pod and seed traits of *Dalbergia sissoo* in India and Nepal and reported significant variation for pod and seed traits between seed sources. Manga and Sen (1996) while conducting experiments on genetic parameters for seed traits in *Prosopis cineraria* concluded that magnitude of improvement in germination through seed size manipulation depends upon the amount of genetic variability and heritability of the traits.

Seeds of *Dalbergia sissoo* collected from different seed sources scattered over almost the entire natural range in India were studied for variation in seed morphology and germination parameters. The study revealed significant genetic variation among all seed sources for rate of germination, while as variation observed for seed morphology has been assigned to be geographical. Thus study indicated that the multi-trait selection might be essential in ranking the desired seed source (Vakshaya *et al.*, 1992).

Ngulube (1989) worked on genetic variation in seed germination and seedling growth of 24 *Gliricidia sepium* provenances and reported significant differences in seed germination and seedling survival between provenances. Shivakumar and Banerjee (1986) studied different provenances of *Acacia nilotica* for seed polymorphism and preliminary field investigations and reported that 100 seed weight, seed viability varied significantly between the provenances.

Seed size and weight are the two important characters for developing quality seedling production and reducing the nursery cost through selection of quality seeds, apart from selecting and delineating provenances, while studying the altitudinal variation in *Pinus brutia* by Isik (1986).

Pathak *et al.* (1984) recorded seed weight and germinability of 30 provenances of *Leucaena leucocephala* from India, Philippines and Australia and concluded that character association and inter group differences were highly significant.

Suri (1984) reported that teak seeds from moist locality were bigger in size and weight as compared to that of dry zone and it was also reported that germination and plant percent are the function of quality of seed rather than size and weight of seed.

Moura (1983) studied the six provenances of *Eucalyptus urophylla* from different altitude for seed characteristics and reported that among six provenance of *Eucalyptus urophylla*, seed size increases with the increase in altitude of provenance.

Clausne *et al.*, (1981) studied the seed source/provenance variation in *Fraxinus americana* and reported that all seed sources registered significant variation for seed and fruit characters of *Fraxinus americana*.

Liu *et al.*, (1975) while conducting studies on interspecific variation and provenance test in genus *Chamaecyparis*, found that there exist significant differences in germination rates and seed size among the provenances of *Chamaecyparis* species.

Some seed sources show better performance in certain locations than the others and use of seed of a superior provenance in areas, very much different in climatic or edaphic conditions from their origin, often results in poor performance or failure (Pirags, 1971 and Read, 1971).

2.2 VARIATION IN OIL CONTENT AND PHYSICO-CHEMICAL TRAITS

Refractive index is the degree of deflection of the beam of light that occurs when it passes from one transparent medium to another. The refractive index of fat and oils is useful for their identification and testing their purity. Generally the refractive index of oil decreases as the temperature rises; however, it increases with the increase in the length of the carbon chain, as well as, with the increase in the degree of unsaturation. Thus, in terms of fat oils, more the degree of unsaturation more will be the refractive index (Nawar, 1985).

Specific gravity is a measure of the density of a substance compared to the density of water at room temperature. Specific gravity of oil tends to increase with the increase in

degree of unsaturation, as well as, with the increase in chain length of fatty acid residues (Meyer, 1987).

Saponification value is the number of milli grams of potassium hydroxide required to saponify the fatty acids resulting from the complete hydrolysis of one gram of fat or oil (Jacob, 1959). Saponification value of oil indicates the average molecular weight of the fatty acids present in it (Ranganna, 1997), which influences the firmness as well as flavor and odour properties of the oil.

Mir (2011) studied seed oil content variation in *Sapindus mukorossi* from different seed sources of Himachal Pradesh and reported the oil content on kernel basis 41.55 to 32.62 per cent and on seed basis 18.17 to 10.77 per cent. Oil content parameters were reported as: relative viscosity (22.77 to 22.02), saponification value (187.07 to 144.98 mg KOH/gm), specific gravity (0.9035 to 0.9025) and refractive index (1.4697 to 1.4674).

Ruan and Huang (2006) conducted an experiment on seed source variation in *Sapindus mukorossi* and reported that saponification value of oil samples extracted from composite seed samples of Taiwan, India and Vietnam ranged between 173-196 mg KOH/g.

Karnik *et al.*, (1971) studied chemical composition of *Sapindus mukorossi*. The oil was extracted by Soxhlet apparatus using solvent petroleum ether (60-80 °C) and reported oil content, refractive index at 30 °C, specific gravity at 30 °C and saponification value 38.0 per cent, 1.4730, 0.9106 and 202-204, respectively.

Dev *et al.*, (1979) while studying chemical composition of *Sapindus mukorossi* reported that refractive index at 24 °C, specific gravity at 22 °C and saponification value of seed oil were 1.4669, 0.9042 and 197.00, respectively.

Aminul Islam *et al.*, (2012) conducted an experiment on *Jatropha curcas* and evaluated seed oil from 9 geographical origins and 24 candidate plus trees. Oil extracted by Soxhlet extraction using n-hexane as solvent, concluded that oil content varied from 40.0 to 48.4 per cent among seeds from different origins and 32.1 to 48.8 per cent (w/w) among CPTs. The lowest saponification values were obtained from seed oil of Philippine origin (189.5 mg KOH/g) and CPT-22

(183.3 mg KOH/g oil) from Malaysia. Density, specific gravity, and refractive index of oil showed very little differences among all the seed sources.

Properties of seeds and oil extracted from fully ripened *Phoenix canariensis* date seeds and observed the saponification number 191.28, the iodine number 76.66 and the refractive index 1.45 by Nehdi *et al.* (2010).

Mukta *et al.*, (2009) assessed wide variability in oil content in 75 germplasm of *Pongamia pinnata* collected from Telengana region of Andhra Pradesh, India and concluded that the saponification number (SN), iodine value (IV) and cetane number (CN) of fatty acid methyl esters of oils varied from 183.3 to 200.91, 74.78 to 100.98 and 50.85 to 59.11, respectively. The range of variability found for various biodiesel standards in accessions of *P. pinnata* can be utilized for the establishment of plantations of promising genotypes through clonal means for increased productivity.

Oyekunle *et al.*, (2007) assessed the oil extracted from *Jatropha curcas*, for various physical properties and concluded that specific gravity measurement varied between 0.9004 to 0.9113 at 80 °C and 0.9125 to 0.9207 at 30 °C. Viscosity measurement, in centipoises, ranged between 7.35 to 9.41 at 80 °C and 38.44 to 60.34 at 30 °C. Refractive index values at 28 °C ranged between 1.4646 and 1.4707 and Foidl *et al.*, (1996) studied the fuel properties of *Jatropha curcas* oil and observed the specific gravity at 15 °C and viscosity at 30 °C as 0.920 gm/cm³ and 52.0 centipoises respectively.

Sayeed *et al.*, (2004) studied the physico-chemical characteristics of seed oils of *Mesua ferrea*, collected from different districts of Bangladesh, reported marginal variation in specific gravity (0.9287 to 0.9312), refractive index (1.4690 to 1.4739), saponification value (199.03 to 206.40), and found non significant variation among different seed sources.

Nasir *et al.*, (1988) characterized the fixed oil of *Jatropha* for its fatty acid composition and physico-chemical properties. The physico-chemical contents were, refractive index at 30 °C, 1.4675; iodine value 102 and saponification value, 196.72. Seeds of *Pinus roxburghii* were collected from 8 stands at 700 to 1975 m attitude in the Western Himalaya and were studied for variation in seed oil content and oil quality parameters. The experimental results of the study revealed that seed oil content,

saponification value and iodine value varied between 42-64 per cent, 210 to 294 and 114 to 120, respectively (Sehgal *et al.*, 1989).

Khan *et al.*, (2009) while studying the variation in seed oil content of *Prunus armeniaca* from 17 different seed sources, reported that the oil content varied significantly across different seed sources ranging between 40.35 to 52.42 per cent on kernel weight basis. While Luna *et al.*, (2008) conducted an experiment to investigate seed source variations in different morphological traits of seed and oil content among twenty four seed sources of *Jatropha curcas* collected from three states of Northern India, viz., Himachal Pradesh, Jammu and Kashmir and Punjab. The experimental results concluded significant variation for 100 seed kernel weight followed by oil content and weight of 100 seeds.

Kaushik *et al.*, (2007) assessed variability in seed traits and oil content of 24 accessions of *Jatropha curcas* collected from different agroclimatic zones of Haryana state, India and resulted that there were significant differences ($P < 0.05$) in seed size, 100 seed weight and oil content between accessions. High heritability and genetic gain were recorded for oil content (99.00% and 18.90%) and seed weight (96.00% and 18.00%), respectively, indicating the additive gene action.

Pant *et al.*, (2006) conducted a trial to determine the variation in yield and oil content by taking composite sample of six *Jatropha curcas* trees randomly selected from two cultural site conditions and three altitudinal ranges in Himachal Pradesh, India and reported that non-arable site with low, altitude recorded highest oil content. Kaushik *et al.*, (2006) collected more than one thousand samples of *Jatropha* seeds, presenting twelve states of India, for oil content analysis and reported that oil content varied significantly among different seed sources ranging between 25 to 44 per cent on seed weight basis.

Ginwal *et al.*, (2005) evaluated ten different seed sources in central India representing the states of Madhya Pradesh and Maharashtra, for oil content variation in *Jatropha curcas* seeds and reported that oil content on both seed and kernel basis varied significantly among different seed sources.

Shah *et al.* (2005) reported that the use of ultrasonication as a pretreatment before aqueous oil extraction was found to be useful for *Jatropha* seed oil extraction. The use of ultrasonication for 10 minutes at pH 9.0 followed by aqueous oil extraction gave a yield

of 67 per cent. However, the maximum yield of 74 per cent was obtained by ultrasonification for 5 minutes followed by aqueous enzymatic oil extraction using an alkaline protease at pH 9.0.

Ginwal *et al.* (2004), while, studying the variation in seed oil content of *Jatropha curcas* of different sources, concluded that the oil content ranged from 33.02 to 39.12 per cent in whole seeds and 47.08% to 58.12% in kernel, across the seed sources.

Keith (2000), while conducted an experiment on oil content of *Jatropha curcas*, reported that the whole seeds of *Jatropha curcas* contain about 36-40 per cent non-edible oil. Seeds of *Jatropha curcas* collected from Madhya Pradesh, Maharashtra and Gujarat were analyzed for their kernel shell ratio and oil content variation. The experimental results concluded that kernel shell ratio and the oil content on kernel basis between the different seed-sources range between 61.39 to 64.36 and 32.4 to 39.0 per cent respectively (Holla *et al.*, 1993).

2.3 VARIATION IN GERMINATION PARAMETERS AND PROGENY PERFORMANCE TRAITS

Ahirwar (2012) studied the effect of seed size and weight on seed germination of *Alangium lamarckii* Thwaites. The data revealed that the large size seeds gave maximum (76.00%) germination followed by medium size (74.00%) and small size seeds characterized by low germination percentage (59.00%). It is evident that the germination percentage significantly declined with reduction in size and weight of the seeds.

Venkatesh and Nagarajaiah (2010) while studying the effect of seed size on germination in *Sapindus emarginatus* (Linn) found that large size seeds possessed higher germination percentage (98%) than the medium (80%) and small size seeds (70%). Similar observations were made in *Sapindus emarginatus* (Linn) by Suresha *et al.* (2007) and both reported that in *Sapindus emarginatus* (Linn.) biomass production was higher in seedlings produced from larger seeds.

Singh and Saxena (2009) studied the effect of seed size on germination parameters of *Jatropha curcas* and observed that germination and related parameters were positively correlated with seed size in laboratory as well as in nursery conditions. Large seeds showed remarkable increment in germination per

cent (50%), germination speed (100%) and germination energy (72%) over the small seeds in the laboratory. This increment in germination and related parameters for large seeds over the small seeds was even greater in nursery condition.

Kumar and Bangarwa (1999) studied progeny testing in *Azadirchta indica* collected seed from ten randomly taken trees of neem growing naturally in Hisar. Significant differences were observed among progenies of vigour index and growth parameters in two months old seedlings. The average germination percent, seedling length, seedling dry matter, vigour index-1, vigour index-2, collar diameter and number of leaves were observed 85.55, 48.65 per cent, 576.30 mg, 1194.96, 4841.94, 2.02 mm and 28.28, respectively. Progeny-6 was found relatively better for vigour index and juvenile growth. Progeny-8 was found relatively better for the same parameters.

The investigation was carried out to study the pattern of genetic variation and character association in 17 exotic provenances from Australia and one local provenance of *Eucalyptus grandis*. The result revealed the presence of high magnitude variation for height, girth and basal area in the present materials. There were fair differences between phenotypic and genotypic co-efficient of variability. Both heritability and genetic advance values were low for all characters (Subramanian *et al.*, 1995).

The study was undertaken with the aim to initiate tree improvement programme in *Eucalyptus* hybrid. Thirty one plus trees were selected and out of them only 16 were progeny tested in nursery along with control. Eleven progenies excelled, one equalled and for were below the control in seedling height. A maximum of 51.3% more height than the control was observed in progeny of plus tree number 17 (Sidhu, 1993).

Clause *et al.*, (1981) studied variation in *Fraxinus americana* and seed of individual white ash parent trees from most of the species range were studied and used to establish a provenance-progeny test. Variation in seed length and length of wing on the seed appeared to be clinal while ploidy variation accounted for

most of the difference in fruit length, seed width, seedling height and date of leaf fall.

Kandya (1978) studied relationship among seed weight and various growth factors in *Pinus oocarpa* seedlings and observed provenance Balize Cayo has highest seed weight (24.54 ± 5.44 mg), height (19.83 ± 0.01 cm), total dry weight (630.10 mg) and root length (19.87 ± 4.22).

Singh and Saxena (2009) studied the effect of seed size on growth and dry weight of *Jatropha curcas* seedlings and evaluated that seed size showed a positive relation with growth and dry weight of seedling. Maximum height, collar diameter, number of leaves and total dry weight was found in the seedlings raised from large seeds; hence large seeds of *Jatropha curcas* should be preferred to get quality seedlings.

Uniyal *et al.*, (2007) studied the effect of seed size on the seedling growth of *Azadirachta indica*. The results revealed that shoot and root length were longer in plants raised from large sized seeds.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled, “**Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh**” was conducted in the laboratory and experimental field nursery of 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 the years 2011-2013. The details of experimental site, experimental material used and the methodologies/techniques followed during the course of investigation has been described in this chapter.

3.1 SITE SELECTION, TREE SELECTION AND FRUIT COLLECTION

Multistage Random Sampling Technique was used to select the trees of soap nut. Six districts, viz., Chamba, Kangara, Mandi, Kullu, Sirmour and Solan were selected from the state of Himachal Pradesh and four seed sources were selected from each district. From each seed source, two diameter classes, i.e., 10-40 cm D.B.H. (D_1) and 40-70 cm D.B.H. (D_2) were selected. Three trees were selected from each diameter class. From the selected and marked trees, fresh and mature fruits were harvested during November- December, 2011. The fresh fruits were collected manually and packed in gunny bags and brought to University campus in the departmental laboratory for detail studies and analysis. The fruits so collected and seeds extracted from such fruits of each site were kept separately with proper identify of site concern.

Experimental Details:-

Seed source	:	24
Diameter classes selected at each site	:	2
Replication	:	3
Total treatment combination	:	$24 \times 2 = 48$
Design employed	:	RBD (Factorial) in Field and CRD in Laboratory

Table 1. Description of seed sources of *Sapindus mukorossi* Gaertn.) in Himachal Pradesh under study

Sr. no.	District	Seed source	Altitude (ma sl)
1	Chamba	Trimuth	1003
		Tornu Kamni	1108
		Patka	1308
		Simble Ghatta	1280
2	Kangara	Jachh	532
		Nagrota Bagwan	550
		Jwalamukhi	609
		Palampur	1300
3	Mandi	Jogindar Nagar	1185
		Baggi	1234
		Chail Chowk	1268
		Pandoh	1358
4	Kullu	Bhuntar	1085
		Garsa	1224
		Panarsa	1200
		Banjar	1530
5	Sirmour	Deothal	1189
		Sarahan	1380
		Naina Tikkar	1365
		Nahan	821
6	Solan	Kanda Ghat	1428
		ThadiSubathu	1260
		Shilly	1480
		Jatoli	1195

3.2 EXPERIMENTAL SITE

3.2.1 Location

After the collection of fruits and recorded data, the experiments were carried out in the laboratory and experimental field of the department- Tree Improvement and Genetic Resources, College of Forestry, Dr. Y S Parmar, UHF, Nauni, Solan, Himachal Pradesh.

3.2.2 Climate

The climate of the study site is sub-tropical to sub-temperate. The area receives an annual rainfall of approximately 1150 mm, most of which is experienced during July – August.

METHODOLOGY ADOPTED AND OBSERVATIONS RECORDED

3.3.1 FRUIT AND SEED MORPHOLOGY

A. 100 fruits weight

Hundred fruits were weighed with the help of Top Pan Balance and the mean was expressed in grams (g).

B. 100 seed weight (g)

Seed after extracted manually fruits were weighed on 100 seed basis per ISTA (1966) method.

C. Rind weight (g)

The rind after removing from fruits manually was weighed single and mean was expressed in grams.

D. Fruits-kernel weight ratio

Fruits-kernel weight ratio was calculated by following formula.

$$\text{Fruits-kernel weight ratio} = \frac{\text{Fruit weight (gm)}}{\text{Kernel weight (gm)}}$$

E. Seed diameter (mm)

Seed width was measured using Digital Varnier calliper and mean expressed in millimetres (mm).

3.3.2 LABORATORY GERMINATION PARAMETERS

A. Seed viability (%)

Seed viability was determined by using Tetrazolium staining test (Bonner, 1974), which indicate the presence of live tissue. One per cent solution of TTC (2, 3, 5 Triphenyl Tetrazolium Chloride) was applied to fully imbibed seeds,

which was cut and opened lengthwise without damaging the embryo. The seeds were left over night for 18 to 24 hrs in the dark at 30⁰C. The live embryo, cotyledons and other tissue stained red indicated that the seeds are viable and unstained embryo is not viable. The seeds were thereafter evaluated as viable and non- viable in percentage.

$$\text{Seed viability (\%)} = \frac{\text{Number of viable seeds}}{\text{Total number of seeds}} \times 100$$

B. Germination percentage (GP)

Before germination studies seeds were treated with concentrate sulphuric acid for 25 minutes. The percent germination was calculated by counting number of seeds in a given sample that actually germinated.

$$\text{GP} = \frac{\text{Number of seed germinated}}{\text{Total number of seed sown}} \times 100$$

C. Germination energy (GE)

Germination energy (GE) was calculated on the basis of the percentage of the total number of seed that will germinate when the germination will reach its peak.

$$\text{GE} = \frac{\text{Number of seed germinated up to the time of peak germination}}{\text{Total number of seed sown}}$$

D. Germination capacity (GC)

Germination capacity was calculated by the number of seeds in a given sample that actually germinated, irrespective of time (ISTA, 1966).

$$\text{GC} = \frac{\text{Total germination} + \text{number of sound ungerminated seeds}}{\text{Total number of seed sown per treatment}}$$

E. Number of days taken to emergence

The number of days taken for initiation of emergence of seedling was recorded for each site.



Fruits of *Sapindus mukorossi*



Seeds of *Sapindus mukorossi*



Rind with seeds



Powdered sample

Plate 1. Fruits, seeds, rind with seeds and powdered sample of *Sapindus mukorossi*

3.3.3 OIL CONTENT AND OIL PHYSICO CHEMICAL TRAITS

A. Oil content

Extraction of oil was carried out following the method of Anonymous (1965), in which both seed and kernels were crushed using pestle and mortar. The oil was extracted from powdered sample (known weight) in Soxhlet extraction apparatus with petroleum ether (60-80 °C) for six hours without interruption by gently heating it on the heating mantle. Either was evaporated on a water bath until no odour of ether remained. The oil yield was expressed in terms of percentage of powdered sample.

$$\text{Oil content (\%)} = \frac{\text{Weight of oil extracted from the sample}}{\text{Weight of sample (100 g)}} \times 100$$

B. Relative viscosity

Viscosity is the measure of a fluid's resistance to flow. The viscosity of oil was taken using Ostwald Viscometer as per as per the standard procedure with the following equation (Ranganna, 1997):

$$\text{Relative viscosity} = \frac{\text{Time required by oil to pass through orifice}}{\text{Time required by water to pass through orifice}} \times 100$$

C. Saponification value

Saponification value of oil was estimated according to the standard method outlined in AOAC (1995). The oil sample (5.0 g) was mixed with alcoholic potassium hydroxide and the mixture was refluxed for 30 minutes to completely saponify the sample and then will titrate against 0.5 N HCl using phenolphthalein as indicator. Blank determination was also carried out along with sample. The value represents the average molecular weight of the oil and is useful for comparative study of the oil and is useful for comparative study of the fatty acid chain length in oils.

$$\text{Saponification value} = \frac{28.05 \times (\text{Blank titre} - \text{Sample titre})}{\text{weight of sample taken in grams}} \times 100$$

D. Refractive index

Refractive index is the degree of deflection of the beam of light that occurs when it passes from one transparent medium to other. It is used as one of

the primary objective test procedures to determine the quality of oil as deviations from the established values is indicative of adulteration. The refractive index of oil was determined using Abbe's Refractometer by placing 2-3 drops on the prism and maintaining a temperature of 30°C throughout the measurements (AOAC, 1995).

E. Specific gravity

Specific gravity is a measure of the density of a substance compared to the density of water at constant room ambient temperature. The specific gravity of oil was measured using specific gravity bottles according to standard method (Ranganna, 1997) and was calculated under:

$$\text{Specific gravity} = \frac{\text{Weight of oil with bottle} - \text{weight of bottle}}{\text{weight of water with bottle} - \text{weight of bottle}} \times 100$$

3.3.4 Progeny performance traits

Three randomly selected seedlings were carefully uprooted without breaking the roots and observations were recorded at interval of 3 and 6 months after sowing.

A. Shoot length (cm)

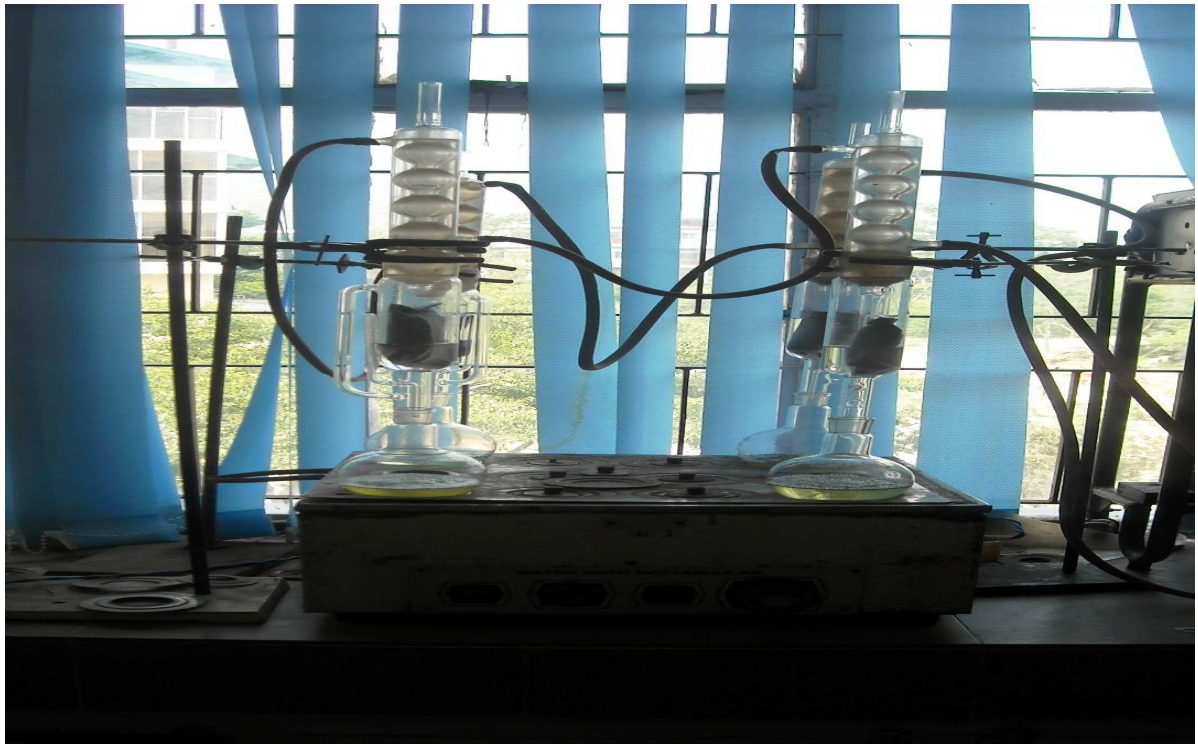
It was measured with the help of meter scale from leading shoot tip to the collar region of seedling at ground.

B. Root length (cm)

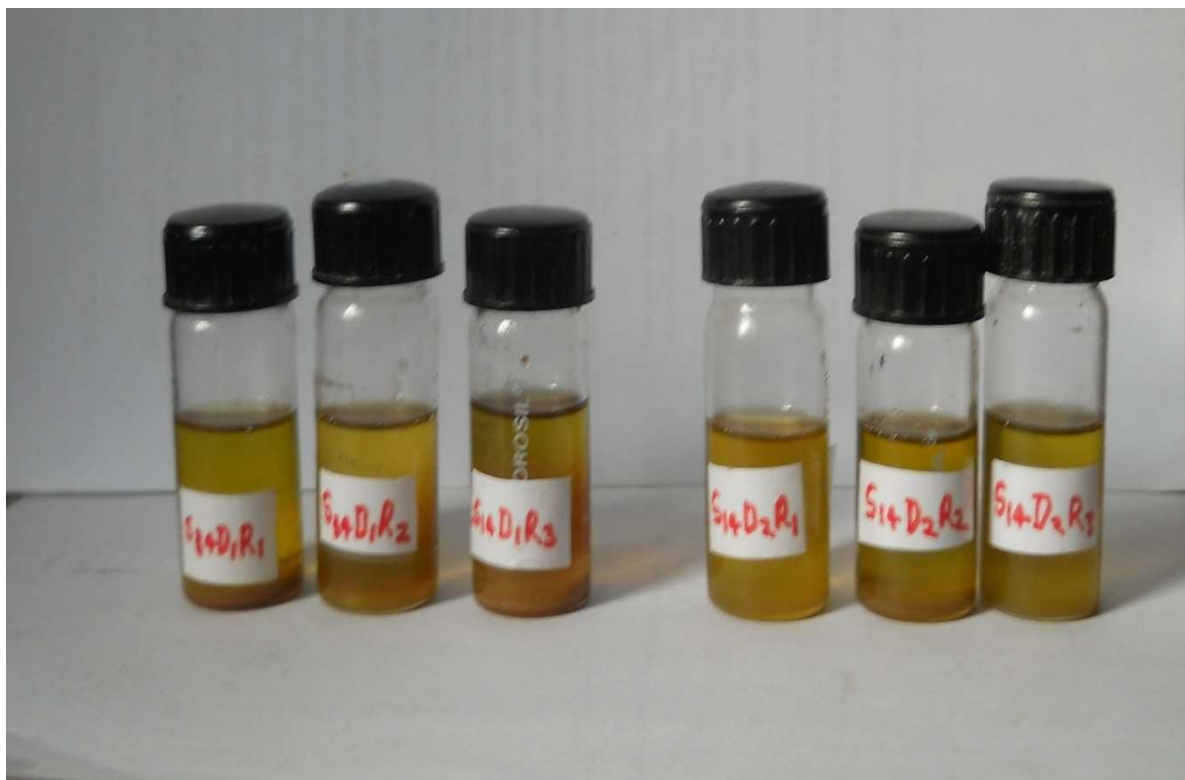
The length of tap root was recorded in centimetres using measuring scale by placing in horizontally on the ground.

C. Collar diameter (mm)

Collar diameter of seedling was measured in millimetres (mm) by using digital Vernier calliper.



Soxhlet apparatus



Oil samples of Garsa (Best Proven) seed source

Plate 2. Soxhlet apparatus and oil samples of Garsa (Best Proven) seed source of *Sapindus mukorossi*

D. Seedling height (cm)

Seedling height was recorded in centimetres using a scale from root tip to the top/ tip of stem.

Seedling height= Shoot length+ Root length

E. Number of leaves

Total number of leaves counted as an average number of leaves per plant.

F. Leaf area

Leaf area per plant was determined in cm² on average basis by using leaf area meter.

G. Seedling dry weight

Seedling washed with water and dried in oven at 65 °C for 72 hours and then seedling dry weight was taken.

3.3.5 STATISTICAL ANALYSIS

Statistical analysis is an important tool for collection, evaluation and interpretation of data. The data was analysed statistically by using RBD. ANOVA (Analysis of Variance) for morphometric traits, germination parameters, chemical traits and progeny performance traits as described Panse and Sukhatme (1967) and Chandel (1984).

A. Critical difference (CD)

In order to compare the mean of various entries, the critical difference was calculated by the formula:

$$CD = S.E \times t_{0.05}$$

$$SE = \sqrt{\frac{2MSE}{r}}$$

where,

MSE = Error mean sum of squares

r = Number of replication

SE = Standard error of the difference of means to be compared.

t = Tabulated value of t at 5% level of significance

Heritability, genetic advance, genetic gain and correlation as described by Burton and DeVane, (1953) and Johnson *et al.* (1955).

B. Coefficient of variability:

Coefficient of variability was worked out by the formula. (Burton and DeVane, 1953).

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

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

$$ECV (\%) = \frac{\sqrt{V_e}}{\bar{X}} \times 100$$

where,

PCV, GCV and ECV are Phenotypic, Genotypic and Environmental Coefficients of variability respectively and $\bar{X}$ the population mean of character.

C. Heritability:

Heritability (h), was calculated as suggested by Burton and DeVane, (1953) and Johnson *et al.*, (1955).

$$h = \frac{V_g}{V_p}$$

where,

h = Broad Sense Heritability

V_g = Genotypic variance

V_p = Phenotypic variance

D. Genetic advance:

$$\text{Genetic advance} = h \times \sqrt{V_p} \times K$$

where,

h = Broad Sense Heritability

V_p = Phenotypic variance

K = Selection differential at 5% selection intensity

K = 2.06 (Allard, 1960)³³

E. Genetic gain:

Genetic gain was calculated as suggest by Johnson *et al.*, (1955).

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

where,

$\bar{X}$ = Population mean of character.

Chapter-4

EXPERIMENTAL RESULTS

The investigation on “**Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh**” was carried out during the year of 2011-13 to determine the variation among the trees and sites for morphological, chemical and progeny performance traits/ parameters. In all, two experiments were conducted, one each in field and laboratory conditions. The results obtained on different aspects are described under the following headings:

- 4.1 Variation in fruits and seeds traits
- 4.2 Variation in laboratory germination traits
- 4.3 Variation in oil content and physico-chemical traits
- 4.4 Variation in progeny performance traits
- 4.5 Estimation of genotypic and phenotypic correlation along with genetic parameters

4.1 VARIATION IN FRUITS AND SEEDS MORPHOMETRIC TRAITS OF *Sapindus mukorossi* AMONG DIFFERENT SEED SOURCES IN DIFFERENT DIAMETER CLASSES

Analysis of variance revealed that some fruits and seeds morphological traits exhibited variation between the seed sources but not among the D.B.H. classes of trees. This part of study was carried out to evaluate variation of seed sources and D.B.H. classes among the seed sources on fruits and seed traits of *Sapindus mukorossi*.

4.1.1 100 fruits weight

It is evident from the data presented in Table 2 (Fig 1) that the mean maximum 100 fruits weight (571.00 g) was recorded in Banjar seed source followed by Garsa (542.95 g) and Naina Tikkar (460.05 g), while the mean minimum fruits weight (240.03 g) was recorded in Kandaghat seed source. All seed sources were significantly different from each other.

On the other hand, two D.B.H. classes were non-significant. When D.B.H. among seed sources interaction was analysed, it also resulted into maximum mean 100 fruits weight shown by S₁₆D₂ (572.10 g) and minimum weight shown by S₂₁D₁ (237.33 g) and non-significant interaction was found between seed sources and D.B.H. classes.

Table 2. Variation in mean 100 fruits weight (g) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	412.53	409.67	411.10
S ₂ (Toruni Kamni)	373.00	366.43	369.72
S ₃ (Patka)	316.77	321.17	318.97
S ₄ (Simble ghatta)	347.27	354.83	351.05
S ₅ (Jachh)	365.03	355.03	360.03
S ₆ (Nagrota Bagwan)	364.87	363.87	364.37
S ₇ (Jwalamukhi)	442.00	435.23	438.62
S ₈ (Palampur)	435.10	434.30	434.70
S ₉ (Jogindra Nagar)	342.07	353.00	347.53
S ₁₀ (Baggi)	305.13	313.63	309.38
S ₁₁ (Chail Chowk)	323.13	334.03	328.58
S ₁₂ (Pandoh)	313.37	313.23	313.30
S ₁₃ (Bhuntar)	418.10	431.10	424.60
S ₁₄ (Garsa)	552.50	533.40	542.95
S ₁₅ (Panarsa)	419.13	429.37	424.25
S ₁₆ (Banjar)	569.90	572.10	571.00
S ₁₇ (Deothal)	440.80	445.13	442.97
S ₁₈ (Sarahan)	413.50	408.80	411.15
S ₁₉ (Naina Tikkar)	462.27	457.83	460.05
S ₂₀ (Nahan)	414.40	425.37	419.88
S ₂₁ (Kandaghat)	237.33	242.73	240.03
S ₂₂ (Thadi Subathu)	334.37	336.40	335.38
S ₂₃ (Shilly)	317.67	324.70	321.18
S ₂₄ (Jatoli)	344.83	340.57	342.70
Mean	386.04	387.58	
CD _{0.05}			
Seed sources (S)	16.139		
D.B.H. classes (D)	NS		
S×D	NS		

4.1.2 100 seed weight

As evident from Table 3 (Fig 2) that seed sources had significant variation on 100 seed weight, the 100 seed weight was observed to be mean maximum (226.05 g) in Banjar seed source, followed by Garsa (218.50 g) and Joginder Nagar (181.17 g),

Fig. 1. Variation in mean 100 fruits weight (g) of *Sapindus mukorossi* among seed sources in two different diameter classes

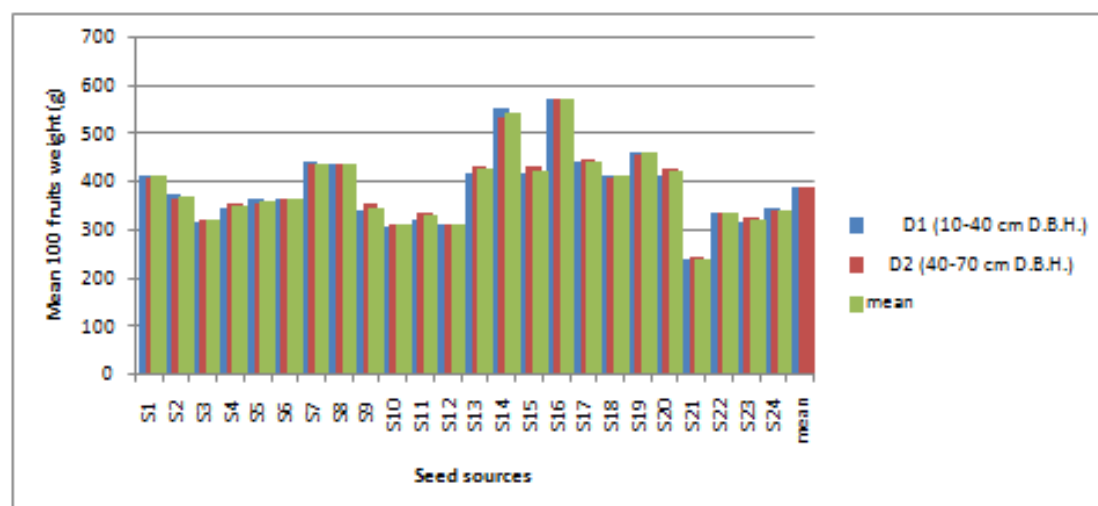


Fig. 2. Variation in mean 100 seeds weight (g) of *Sapindus mukorossi* among seed sources in two different diameter classes



whereas mean minimum seed weight was shown by Kandaghat seed source. Patka (140.63 g) and Shilly (141.95 g) were found statistically at par. On other hand D.B.H. classes showed non-significant variation. Interaction of seed sources and D.B.H. classes showed maximum mean seed weight for S₁₆D₂ and minimum for S₂₁D₁.

Table 3. Variation in mean 100 seed weight (g) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	141.73	146.83	144.28
S ₂ (Toruni Kamni)	145.37	143.77	144.57
S ₃ (Patka)	139.67	141.60	140.63
S ₄ (Simble ghatta)	160.30	161.13	160.72
S ₅ (Jachh)	163.00	161.53	162.27
S ₆ (Nagrota Bagwan)	160.30	161.83	161.07
S ₇ (Jwalamukhi)	169.77	168.40	169.08
S ₈ (Palampur)	167.63	166.17	166.90
S ₉ (Jogindra Nagar)	179.60	182.73	181.17
S ₁₀ (Baggi)	176.37	177.87	177.12
S ₁₁ (Chail Chowk)	176.60	177.00	176.80
S ₁₂ (Pandoh)	175.27	174.97	175.12
S ₁₃ (Bhuntar)	179.40	181.50	180.45
S ₁₄ (Garsa)	223.77	213.23	218.50
S ₁₅ (Panarsa)	181.70	188.87	185.28
S ₁₆ (Banjar)	225.77	226.33	226.05
S ₁₇ (Deothal)	158.10	159.87	158.98
S ₁₈ (Sarahan)	159.87	157.20	158.53
S ₁₉ (Naina Tikkar)	165.73	165.20	165.47
S ₂₀ (Nahan)	163.30	164.53	163.92
S ₂₁ (Kandaghat)	138.67	138.87	138.77
S ₂₂ (Thadi Subathu)	145.50	145.77	145.63
S ₂₃ (Shilly)	141.60	142.30	141.95
S ₂₄ (Jatoli)	152.47	151.43	151.95
Mean	166.31	166.62	
CD _{0.05}			
Seed sources (S)	3.057		
D.B.H. classes (D)	NS		
S×D	4.324		

4.1.3 Rind weight

Table 4 (Fig 3) illustrates the mean maximum rind weight (3.45 g) for Banjar seed source and followed by Garsa (3.24 g), Naina Tikkar (2.94 g), whereas mean minimum rind weight 1.32 g for Baggi and Kandaghat. For among D.B.H. class

variation, mean maximum rind weight recorded for D₂ (2.22 g) and mean minimum rind weight recorded for D₁ (2.20 g). Interaction of seed sources and D.B.H. classes showed mean maximum rind weight (3.46 g) in S₁₆D₂ and S₁₆D₁ (3.44 g) which were statistically at par, whereas mean minimum rind weight (1.28 g) recorded for S₁₀D₁ and S₂₁D₁ (1.29 g) found statistically at par.

Table 4. Variation in mean rind weight (g) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	2.70	2.62	2.66
S ₂ (Toruni Kamni)	2.28	2.23	2.26
S ₃ (Patka)	1.77	1.79	1.78
S ₄ (Simble ghatta)	1.84	1.93	1.89
S ₅ (Jachh)	2.02	1.93	1.98
S ₆ (Nagrota Bagwan)	2.05	2.03	2.04
S ₇ (Jwalamukhi)	2.72	2.67	2.70
S ₈ (Palampur)	2.67	2.67	2.67
S ₉ (Jogindra Nagar)	1.63	1.71	1.67
S ₁₀ (Baggi)	1.28	1.36	1.32
S ₁₁ (Chail Chowk)	1.46	1.57	1.51
S ₁₂ (Pandoh)	1.38	1.38	1.38
S ₁₃ (Bhuntar)	2.39	2.48	2.44
S ₁₄ (Garsa)	3.29	3.20	3.24
S ₁₅ (Panarsa)	2.37	2.44	2.41
S ₁₆ (Banjar)	3.44	3.46	3.45
S ₁₇ (Deothal)	2.82	2.85	2.83
S ₁₈ (Sarahan)	2.54	2.51	2.53
S ₁₉ (Naina Tikkar)	2.96	2.92	2.94
S ₂₀ (Nahan)	2.51	2.61	2.56
S ₂₁ (Kandaghat)	1.29	1.34	1.32
S ₂₂ (Thadi Subathu)	1.89	1.90	1.90
S ₂₃ (Shilly)	1.69	1.82	1.76
S ₂₄ (Jatoli)	1.92	1.89	1.90
Mean	2.21	2.22	
CD _{0.05}			
Seed sources (S)	0.030		
D.B.H. classes (D)	0.009		
S×D	0.042		

4.1.4 Seed diameter

Data appended in Table 5 (Fig 4) showed significant variation for seed sources, D.B.H. classes as well as for interaction of seed sources and D.B.H. classes.

Fig. 3. Variation in mean rind weight (g) of *Sapindus mukorossi* among seed sources in two different diameter classes

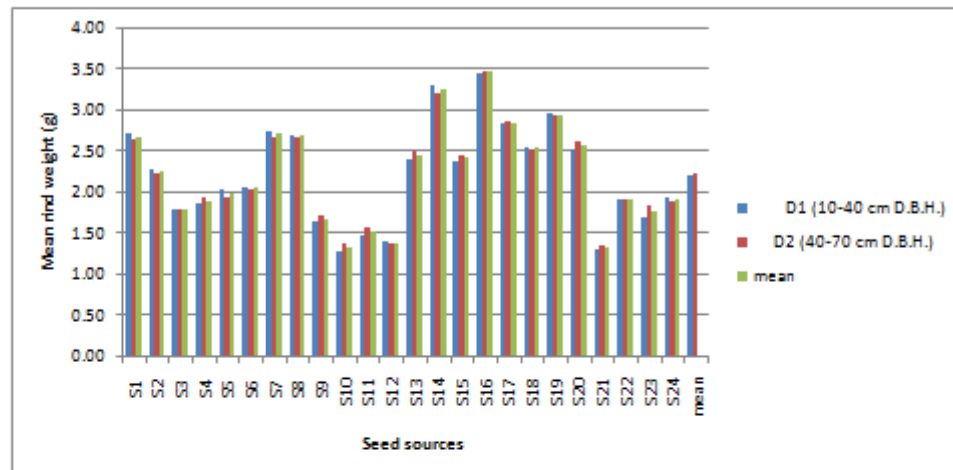
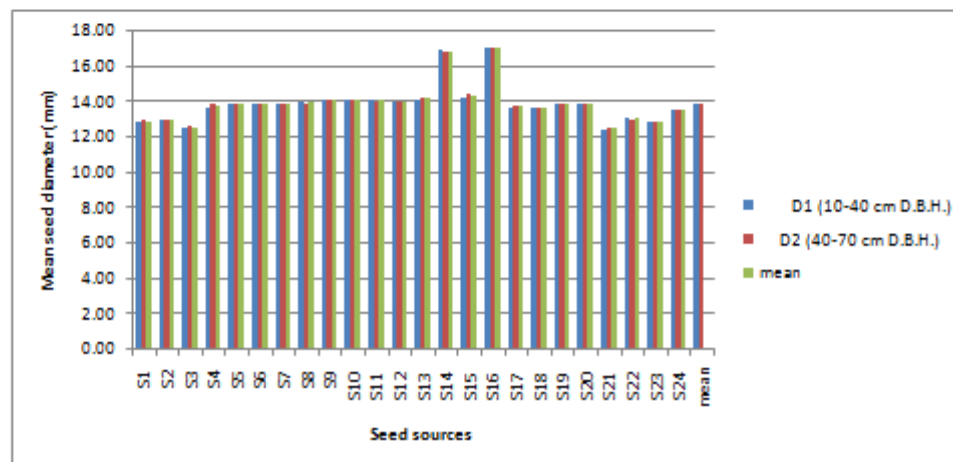


Fig. 4. Variation in mean seed diameter (mm) of *Sapindus mukorossi* among seed sources in two different diameter classes



Mean maximum seed diameter recorded for Banjar (17.02 mm) followed by Garsa (16.78 mm) and Panarsa (14.25 mm) seed sources, while minimum seed diameter recorded for Kandaghat (12.40 mm) followed by Patka (12.50 mm) and Shilly (12.81 mm) seed source. On the other hand mean maximum seed diameter recorded for D₂ (13.84 mm), while mean minimum for D₁ (13.82 mm). Interaction of seed sources and D.B.H. classes showed mean maximum diameter for combination S₁₆D₂ (17.03 mm) and S₁₆D₁ (17.01mm) which was statistically at par, while mean minimum seed diameter for S₂₁D₁ (12.38 mm) and S₂₁D₂ (12.42 mm) which was statistically at par.

Table 5. Variation in mean seed diameter (mm) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	12.78	12.91	12.85
S ₂ (Toruni Kamni)	12.90	12.87	12.89
S ₃ (Patka)	12.48	12.53	12.50
S ₄ (Simble ghatta)	13.56	13.80	13.68
S ₅ (Jachh)	13.78	13.81	13.80
S ₆ (Nagrota Bagwan)	13.80	13.79	13.80
S ₇ (Jwalamukhi)	13.85	13.87	13.86
S ₈ (Palampur)	13.93	13.85	13.89
S ₉ (Jogindra Nagar)	14.01	14.08	14.04
S ₁₀ (Baggi)	14.04	14.00	14.02
S ₁₁ (Chail Chowk)	14.02	13.95	13.99
S ₁₂ (Pandoh)	13.98	13.95	13.96
S ₁₃ (Bhuntar)	14.06	14.15	14.10
S ₁₄ (Garsa)	16.81	16.75	16.78
S ₁₅ (Panarsa)	14.17	14.32	14.25
S ₁₆ (Banjar)	17.01	17.03	17.02
S ₁₇ (Deothal)	13.62	13.69	13.66
S ₁₈ (Sarahan)	13.63	13.59	13.61
S ₁₉ (Naina Tikkar)	13.77	13.82	13.79
S ₂₀ (Nahan)	13.80	13.78	13.79
S ₂₁ (Kandaghat)	12.38	12.42	12.40
S ₂₂ (Thadi Subathu)	12.98	12.95	12.97
S ₂₃ (Shilly)	12.79	12.83	12.81
S ₂₄ (Jatoli)	13.53	13.49	13.51
Mean	13.82	13.84	
CD _{0.05}			
Seed sources (S)	0.032		
D.B.H. classes (D)	0.009		
S×D	0.045		

4.1.5 Kernel weight

A critical observation of data represented in Table 6 (Fig 5) depicted that variation between the seed sources in case of kernel weight were observed significant with highest mean kernel weight (613.48 mg) followed by Garsa (565.53 mg) and Baggi (455.55 mg), whereas mean minimum kernel weight observed for Kandaghat (352.80 mg). Among the site were shown significant variation with highest mean kernel weight of D₁ (420.66 mg) and minimum of D₂ (417.94 mg). For interaction of seed sources and D.B.H. classes mean maximum value is found of S₁₆D₁ (615.60 mg) and S₂₁D₂ (343.40 mg) significantly.

Table 6. Variation in mean kernel weight (mg) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	367.40	387.77	377.58
S ₂ (Toruni Kamni)	412.67	406.23	409.45
S ₃ (Patka)	383.63	395.60	389.62
S ₄ (Simble ghatta)	388.93	382.67	385.80
S ₅ (Jachh)	447.53	443.77	445.65
S ₆ (Nagrota Bagwan)	432.63	426.43	429.53
S ₇ (Jwalamukhi)	434.73	426.70	430.72
S ₈ (Palampur)	405.33	411.60	408.47
S ₉ (Jogindra Nagar)	431.43	442.90	437.17
S ₁₀ (Baggi)	452.53	458.57	455.55
S ₁₁ (Chail Chowk)	425.50	378.23	401.87
S ₁₂ (Pandoh)	361.97	380.90	371.43
S ₁₃ (Bhuntar)	412.60	405.67	409.13
S ₁₄ (Garsa)	576.40	554.67	565.53
S ₁₅ (Panarsa)	365.93	371.40	368.67
S ₁₆ (Banjar)	615.60	611.37	613.48
S ₁₇ (Deothal)	423.87	407.67	415.77
S ₁₈ (Sarahan)	421.77	424.30	423.03
S ₁₉ (Naina Tikkar)	397.40	402.23	399.82
S ₂₀ (Nahan)	361.70	354.73	358.22
S ₂₁ (Kandaghat)	362.20	343.40	352.80
S ₂₂ (Thadi Subathu)	425.70	428.67	427.18
S ₂₃ (Shilly)	385.87	382.50	384.18
S ₂₄ (Jatoli)	402.57	402.50	402.53
Mean	420.66	417.94	
CD _{0.05}			
Seed sources (S)	2.577		
D.B.H. classes (D)	0.744		
S×D	3.645		

Fig. 5. Variation in mean kernel weight (mg) of *Sapindus mukorossi* among seed sources in two different diameter classes

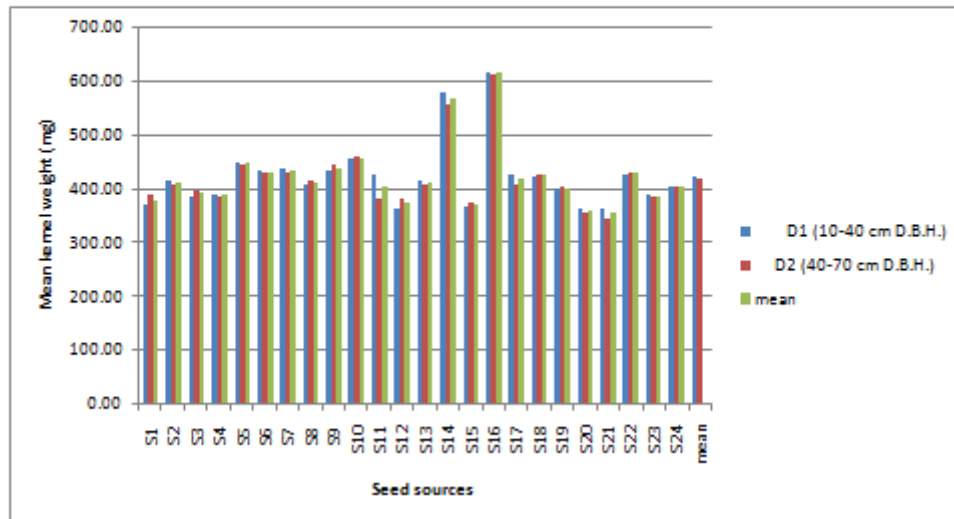
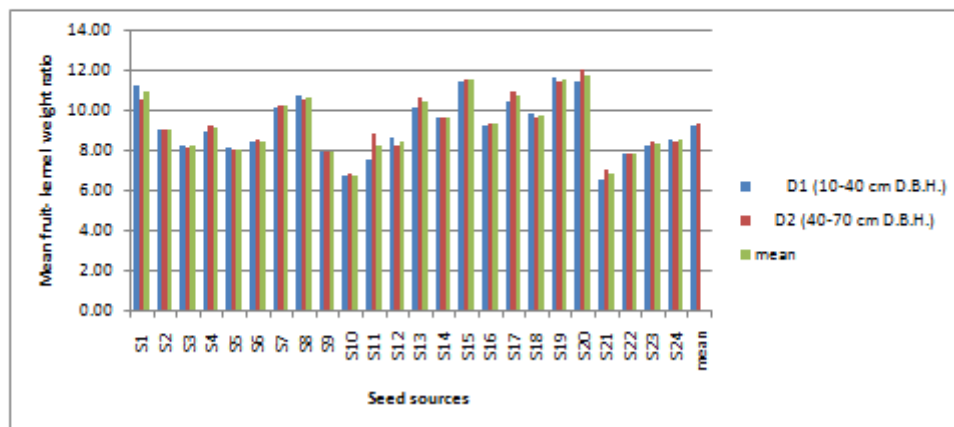


Fig. 6. Variation in mean fruit- kernel weight ratio of *Sapindus mukorossi* among seed sources in two different diameter classes



4.1.6 Fruit- kernel weight ratio

As evident from Table 7 (Fig 6) that seed sources, D.B.H. classes and interaction of seed sources and D.B.H. classes had significant variation on fruit-kernel weight ratio. The significant and highest mean fruit- kernel weight ratio (11.72) was recorded for Nahan, which was followed by Naina Tikkar (11.50) and Panarsa (11.50) both same, while least fruit- kernel weight ratio was recorded for Baggi (6.79) seed source which was statistically at par with Kandaghat (6.81). Among the D.B.H. classes maximum significantly variation on fruit- kernel weight ratio was shown by D₂ (9.30) and minimum by D₁ (9.20) diameter classes. Among various treatment combinations maximum Fruit- kernel weight ratio was recorded in S₂₀D₂ (11.99), whereas mean minimum fruit- kernel weight ratio was recorded in S₂₁D₁ (6.55).

Table 7. Variation in mean fruit- kernel weight ratio of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	11.23	10.56	10.90
S ₂ (Toruni Kamni)	9.04	9.02	9.03
S ₃ (Patka)	8.27	8.12	8.19
S ₄ (Simble ghatta)	8.93	9.27	9.10
S ₅ (Jachh)	8.16	8.00	8.08
S ₆ (Nagrota Bagwan)	8.43	8.53	8.48
S ₇ (Jwalamukhi)	10.17	10.20	10.19
S ₈ (Palampur)	10.73	10.55	10.64
S ₉ (Jogindra Nagar)	7.93	7.97	7.95
S ₁₀ (Baggi)	6.74	6.84	6.79
S ₁₁ (Chail Chowk)	7.59	8.83	8.21
S ₁₂ (Pandoh)	8.66	8.22	8.44
S ₁₃ (Bhuntar)	10.13	10.63	10.38
S ₁₄ (Garsa)	9.59	9.62	9.61
S ₁₅ (Panarsa)	11.45	11.56	11.50
S ₁₆ (Banjar)	9.26	9.36	9.31
S ₁₇ (Deothal)	10.44	10.92	10.68
S ₁₈ (Sarahan)	9.81	9.63	9.72
S ₁₉ (Naina Tikkar)	11.63	11.38	11.50
S ₂₀ (Nahan)	11.46	11.99	11.72
S ₂₁ (Kandaghat)	6.55	7.07	6.81
S ₂₂ (Thadi Subathu)	7.85	7.85	7.85
S ₂₃ (Shilly)	8.23	8.49	8.36
S ₂₄ (Jatoli)	8.57	8.46	8.52
Mean	9.20	9.30	
CD _{0.05}			
Seed sources (S)	0.019		
D.B.H. classes (D)	0.005		
S×D	0.027		

4.2 VARIATION IN LABORATORY GERMINATION TRAITS OF *Sapindus mukorossi* AMONG DIFFERENT SEED SOURCES IN DIFFERENT DIAMETER CLASSES

This part of study was carried out to investigate the variation of seed sources among different D.B.H. classes on seed viability and germination parameters of *Sapindus mukorossi* under laboratory conditions. The data pertaining to laboratory germination traits are presented in Tables 8-12 (Fig 7-11).

4.2.1 Seed viability

The contents of Table 8 (Fig 7) showed that seed variability does not varied significantly among different seed sources and D.B.H. classes. However, it

Table 8. Variation in mean seed viability (%) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	87.00	85.00	86.00
S ₂ (Toruni Kamni)	88.00	87.00	87.50
S ₃ (Patka)	83.67	88.67	86.17
S ₄ (Simble ghatta)	89.00	87.00	88.00
S ₅ (Jachh)	88.67	89.00	88.83
S ₆ (Nagrota Bagwan)	83.00	87.67	85.33
S ₇ (Jwalamukhi)	87.00	83.67	85.33
S ₈ (Palampur)	83.67	87.00	85.33
S ₉ (Jogindra Nagar)	86.00	87.33	86.67
S ₁₀ (Baggi)	90.00	85.00	87.50
S ₁₁ (Chail Chowk)	88.33	84.67	86.50
S ₁₂ (Pandoh)	85.67	87.00	86.33
S ₁₃ (Bhuntar)	89.00	83.67	86.33
S ₁₄ (Garsa)	85.33	88.67	87.00
S ₁₅ (Panarsa)	88.67	86.67	87.67
S ₁₆ (Banjar)	90.00	89.67	89.83
S ₁₇ (Deothal)	86.00	82.67	84.33
S ₁₈ (Sarahan)	85.67	82.00	83.83
S ₁₉ (Naina Tikkar)	87.00	86.67	86.83
S ₂₀ (Nahan)	82.00	82.00	82.00
S ₂₁ (Kandaghat)	85.00	85.00	85.00
S ₂₂ (Thadi Subathu)	87.00	87.333	87.167
S ₂₃ (Shilly)	82.67	81.333	82.000
S ₂₄ (Jatoli)	82.33	84.667	83.500
Mean	86.28	85.806	
CD _{0.05}			
Seed sources (S) NS			
D.B.H. classes (D) NS			
S×D NS			

Fig. 7 Variation in mean seed viability (%) of *Sapindus mukorossi* among seed sources in two different diameter classes

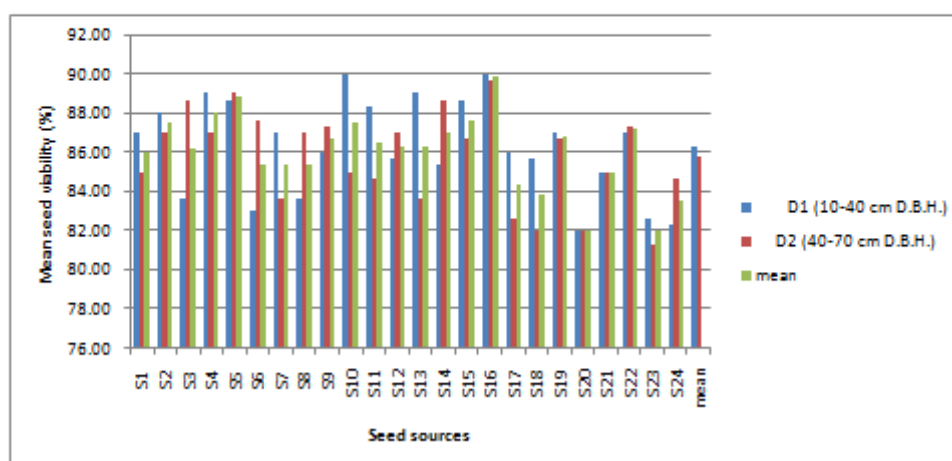
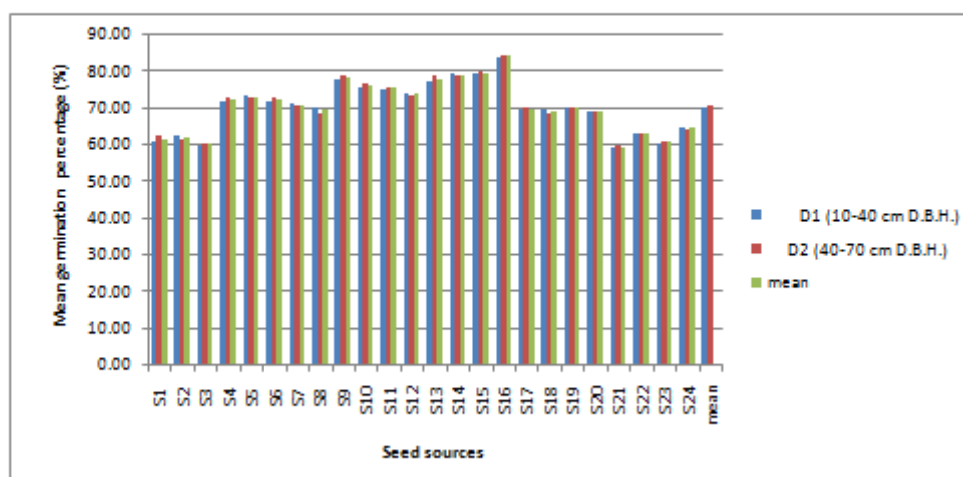


Fig. 8 Variation in mean germination percentage among seed sources in two different diameter classes



was recorded mean maximum (89.83%) for Banjar seed source followed by Jachh (88.83%) and Simble Ghatta (88.00%) seed source, whereas mean minimum seed variability recorded (82.00%) for Nahan and Shilly among different seed sources. Variation in seed sources, D.B.H. classes and interaction of seed sources and D.B.H. classes was found non-significant.

4.2.2 Germination percentage

It is evident from data presented in Table 9 (Fig 8) that germination percentage was significantly affected by the different seed sources, while D.B.H. classes and interaction of seed sources and D.B.H. classes was found non-significant

Table 9. Variation in mean germination percentage (%) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	60.67	62.00	61.33
S ₂ (Toruni Kamni)	62.33	61.33	61.83
S ₃ (Patka)	59.67	60.00	59.83
S ₄ (Simble ghatta)	71.33	72.33	71.83
S ₅ (Jachh)	73.00	72.33	72.67
S ₆ (Nagrota Bagwan)	71.67	72.33	72.00
S ₇ (Jwalamukhi)	70.67	70.33	70.50
S ₈ (Palampur)	69.67	68.33	69.00
S ₉ (Jogindra Nagar)	77.33	78.33	77.83
S ₁₀ (Baggi)	75.33	76.33	75.83
S ₁₁ (Chail Chowk)	75.00	75.33	75.17
S ₁₂ (Pandoh)	73.67	73.33	73.50
S ₁₃ (Bhuntar)	76.67	78.67	77.67
S ₁₄ (Garsa)	79.00	78.33	78.67
S ₁₅ (Panarsa)	79.00	79.67	79.33
S ₁₆ (Banjar)	83.67	84.00	83.83
S ₁₇ (Deothal)	69.00	69.67	69.33
S ₁₈ (Sarahan)	69.33	68.33	68.83
S ₁₉ (Naina Tikkar)	70.00	69.67	69.83
S ₂₀ (Nahan)	68.67	68.67	68.67
S ₂₁ (Kandaghat)	58.67	59.33	59.00
S ₂₂ (Thadi Subathu)	62.67	62.67	62.67
S ₂₃ (Shilly)	60.00	60.667	60.333
S ₂₄ (Jatoli)	64.33	64.000	64.167
Mean	70.06	70.250	
CD _{0.05}			
Seed sources (S)	1.977		
D.B.H. classes (D)	NS		
S×D	NS		

for germination percentage. Significant mean maximum (83.83%) germination percentage recorded for Banjar seed sources, followed by Panarsa (79.33%) and Garsa (78.67%) seed sources, whereas mean minimum germination percentage was recorded for Kandaghat (59.00%) which was statistically at par with Patka (59.83%) and Shilly (60.33%), among different seed sources.

4.2.3 Germination capacity

The germination capacity of the seeds of *Sapindus mukorossi* was studied and the data is enshrined in Table 10 (Fig 9). The contents of the table revealed that the germination capacity showed significant variation among seed sources. The maximum mean germination capacity (88.00%) was recorded for Banjar seed source, which is closely followed by Panarsa (85.83%) and Garsa (84.83%)

Table 10. Variation in mean germination capacity (%) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	67.00	67.00	67.00
S ₂ (Toruni Kamni)	68.67	68.67	68.67
S ₃ (Patka)	64.83	64.83	64.83
S ₄ (Simble ghatta)	73.17	73.17	73.17
S ₅ (Jachh)	74.67	74.67	74.67
S ₆ (Nagrota Bagwan)	76.00	76.00	76.00
S ₇ (Jwalamukhi)	77.50	77.50	77.50
S ₈ (Palampur)	75.33	75.33	75.33
S ₉ (Jogindra Nagar)	82.67	82.67	82.67
S ₁₀ (Baggi)	81.00	81.00	81.00
S ₁₁ (Chail Chowk)	79.67	79.67	79.67
S ₁₂ (Pandoh)	77.50	77.50	77.50
S ₁₃ (Bhuntar)	82.50	82.50	82.50
S ₁₄ (Garsa)	84.83	84.83	84.83
S ₁₅ (Panarsa)	85.83	85.83	85.83
S ₁₆ (Banjar)	88.00	88.00	88.00
S ₁₇ (Deothal)	76.50	76.50	76.50
S ₁₈ (Sarahan)	74.83	74.83	74.83
S ₁₉ (Naina Tikkar)	75.67	75.67	75.67
S ₂₀ (Nahan)	75.17	75.17	75.17
S ₂₁ (Kandaghat)	64.17	64.17	64.17
S ₂₂ (Thadi Subathu)	73.00	73.00	73.00
S ₂₃ (Shilly)	66.33	66.33	66.33
S ₂₄ (Jatoli)	70.83	70.83	70.83
Mean			
CD _{0.05}			
Seed sources (S)	1.512		
D.B.H. classes (D)	NS		
S×D	NS		

Fig. 9. Variation in mean germination capacity (%) of *Sapindus mukorossi* among seed sources in two different diameter classes

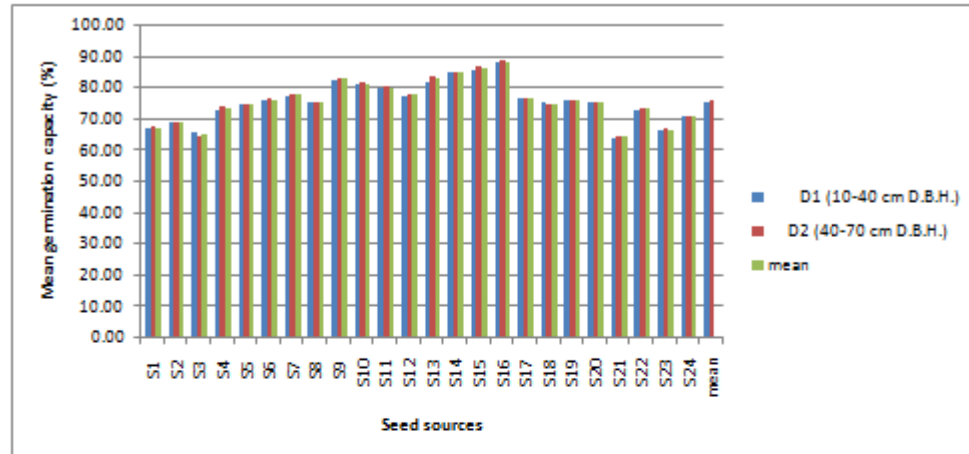
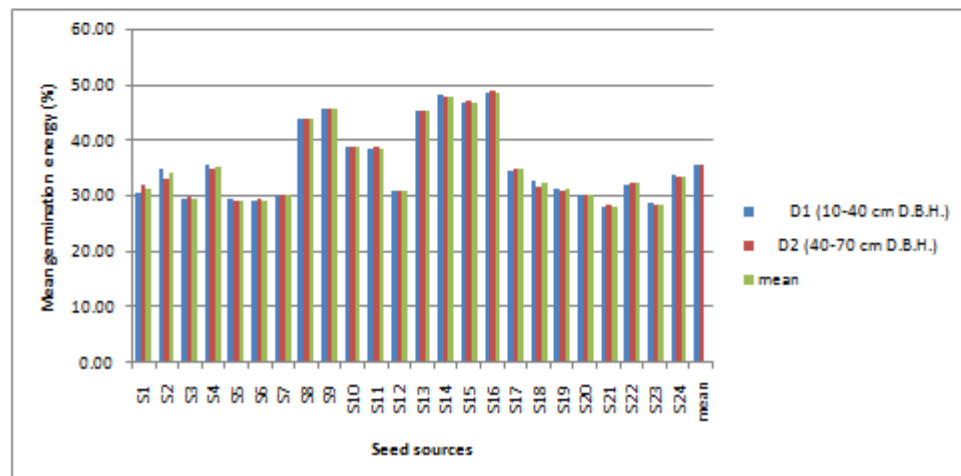


Fig. 10. Variation in mean germination energy (%) of *Sapindus mukorossi* among seed sources in two different diameter classes



among different seed sources, whereas mean minimum germination capacity was recorded for Kandaghat (64.17%) seed sources which was statistically at par with Patka (64.83%) among different seed sources. On the other hand, when the difference analysed among D.B.H. classes was found non-significant and interaction of seed sources and D.B.H. classes was also found non-significant for germination capacity.

4.2.4 Germination energy

The critical analysis of data presented in Table 11 (Fig 10) reflects that significant variation has been noticed on germination energy among different seed sources, while D.B.H. classes and interaction of seed sources and D.B.H. classes recorded non-significant variation for germination energy. The highest mean

Table 11. Variation in mean germination energy (%) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	30.67	32.00	31.33
S ₂ (Toruni Kamni)	35.00	33.00	34.00
S ₃ (Patka)	29.33	29.67	29.50
S ₄ (Simble ghatta)	35.67	35.00	35.33
S ₅ (Jachh)	29.33	29.00	29.17
S ₆ (Nagrota Bagwan)	29.00	29.33	29.17
S ₇ (Jwalamukhi)	30.00	30.33	30.17
S ₈ (Palampur)	44.00	43.67	43.83
S ₉ (Jogindra Nagar)	45.67	45.67	45.67
S ₁₀ (Baggi)	38.67	38.67	38.67
S ₁₁ (Chail Chowk)	38.33	38.67	38.50
S ₁₂ (Pandoh)	31.00	31.00	31.00
S ₁₃ (Bhuntar)	45.33	45.33	45.33
S ₁₄ (Garsa)	48.00	47.67	47.83
S ₁₅ (Panarsa)	46.67	47.00	46.83
S ₁₆ (Banjar)	48.33	49.00	48.67
S ₁₇ (Deothal)	34.67	35.00	34.83
S ₁₈ (Sarahan)	32.67	31.67	32.17
S ₁₉ (Naina Tikkar)	31.33	31.00	31.17
S ₂₀ (Nahan)	30.33	30.33	30.33
S ₂₁ (Kandaghat)	28.00	28.33	28.17
S ₂₂ (Thadi Subathu)	32.00	32.33	32.17
S ₂₃ (Shilly)	28.67	28.33	28.50
S ₂₄ (Jatoli)	33.67	33.33	33.50
mean	35.68	35.64	
CD _{0.05}			
Seed sources (S)	5.274		
D.B.H. classes (D)	NS		
S×D	NS		

energy was recorded for Banjar (48.67%) which was statistically at par with Garsa (47.83%), Panarsa (46.83%), Jogindra Nagar (45.67%) and Bhunter (45.33%) whereas the lowest mean germination energy was recorded for Kandaghat (28.17%) which was statistically at par with Shilly (28.50%), Jachh and Nagrota Bagwan (29.17%), Patka (29.50%), Jwalamukhi (30.17%), Nahan(30.33%), Pandoh (31.00%), Naina Tikkar (31.17%), Trimuth (31.33%), Thadi Subathu (32.17%) and Sarahan (32.17%) among different seed sources.

4.2.5 Number of days taken to initiate germination

The contents of the Table 12 (Fig 11) revealed that seed sources have significant effect on the number of days taken to initiate germination. It has been

Table 12. Variation in mean number of days taken for initiation of germination in *Sapindus mukorossi* at different seed source in different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	27.67	25.67	26.67
S ₂ (Toruni Kamni)	26.00	26.33	26.17
S ₃ (Patka)	28.00	28.00	28.00
S ₄ (Simble ghatta)	27.00	26.67	26.83
S ₅ (Jachh)	26.00	25.67	25.83
S ₆ (Nagrota Bagwan)	28.00	27.00	27.50
S ₇ (Jwalamukhi)	25.00	25.33	25.17
S ₈ (Palampur)	25.33	25.00	25.17
S ₉ (Jogindra Nagar)	22.67	21.67	22.17
S ₁₀ (Baggi)	24.00	23.67	23.83
S ₁₁ (Chail Chowk)	24.33	24.00	24.17
S ₁₂ (Pandoh)	23.00	23.00	23.00
S ₁₃ (Bhuntar)	24.00	23.00	23.50
S ₁₄ (Garsa)	20.00	21.67	20.83
S ₁₅ (Panarsa)	24.00	23.67	23.83
S ₁₆ (Banjar)	19.67	19.00	19.33
S ₁₇ (Deothal)	24.00	24.67	24.33
S ₁₈ (Sarahan)	24.67	25.00	24.83
S ₁₉ (Naina Tikkar)	25.33	25.67	25.50
S ₂₀ (Nahan)	25.00	24.33	24.67
S ₂₁ (Kandaghat)	29.33	29.33	29.33
S ₂₂ (Thadi Subathu)	25.33	25.33	25.33
S ₂₃ (Shilly)	28.33	28.00	28.17
S ₂₄ (Jatoli)	25.00	25.33	25.17
Mean	25.07	24.88	
CD _{0.05}			
Seed sources (S)	3.210		
D.B.H. classes (D)	NS		
S×D	NS		

Fig. 11. Variation in mean number of days taken for initiation germination among seed sources in two different diameter classes

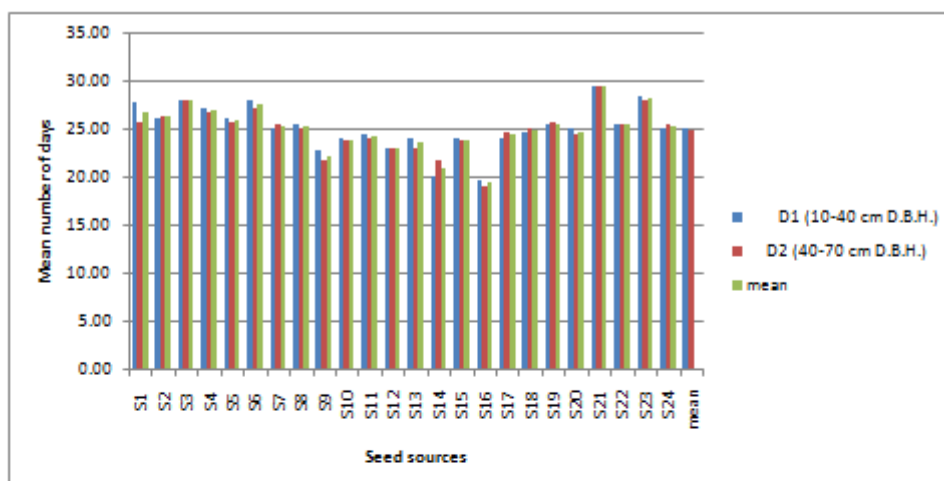
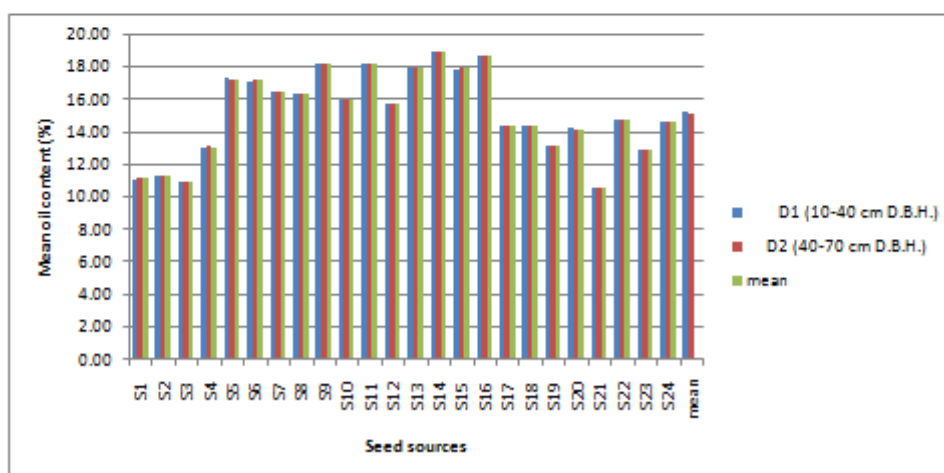


Fig. 12. Variation in mean oil content (%) of *Sapindus mukorossi* among seed sources in two different diameter classes



recorded that Banjar took mean minimum number of days (19.33 days) to start germination which was statistically at par with Garsa (20.83 days) and Jogindra Nagar (22.17 days) whereas Kandaghat (29.33 days) took mean maximum number of days to start germination which was statistically at par with Shilly (28.17 days), Patka (28.00 days), Nagrota Bagwan (27.50 days), Simble Ghatta (26.83 days), Trimuth (26.67 days) and Tornu Kamni (26.17 days) among different seed sources. On the other hand non significant variation has been recorded on number of days taken to initiate germination among different D.B.H. classes. Interaction of seed sources and D.B.H. classes recorded also non-significant for number of days taken to initiate germination.

4.3 VARIATION IN OIL CONTENT AND PHYSICO-CHEMICAL TRAITS VARIATION OF *Sapindus mukorossi* AMONG DIFFERENT SEED SOURCES IN DIFFERENT DIAMETER CLASSES

This part of study was carried out to investigate the variation of seed sources among different D.B.H. classes on oil content and physico-chemical traits parameters of *Sapindus mukorossi* under laboratory conditions. The data pertaining to this study are presented in Tables 13-14 (Fig 12-16).

4.3.1 Variation in oil content

The content of the data presented in Table 13 (Fig 12) showed that all the seed sources of *Sapindus mukorossi* registered a significant variation in seed oil content. On seed basis highest mean oil content (18.91%) was recorded in Garsa seed sources followed by Banjar (18.71%) and Jogindra Nagar (18.18%) whereas mean minimum oil content was recorded in Kandadgat (10.52%) followed by Patka (10.95%) and Trimuth (11.12%) among different seed sources. The variation among D.B.H. revealed that mean maximum oil content was recorded in D₁ (15.15%) whereas mean minimum oil content was recorded in D₂ but these D.B.H. classes don't show distinct significant variation.

Among the seed sources and D.B.H. classes interaction, mean maximum oil content was shown by S₁₄D₁ (18.93%) which was statistically at par with S₁₄D₂

(18.89%) whereas mean minimum oil content shown by S₂₁D₂ (10.52%) which was statistically at par with S₂₁D₁ (10.52%).

Table 13. Variation in mean oil content (%) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	Diameter classes		Mean
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	
S ₁ (Trimuth)	11.08	11.17	11.12
S ₂ (Toruni Kamni)	11.29	11.23	11.26
S ₃ (Patka)	10.92	10.98	10.95
S ₄ (Simble ghatta)	13.01	13.09	13.05
S ₅ (Jachh)	17.29	17.19	17.24
S ₆ (Nagrota Bagwan)	17.11	17.13	17.12
S ₇ (Jwalamukhi)	16.43	16.41	16.42
S ₈ (Palampur)	16.32	16.31	16.32
S ₉ (Jogindra Nagar)	18.21	18.16	18.18
S ₁₀ (Baggi)	15.91	15.95	15.93
S ₁₁ (Chail Chowk)	18.12	18.12	18.12
S ₁₂ (Pandoh)	15.74	15.65	15.70
S ₁₃ (Bhuntar)	17.90	17.91	17.90
S ₁₄ (Garsa)	18.93	18.89	18.91
S ₁₅ (Panarsa)	17.85	17.86	17.85
S ₁₆ (Banjar)	18.70	18.71	18.71
S ₁₇ (Deothal)	14.38	14.39	14.39
S ₁₈ (Sarahan)	14.38	14.31	14.34
S ₁₉ (Naina Tikkar)	13.19	13.19	13.19
S ₂₀ (Nahan)	14.18	14.16	14.17
S ₂₁ (Kandaghat)	10.52	10.52	10.52
S ₂₂ (Thadi Subathu)	14.76	14.76	14.76
S ₂₃ (Shilly)	12.89	12.90	12.90
S ₂₄ (Jatoli)	14.60	14.59	14.59
Mean	15.16	15.15	
CD _{0.05}			
Seed sources (S)	0.042		
D.B.H. classes (D)	0.012		
S×D	0.059		

4.3.2 Variation in chemical traits

4.3.2.1 Viscosity

The content of Table 14 (Fig 13) reflects that no significant variation has been observed in different seed sources for viscosity of extracted oil. Viscosity among D.B.H. classes and Interaction of seed sources and D.B.H. classes were also recorded to be non-significant. However highest mean value was recorded in oil samples extracted from seed of Bhunter (22.808) seed sources followed by Banjar

Fig. 13. Variation in mean viscosity of *Sapindus mukorossi* among seed sources in two different diameter classes

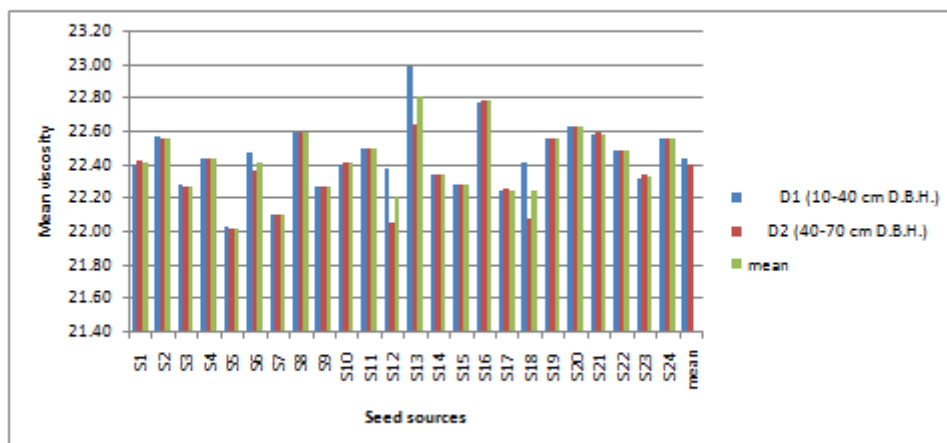
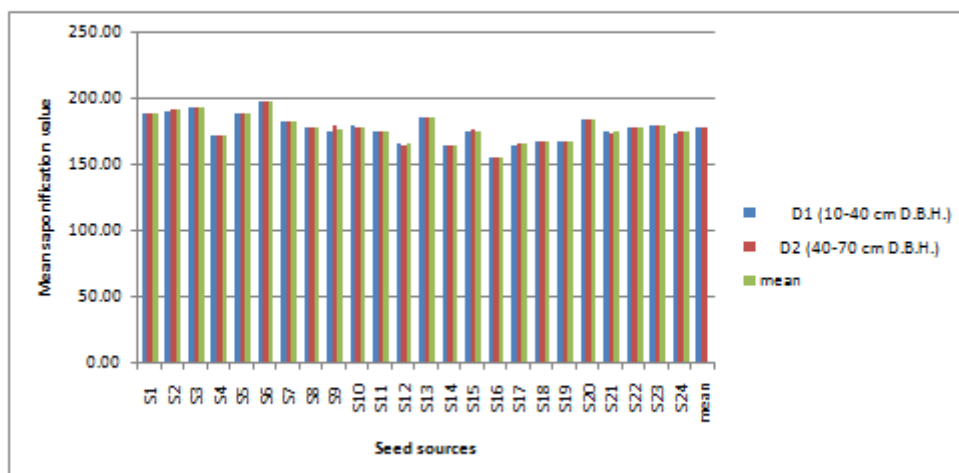


Fig. 14. Variation in mean saponification value of *Sapindus mukorossi* among seed sources in two different diameter classes



(22.775) and Nahan (22.625) among different seed sources. Whereas lowest mean value of viscosity was recorded in oil samples extracted from seed of Jachh (22.017) followed by Jwalamukhi (22.775) and Nahan (22.207) among different seed sources.

4.3.2.2 Saponification value

Table 14 (Fig 14) illustrates the highest mean saponification value among different seed sources observed for Nagrota Bagwan (196.988 mg KOH/g) followed by Patka (191.860 mg KOH/g) and Tornu Kamni (190.578 mg KOH/g), whereas lowest mean value was observed for Banjar (154.738 mg KOH/g) followed by Garsa (163.337 mg KOH/g) and Tornu Kamni (164.337 mg KOH/g).

The content of Table 14 revealed that no significant variation has been observed for saponification value among different seed sources, D.B.H. classes and interaction of seed sources and D.B.H. classes.

4.3.2.3 Specific gravity

The critical analysis of data presented in Table 14 (Fig 15) revealed that no significant variation has been observed for specific gravity among different seed sources, D.B.H. classes and interaction of seed sources and D.B.H. classes. Specific gravity ranged between 0.903 to 0.904.

4.3.2.4 Refractive index

Data presented in Table 14 (Fig 16) indicate that no significant variation has been observed for refractive index among different seed sources, D.B.H. classes and interaction of seed sources and D.B.H. classes. Refractive index value ranged from 1.467-1.468.

Table 14. Variation in mean physico-chemical traits of *Sapindus mukorossi* among different seed sources in two different diameter classes

SEED SOURCES	VISCOSITY			SAPONIFICATION VALUE			SPECIFIC GRAVITY			REFRACTIVE INDEX		
	D ₁	D ₂	Mean	D ₁	D ₂	Mean	D ₁	D ₂	Mean	D ₁	D ₂	Mean
S ₁ (Trimuth)	22.400	22.423	22.412	187.350	187.567	187.458	0.904	0.904	0.904	1.467	1.467	1.467
S ₂ (Toruni Kamni)	22.563	22.550	22.557	190.113	191.043	190.578	0.903	0.903	0.903	1.467	1.467	1.467
S ₃ (Patka)	22.273	22.263	22.268	191.700	191.860	191.780	0.904	0.904	0.904	1.467	1.467	1.467
S ₄ (Simble ghatta)	22.433	22.437	22.435	170.963	170.593	170.778	0.903	0.903	0.903	1.468	1.467	1.468
S ₅ (Jachh)	22.020	22.013	22.017	188.260	188.157	188.208	0.903	0.903	0.903	1.467	1.467	1.467
S ₆ (Nagrota Bagwan)	22.467	22.357	22.412	197.000	196.977	196.988	0.903	0.903	0.903	1.468	1.467	1.467
S ₇ (Jwalamukhi)	22.100	22.093	22.097	182.043	181.720	181.882	0.903	0.903	0.903	1.467	1.468	1.467
S ₈ (Palampur)	22.587	22.590	22.588	177.763	177.373	177.568	0.903	0.903	0.903	1.467	1.467	1.467
S ₉ (Jogindra Nagar)	22.260	22.260	22.260	174.540	178.303	176.422	0.903	0.904	0.903	1.467	1.467	1.467
S ₁₀ (Baggi)	22.397	22.413	22.405	178.037	177.390	177.713	0.903	0.903	0.903	1.468	1.467	1.467
S ₁₁ (Chail Chowk)	22.490	22.487	22.488	174.593	174.903	174.748	0.904	0.904	0.904	1.468	1.468	1.468
S ₁₂ (Pandoh)	22.370	22.043	22.207	164.593	164.230	164.412	0.903	0.903	0.903	1.467	1.467	1.467
S ₁₃ (Bhuntar)	22.980	22.637	22.808	185.093	185.350	185.222	0.904	0.904	0.904	1.468	1.468	1.468
S ₁₄ (Garsa)	22.337	22.337	22.337	163.403	163.270	163.337	0.903	0.903	0.903	1.468	1.468	1.468
S ₁₅ (Panarsa)	22.277	22.270	22.273	174.233	175.667	174.950	0.905	0.904	0.904	1.468	1.468	1.468
S ₁₆ (Banjar)	22.773	22.777	22.775	155.063	154.413	154.738	0.904	0.903	0.903	1.468	1.468	1.468
S ₁₇ (Deothal)	22.240	22.247	22.243	164.383	165.437	164.910	0.904	0.904	0.904	1.468	1.468	1.468
S ₁₈ (Sarahan)	22.410	22.077	22.243	166.013	166.137	166.075	0.903	0.903	0.903	1.467	1.467	1.467
S ₁₉ (Naina Tikkar)	22.547	22.557	22.552	166.097	166.130	166.113	0.904	0.904	0.904	1.467	1.467	1.467
S ₂₀ (Nahan)	22.630	22.620	22.625	183.443	183.800	183.622	0.903	0.903	0.903	1.468	1.468	1.468
S ₂₁ (Kandaghat)	22.573	22.583	22.578	173.947	173.027	173.487	0.904	0.904	0.904	1.467	1.467	1.467
S ₂₂ (Thadi Subathu)	22.483	22.483	22.483	177.160	177.503	177.332	0.903	0.903	0.903	1.467	1.468	1.467
S ₂₃ (Shilly)	22.317	22.340	22.328	179.083	179.540	179.312	0.904	0.904	0.904	1.467	1.467	1.467
S ₂₄ (Jatoli)	22.550	22.553	22.552	173.397	174.393	173.895	0.903	0.903	0.903	1.468	1.467	1.467
Mean	22.437	22.392		176.595	176.866		0.903	0.903		1.467	1.467	
CD _{0.05}												
Seed Sources (S)	NS			NS			NS			NS		
D.B.H. classes (D)	NS			NS			NS			NS		
SXD	NS			NS			NS			NS		

Fig. 15. Variation in mean specific gravity of *Sapindus mukorossi* among seed sources in two different diameter classes

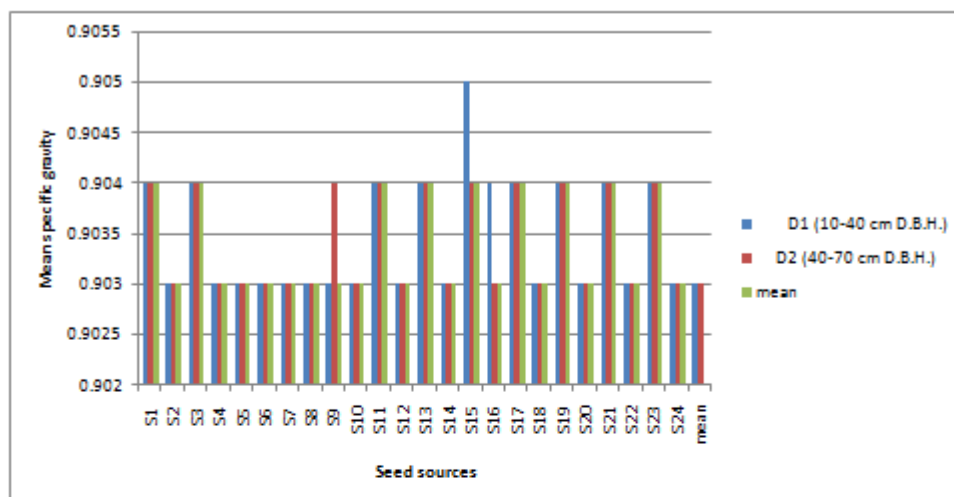
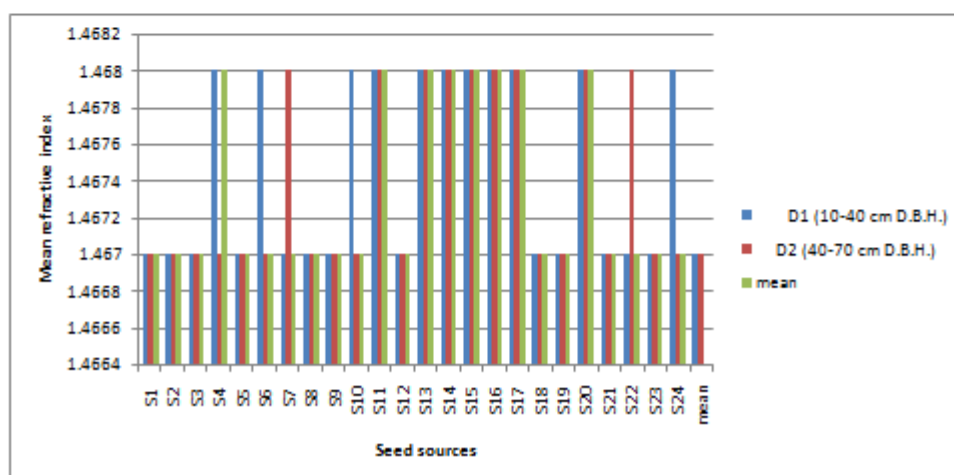


Fig. 16. Variation in mean refractive index of *Sapindus mukorossi* among seed sources in two different diameter classes



4.4 VARIATION IN PROGENY PERFORMANCE TRAITS OF *Sapindus mukorossi* AMONG DIFFERENT SEED SOURCES IN DIFFERENT DIAMETER CLASSES

This part of study was carried out to investigate the variation of seed sources among different D.B.H. classes on progeny performance traits of *Sapindus mukorossi* in nursery. The data pertaining to this study are presented in Tables 15-21 (Fig 17-23).

4.4.1 Shoot length

Table 15. Variation in mean shoot length (cm) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	12.57	13.37	12.97	37.40	38.90	38.15
S ₂ (Toruni Kamni)	12.93	12.93	12.93	38.10	37.80	37.95
S ₃ (Patka)	12.13	12.10	12.12	37.10	37.20	37.15
S ₄ (Simble ghatta)	14.80	15.07	14.93	42.80	43.20	43.00
S ₅ (Jachh)	15.50	15.27	15.38	44.20	43.50	43.85
S ₆ (Nagrota Bagwan)	14.90	15.07	14.98	42.70	43.60	43.15
S ₇ (Jwalamukhi)	17.83	17.60	17.72	46.80	46.40	46.60
S ₈ (Palampur)	17.37	17.43	17.40	46.20	46.10	46.15
S ₉ (Jogindra Nagar)	19.10	19.77	19.43	49.70	50.60	50.15
S ₁₀ (Baggi)	18.33	18.83	18.58	48.40	49.10	48.75
S ₁₁ (Chail Chowk)	18.50	18.60	18.55	48.30	48.80	48.55
S ₁₂ (Pandoh)	18.43	18.13	18.28	47.40	47.10	47.25
S ₁₃ (Bhuntar)	19.30	19.60	19.45	49.80	50.40	50.10
S ₁₄ (Garsa)	22.63	21.67	22.15	56.20	54.70	55.45
S ₁₅ (Panarsa)	19.80	20.13	19.97	50.90	51.10	51.00
S ₁₆ (Banjar)	22.93	23.77	23.35	57.20	57.40	57.30
S ₁₇ (Deothal)	14.30	14.53	14.42	41.60	42.10	41.85
S ₁₈ (Sarahan)	14.53	14.10	14.32	42.00	41.20	41.60
S ₁₉ (Naina Tikkar)	16.77	16.90	16.83	45.50	45.50	45.50
S ₂₀ (Nahan)	16.10	16.17	16.13	44.40	44.80	44.60
S ₂₁ (Kandaghat)	11.13	11.43	11.28	34.10	35.10	34.60
S ₂₂ (Thadi Subathu)	13.10	13.33	13.22	38.60	38.80	38.70
S ₂₃ (Shilly)	12.20	12.40	12.30	37.44	37.70	37.57
S ₂₄ (Jatoli)	13.63	13.57	13.60	40.50	40.30	40.40
Mean	16.20	16.32		44.47	44.64	
CD _{0.05}						
Seed Sources (S)	3.063			3.065		
D.B.H. classes (D)	NS			NS		
SXD	NS			NS		

Shoot length was observed at intervals of 3 months and 6 months and the data obtained is presented in Table 15 (Fig 17). The data revealed that at 3 months after sowing, seed sources showed significant variation and highest shoot length 23.35 cm for Banjar seed source which was statistically at par with 22.15 cm for Garsa seed source, while Kandaghat seed source showed lowest 11.18 cm shoot length, which was statistically at par with 12.12 cm, 12.30 cm, 12.93 cm, 12.97 cm, 13.222 cm, 13.60 cm and 14.32 cm recorded for Patka, Shilly, Tornu Kamni, Trimuth, Thadi Subathu, Jatoli and Sarahan seed sources. On the other hand non significant variation has been recorded on number of days taken to initiate germination among different D.B.H. classes. Interaction of seed sources and D.B.H. classes also recorded non-significant variation for number of days taken to initiate germination.

At an interval of 6 months after sowing among different seed sources, maximum seedling height 57.30 cm was observed for Banjar seed sources which was statistically at par with 55.45 cm for Garsa seed source, which registered significant variation among all other seed sources, while minimum 34.60 cm was recorded for Kandaghat, which was found statistically at par with 37.57 cm for Shilly seed sources. On the other hand, the difference among D.B.H. classes and interaction of seed sources and D.B.H. classes was found non-significant for shoot length.

4.4.2 Root length

The contents of Table 16 (Fig 18) revealed that at an interval of 3 month after sowing, significant variation has been observed on root length among different seed sources, while among D.B.H. classes and interaction of seed sources and D.B.H. classes were found non-significant for shoot length. Maximum root length was recorded for Banjar seed sources (18.47 cm), which has been found statistically at par with Garsa (17.43 cm) seed source and minimum root length was recorded for Kandaghat (8.65 cm) seed sources, which has been found statistically at par with Patka (9.23 cm), Tornu Kamni (9.95 cm) and Trimuth (10.10 cm) seed sources.

At an interval of 6 months after sowing, among different seed sources maximum seedling height was observed for Garsa (42.20 cm) seed source which

Fig. 17. Variation in mean shoot length (cm) of *Sapindus mukorossi* among seed sources in two different diameter classes

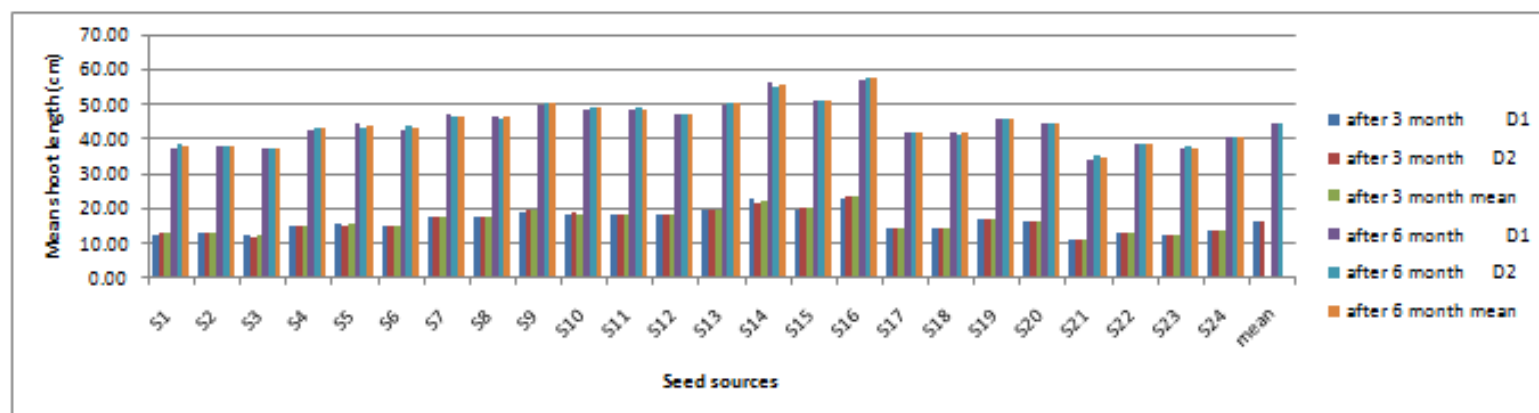
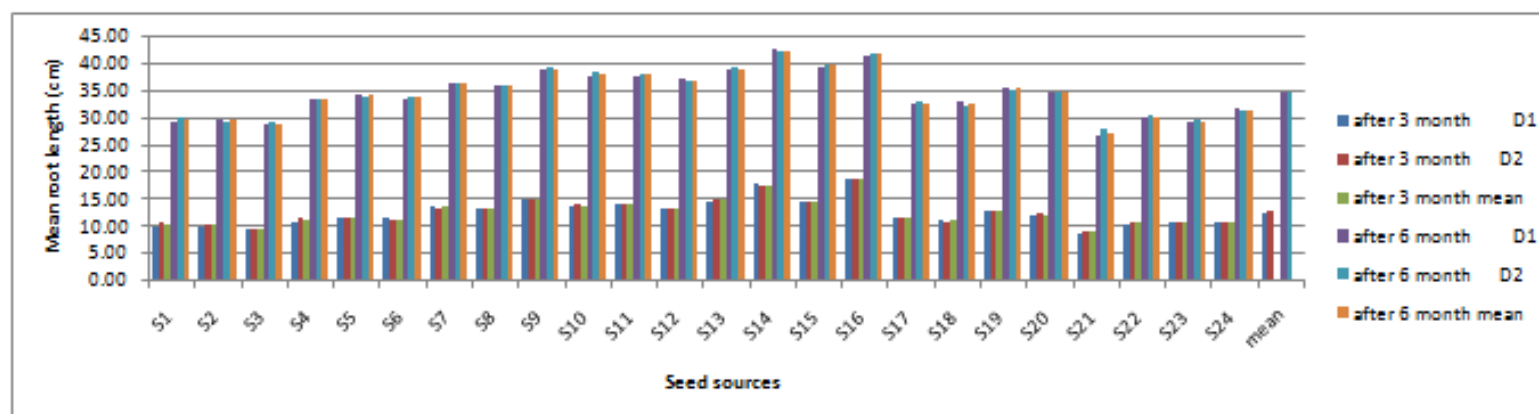


Fig. 18. Variation in mean root length (cm) of *Sapindus mukorossi* among seed sources in two different diameter classes





Nursery bed preparation for testing progeny performance traits



Three months after sowing



Six months after sowing

Plate 3. Experimental field view under progeny performance area of *Sapindus mukorossi*

was statistically at par with Banjar (41.50 cm) and minimum root length 26.95 cm was observed for Kandaghat seed source, while non significant variation were found between D.B.H. class and interaction of seed sources and D.B.H. classes.

Table 16. Variation in mean root length (cm) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	9.60	10.60	10.10	29.11	29.81	29.46
S ₂ (Toruni Kamni)	9.80	10.10	9.95	29.61	29.20	29.41
S ₃ (Patka)	9.10	9.37	9.23	28.53	28.91	28.72
S ₄ (Simble ghata)	10.57	11.43	11.00	33.21	33.43	33.32
S ₅ (Jachh)	11.20	11.40	11.30	34.21	33.70	33.96
S ₆ (Nagrota Bagwan)	11.27	10.93	11.10	33.20	33.80	33.50
S ₇ (Jwalamukhi)	13.47	13.10	13.28	36.30	36.00	36.15
S ₈ (Palampur)	12.93	12.93	12.93	35.90	35.70	35.80
S ₉ (Jogindra Nagar)	14.70	14.80	14.75	38.60	39.00	38.80
S ₁₀ (Baggi)	13.30	13.90	13.60	37.60	38.20	37.90
S ₁₁ (Chail Chowk)	13.70	13.97	13.83	37.50	37.90	37.70
S ₁₂ (Pandoh)	13.20	13.07	13.13	36.90	36.40	36.65
S ₁₃ (Bhuntar)	14.37	14.83	14.60	38.70	39.00	38.85
S ₁₄ (Garsa)	17.50	17.37	17.43	42.40	42.00	42.20
S ₁₅ (Panarsa)	14.37	14.43	14.40	39.30	39.50	39.40
S ₁₆ (Banjar)	18.33	18.60	18.47	41.40	41.60	41.50
S ₁₇ (Deothal)	11.20	11.43	11.32	32.30	32.70	32.50
S ₁₈ (Sarahan)	10.90	10.67	10.78	32.60	31.90	32.25
S ₁₉ (Naina Tikkar)	12.57	12.70	12.63	35.20	35.10	35.15
S ₂₀ (Nahan)	11.73	12.00	11.87	34.30	34.60	34.45
S ₂₁ (Kandaghat)	8.53	8.77	8.65	26.30	27.60	26.95
S ₂₂ (Thadi Subathu)	10.30	10.60	10.45	29.90	30.10	30.00
S ₂₃ (Shilly)	10.50	10.63	10.57	29.10	29.30	29.20
S ₂₄ (Jatoli)	10.67	10.67	10.67	31.40	31.20	31.30
Mean	12.24	12.43		34.32	34.44	
CD _{0.05}						
Seed Sources (S)	1.42			1.42		
D.B.H. classes (D)	NS			NS		
SXD	NS			NS		

4.4.3 Seedling height

Seedling height of soapnut seedling was recorded at interval of 3 and 6 months after sowing and the respective data presented in Table 17 (Fig 19). After 3 months, among seed sources, maximum seedling height of 41.82 cm was recorded for Banjar which was statistically at par with 39.58 cm recorded for Garsa seed source, while minimum seedling height was recorded for Kandaghat (19.93 cm), which was statistically at par with 21.35 cm, 22.88 cm, 22.88 cm and 23.08 cm for Patka, Shilly, Tornu Kamni and Trimuth seed sources respectively.

The variations among D.B.H. and interaction of D.B.H. and seed sources revealed non-significant variation.

After 6 months of sowing significant variation was observed among different seed sources for seedling height, while non-significant variation was observed among D.B.H. classes and interaction of D.B.H. classes and seed sources. The maximum seedling height (98.80 cm) was observed for Banjar Seed source, which was statistically at par with Garsa (97.65 cm) seed source, while minimum seedling height (61.55 cm) was observed for Kandaghat seed source.

Table 17. Variation in mean seedling height (cm) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	22.20	23.97	23.08	66.51	68.70	67.61
S ₂ (Toruni Kamni)	22.73	23.03	22.88	67.71	67.01	67.36
S ₃ (Patka)	21.23	21.47	21.35	65.64	66.11	65.87
S ₄ (Simble ghatta)	25.37	26.50	25.93	76.01	76.63	76.32
S ₅ (Jachh)	26.70	26.67	26.68	78.41	77.20	77.81
S ₆ (Nagrota Bagwan)	26.17	26.00	26.08	75.90	77.40	76.65
S ₇ (Jwalamukhi)	31.30	30.70	31.00	83.10	82.40	82.75
S ₈ (Palampur)	30.30	30.37	30.33	82.10	81.80	81.95
S ₉ (Jogindra Nagar)	33.80	34.57	34.18	88.30	89.60	88.95
S ₁₀ (Baggi)	31.63	32.73	32.18	86.00	87.30	86.65
S ₁₁ (Chail Chowk)	32.20	32.57	32.38	85.80	86.70	86.25
S ₁₂ (Pandoh)	31.63	31.20	31.42	84.30	83.50	83.90
S ₁₃ (Bhuntar)	33.67	34.43	34.05	88.50	89.40	88.95
S ₁₄ (Garsa)	40.13	39.03	39.58	98.60	96.70	97.65
S ₁₅ (Panarsa)	34.17	34.57	34.37	90.20	90.60	90.40
S ₁₆ (Banjar)	41.27	42.37	41.82	98.60	99.00	98.80
S ₁₇ (Deothal)	25.50	25.97	25.73	73.90	74.80	74.35
S ₁₈ (Sarahan)	25.43	24.77	25.10	74.60	73.10	73.85
S ₁₉ (Naina Tikkar)	29.33	29.60	29.47	80.70	80.60	80.65
S ₂₀ (Nahan)	27.83	28.17	28.00	78.70	79.40	79.05
S ₂₁ (Kandaghat)	19.67	20.20	19.93	60.40	62.70	61.55
S ₂₂ (Thadi Subathu)	23.40	23.93	23.67	68.50	68.90	68.70
S ₂₃ (Shilly)	22.70	23.03	22.87	66.54	67.00	66.77
S ₂₄ (Jatoli)	24.30	24.23	24.27	71.90	71.50	71.70
Mean	28.44	28.75		78.79	79.09	
CD _{0.05}						
Seed Sources (S)	3.227			3.540		
D.B.H. classes (D)	NS			NS		
SXD	NS			NS		

Fig. 19. Variation in mean seedling height (cm) of *Sapindus mukorossi* among seed sources in two different diameter classes

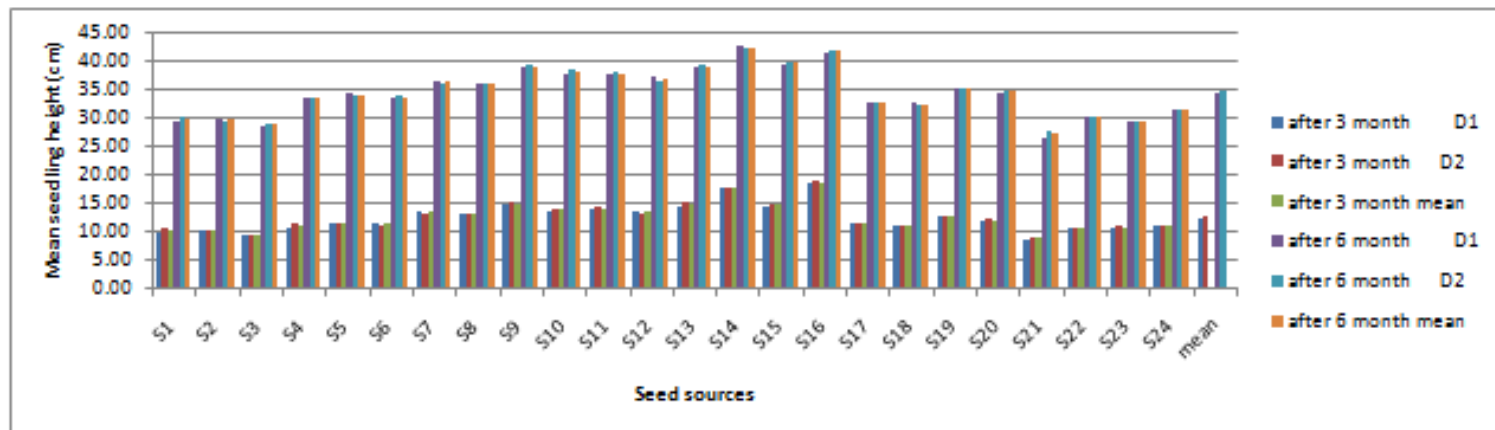
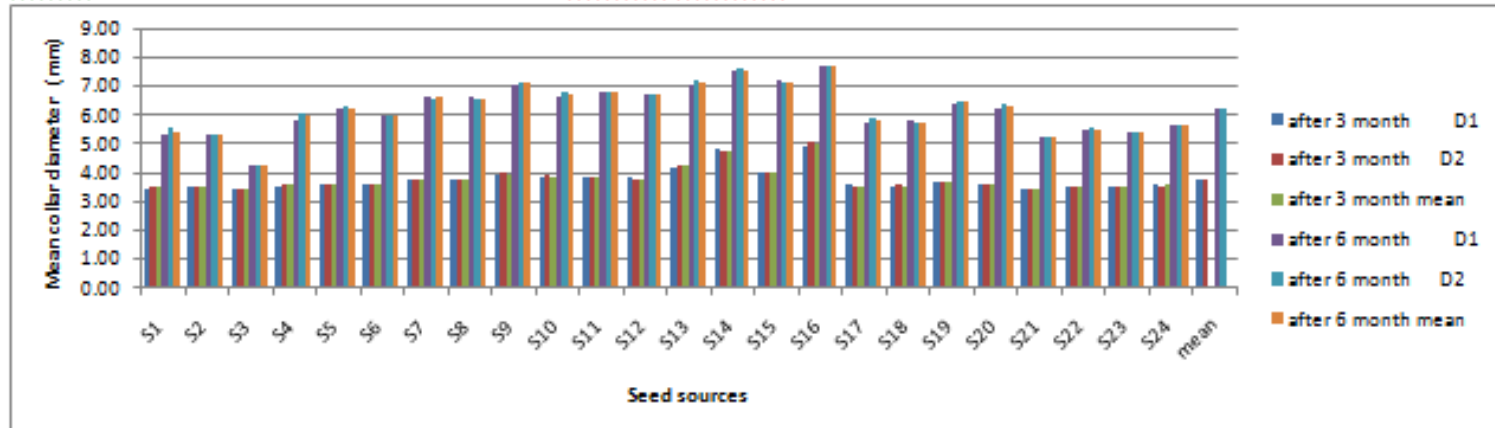


Fig. 20. Variation in mean collar diameter (mm) of *Sapindus mukorossi* among seed sources in two different diameter classes



4.4.4 Collar diameter

Collar diameter of soapnut seedlings was observed at intervals at 3, 6 months after sowing and presented in Table 18 (Fig 20). The data revealed that at an interval of 3 months, seed source exerted significant effect on collar diameter of soapnut seeds. As evident from the data it was Banjar seed sources which registered significant maximum collar diameter 4.97 mm, which was statistically at par with Garsa 4.76 mm. However minimum collar diameter of 3.43 mm was recorded for Kandaghat seed source, which was statistically at par with Patka (3.47 mm), Tornu Kamni (3.50 mm), Shilly (3.50mm), Trimuth (3.51 mm), Thadi Subathu (3.51 mm), Deothal (3.56 mm), Sarahan (3.56 mm), Simble

Table 18. Variation in mean collar diameter (mm) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	3.48	3.54	3.51	5.29	5.59	5.44
S ₂ (Toruni Kamni)	3.49	3.49	3.49	5.31	5.35	5.33
S ₃ (Patka)	3.47	3.47	3.47	4.24	4.23	4.24
S ₄ (Simble ghatta)	3.53	3.59	3.56	5.81	6.08	5.95
S ₅ (Jachh)	3.61	3.62	3.62	6.21	6.26	6.24
S ₆ (Nagrota Bagwan)	3.57	3.56	3.56	6.01	5.97	5.99
S ₇ (Jwalamukhi)	3.79	3.72	3.76	6.65	6.54	6.60
S ₈ (Palampur)	3.73	3.74	3.73	6.59	6.52	6.56
S ₉ (Jogindra Nagar)	3.93	3.98	3.96	7.02	7.15	7.09
S ₁₀ (Baggi)	3.85	3.90	3.88	6.67	6.79	6.73
S ₁₁ (Chail Chowk)	3.86	3.84	3.85	6.78	6.76	6.77
S ₁₂ (Pandoh)	3.82	3.75	3.79	6.69	6.68	6.68
S ₁₃ (Bhuntar)	4.21	4.29	4.25	7.01	7.21	7.11
S ₁₄ (Garsa)	4.80	4.72	4.76	7.54	7.59	7.56
S ₁₅ (Panarsa)	3.97	3.97	3.97	7.16	7.13	7.15
S ₁₆ (Banjar)	4.88	5.06	4.97	7.68	7.67	7.68
S ₁₇ (Deothal)	3.56	3.55	3.56	5.76	5.93	5.84
S ₁₈ (Sarahan)	3.55	3.56	3.56	5.80	5.69	5.75
S ₁₉ (Naina Tikkar)	3.69	3.68	3.68	6.41	6.47	6.44
S ₂₀ (Nahan)	3.61	3.63	3.62	6.24	6.39	6.31
S ₂₁ (Kandaghat)	3.42	3.43	3.43	5.21	5.23	5.22
S ₂₂ (Thadi Subathu)	3.51	3.51	3.51	5.47	5.53	5.50
S ₂₃ (Shilly)	3.50	3.50	3.50	5.38	5.42	5.40
S ₂₄ (Jatoli)	3.61	3.53	3.57	5.64	5.63	5.64
Mean	3.77	3.78		6.19	6.24	
CD _{0.05} Seed Sources (S) D.B.H. classes (D) SXD	0.274 NS NS			0.570 NS NS		

Ghatta (3.56 mm), Nagrota Bagwan (3.56 mm), Jatoli (3.57 mm), Nahan (3.62 mm), Jachh (3.62) and Naina Tikkar (3.82 mm) seed sources. Whereas variation among D.B.H. class and interaction of seed sources and D.B.H. classes were found non-significant for collar diameter.

At the interval of 6 months Table 18 illustrates the maximum collar diameter within seed sources was recorded for Banjar (7.67 mm) which was significantly at par with Garsa (7.56 mm), Panarsa (7.14 mm) and Bhuntar (7.11 mm) seed sources and the minimum value for the same was recorded for Patka (4.23 mm) among seed sources. Whereas variation among D.B.H. class and interaction of seed sources and D.B.H. classes were also found non-significant.

4.4.5 Number of leaves

Number of leaves was observed at intervals of 3 and 6 months and the data obtained is presented in Table 19 (Fig 21). The data revealed that at 3 month after sowing, the highest mean number of leaves within seed sources was recorded for Sarahan (72.67) which was significantly at par with Bhuntar (68.17), Garsa (68.50), Banjar (66.67), Nahan (66.00) and Panarsa (61.67) and the minimum mean value for the same was recorded for Kandaghat (31.00) seed sources which was significantly at par with Chail Chowk (34.67), Jwalamukhi (34.83), Jogindra Nagar (36.00), Simble Ghatta (37.83), Jachh (38.17), Baggi (38.33), Nagrota Bagwan (39.00) and Thadi Subathu (39.50) seed sources. Mean number of leaves within D.B.H. classes was recorded non-significantly, whereas interaction between D.B.H. classes and seed sources also showed non significant variation.

At an interval of 6 month after sowing, mean number of leaves within seed sources was recorded maximum for Sarahan (112.00) which was significantly at par with Bhuntar (109.50), Banjar (103.50) and Garsa (100.50), whereas minimum mean number of leaves for Kandaghat (42.17) which was significantly at par with Jwalamukhi (46.17), Simble Ghatta (54.50), Chail Chowk (56.67), Baggi (57.17), Nagrota Bagwan (57.17), Thadi Subathu (57.33), Tornu Kamni (57.50), Jachh (57.83) and Jogindra Nagar (58.17) seed sources. However, number of leaves variation within D.B.H. classes and interaction of D.B.H. class and seed sources was found non-significant.

Fig. 21. Variation in mean number of leaves of *Sapindus mukorossi* among seed sources in two different diameter classes

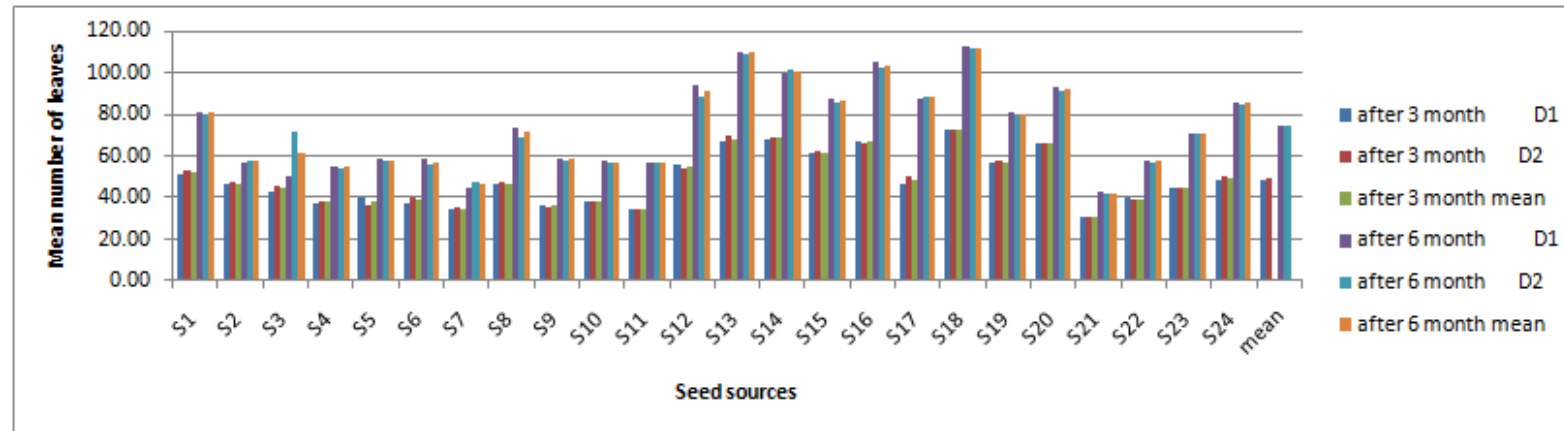


Fig. 22. Variation in mean leaf area (cm^2) of *Sapindus mukorossi* among seed sources in two different diameter classes

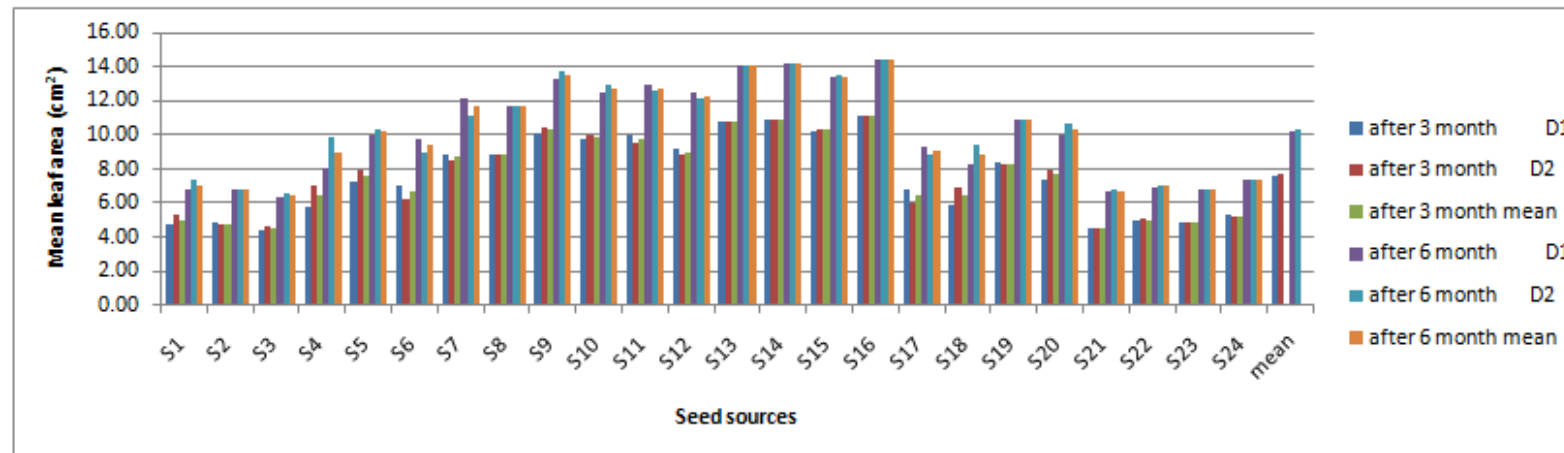


Table 19. Variation in number of leaves of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	51.00	53.33	52.17	80.67	80.33	80.50
S ₂ (Toruni Kamni)	46.33	47.33	46.83	57.00	58.00	57.50
S ₃ (Patka)	43.00	45.67	44.33	50.00	72.00	61.00
S ₄ (Simble ghatta)	37.67	38.00	37.83	54.67	54.33	54.50
S ₅ (Jachh)	40.33	36.00	38.17	58.33	57.33	57.83
S ₆ (Nagrota Bagwan)	37.67	40.33	39.00	58.33	56.00	57.17
S ₇ (Jwalamukhi)	34.00	35.67	34.83	45.00	47.33	46.17
S ₈ (Palampur)	46.67	47.00	46.83	73.67	69.00	71.33
S ₉ (Jogindra Nagar)	36.33	35.67	36.00	58.33	58.00	58.17
S ₁₀ (Baggi)	38.33	38.33	38.33	57.67	56.67	57.17
S ₁₁ (Chail Chowk)	34.67	34.67	34.67	57.00	56.33	56.67
S ₁₂ (Pandoh)	56.00	53.67	54.83	93.67	88.00	90.83
S ₁₃ (Bhuntar)	67.00	69.33	68.17	110.00	109.00	109.50
S ₁₄ (Garsa)	68.00	69.00	68.50	99.67	101.33	100.50
S ₁₅ (Panarsa)	61.33	62.00	61.67	87.67	86.00	86.83
S ₁₆ (Banjar)	67.33	66.00	66.67	105.00	102.00	103.50
S ₁₇ (Deothal)	46.67	50.33	48.50	87.33	88.67	88.00
S ₁₈ (Sarahan)	72.67	72.67	72.67	112.67	111.33	112.00
S ₁₉ (Naina Tikkar)	57.00	57.33	57.17	81.00	79.33	80.17
S ₂₀ (Nahan)	66.33	65.67	66.00	93.00	91.00	92.00
S ₂₁ (Kandaghat)	31.00	31.00	31.00	42.33	42.00	42.17
S ₂₂ (Thadi Subathu)	40.00	39.00	39.50	58.00	56.67	57.33
S ₂₃ (Shilly)	44.67	44.67	44.67	70.67	70.67	70.67
S ₂₄ (Jatoli)	48.00	50.33	49.17	85.67	85.00	85.33
Mean	48.83	49.29		74.06	74.01	
CD _{0.05}						
Seed Sources (S)	11.703			16.070		
D.B.H. classes (D)	NS			NS		
SXD	NS			NS		

4.4.6 Leaf area

The observation recorded on leaf area at intervals of 3 and 6 months after sowing and the respective observations are presented in Table 20 (Fig 22). The contents revealed that at 3 months, the mean maximum leaf area 11.08 cm² was recorded for Banjar seed source, which was statistically at par with 10.89, 10.78, 10.31 and 10.28 cm² for Garsa, Bhuntar and Panarasa seed sources respectively. However mean minimum leaf area 4.57 cm² was recorded for Kandaghat seed sources, which was statistically at par with 4.56, 4.81, 4.91, 5.00, 5.03 and 5.27 cm² for Patka, Tornu Kamni, Shilly, Trimuth, Thadi Subathu and Jatoli seed sources respectively which showed significant variation among different seed

sources, while D.B.H. classes and interaction between seed source and D.B.H. class showed non-significant variation.

Table 20. Variation in leaf area (cm²) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	4.72	5.28	5.00	6.76	7.38	7.07
S ₂ (Toruni Kamni)	4.85	4.78	4.82	6.81	6.76	6.78
S ₃ (Patka)	4.42	4.70	4.56	6.39	6.56	6.48
S ₄ (Simble ghatta)	5.78	7.08	6.43	8.09	9.83	8.96
S ₅ (Jachh)	7.29	7.89	7.59	9.99	10.33	10.16
S ₆ (Nagrota Bagwan)	7.05	6.23	6.64	9.81	8.99	9.40
S ₇ (Jwalamukhi)	8.87	8.53	8.70	12.11	11.16	11.64
S ₈ (Palampur)	8.83	8.81	8.82	11.71	11.70	11.71
S ₉ (Jogindra Nagar)	10.14	10.42	10.28	13.22	13.71	13.47
S ₁₀ (Baggi)	9.72	10.01	9.87	12.47	12.92	12.69
S ₁₁ (Chail Chowk)	9.95	9.54	9.75	12.89	12.55	12.72
S ₁₂ (Pandoh)	9.15	8.89	9.02	12.46	12.15	12.31
S ₁₃ (Bhuntar)	10.79	10.78	10.79	14.06	14.03	14.05
S ₁₄ (Garsa)	10.87	10.91	10.89	14.16	14.18	14.17
S ₁₅ (Panarsa)	10.25	10.37	10.31	13.34	13.51	13.42
S ₁₆ (Banjar)	11.08	11.07	11.08	14.39	14.38	14.38
S ₁₇ (Deothal)	6.86	6.04	6.45	9.30	8.90	9.10
S ₁₈ (Sarahan)	5.92	6.97	6.45	8.23	9.41	8.82
S ₁₉ (Naina Tikkar)	8.37	8.27	8.32	10.94	10.84	10.89
S ₂₀ (Nahan)	7.37	7.98	7.68	10.01	10.64	10.33
S ₂₁ (Kandaghat)	4.56	4.59	4.57	6.64	6.83	6.74
S ₂₂ (Thadi Subathu)	4.99	5.08	5.04	6.97	7.01	6.99
S ₂₃ (Shilly)	4.92	4.89	4.91	6.86	6.84	6.85
S ₂₄ (Jatoli)	5.31	5.24	5.27	7.40	7.37	7.39
Mean	7.59	7.68		10.21	10.33	
CD _{0.05}						
Seed Sources (S)	1.18			1.17		
D.B.H. classes (D)	NS			NS		
SXD	NS			NS		

After 6 months of sowing, the mean maximum leaf area 14.38 cm² was recorded for Banjar seed source, which was statistically at par with 14.17, 14.05, 13.47 and 13.42 cm² for Garsa, Bhuntar, Joginder Nagar and Panarasa seed sources, respectively. However mean minimum leaf area 6.47 cm² was recorded for Patka seed sources, which was statistically at par with 6.34, 6.78, 6.85, 6.99, 7.07 and 7.39 cm² recorded for Kandaghat, Tornu Kamni, Shilly, Thadi Subathu, Trimuth and Jatoli seed sources respectively, which showed significant variation

among different seed sources, while D.B.H. classes and interaction between seed source and D.B.H. class showed non-significant variation.

4.4.7 Seedling dry weight

Total dry weight of *Sapindus mukorossi* seedling was recorded at an interval of 3 and 6 months after sowing and the respective data prescribed in Table 21 (Fig 23). The data revealed that at 3 months after sowing seed source exerted significant effect on total dry weight of seedling. As evident from the

Table 21. Variation in mean seedling dry weight (g) of *Sapindus mukorossi* among different seed sources in two different diameter classes

Seed sources	After 3 month			After 6 month		
	D ₁ (10-40 cm D.B.H.)	D ₂ (40-70 cm D.B.H.)	Mean	D ₁ (40-70 cm D.B.H.)	D ₂ (10-40 cm D.B.H.)	Mean
S ₁ (Trimuth)	2.02	2.12	2.07	4.76	4.81	4.79
S ₂ (Toruni Kamni)	2.02	2.06	2.04	4.78	4.72	4.75
S ₃ (Patka)	1.97	1.98	1.97	4.57	4.62	4.60
S ₄ (Simble ghatta)	2.23	2.27	2.25	5.66	5.65	5.66
S ₅ (Jachh)	2.36	2.34	2.35	5.81	5.77	5.79
S ₆ (Nagrota Bagwan)	2.31	2.29	2.30	5.64	5.71	5.68
S ₇ (Jwalamukhi)	2.68	2.63	2.66	6.31	6.25	6.28
S ₈ (Palampur)	2.60	2.59	2.60	6.20	6.18	6.19
S ₉ (Jogindra Nagar)	2.88	3.04	2.96	6.87	6.94	6.91
S ₁₀ (Baggi)	2.72	2.81	2.77	6.65	6.72	6.69
S ₁₁ (Chail Chowk)	2.75	2.78	2.76	6.58	6.63	6.60
S ₁₂ (Pandoh)	2.71	2.68	2.70	6.44	6.37	6.41
S ₁₃ (Bhuntar)	2.85	2.98	2.92	6.85	6.94	6.89
S ₁₄ (Garsa)	3.37	3.32	3.35	7.47	7.41	7.44
S ₁₅ (Panarsa)	2.91	3.08	3.00	7.01	7.07	7.04
S ₁₆ (Banjar)	3.51	3.54	3.53	7.62	7.70	7.66
S ₁₇ (Deothal)	2.23	2.26	2.24	5.38	5.47	5.43
S ₁₈ (Sarahan)	2.22	2.15	2.19	5.45	5.37	5.41
S ₁₉ (Naina Tikkar)	2.51	2.53	2.52	6.07	6.04	6.05
S ₂₀ (Nahan)	2.39	2.44	2.41	5.88	5.93	5.91
S ₂₁ (Kandaghat)	1.82	1.84	1.83	4.21	4.28	4.25
S ₂₂ (Thadi Subathu)	2.09	2.10	2.09	4.84	4.89	4.87
S ₂₃ (Shilly)	2.03	2.05	2.04	4.64	4.73	4.69
S ₂₄ (Jatoli)	2.15	2.13	2.14	5.20	5.13	5.16
Mean	2.47	2.50		5.87	5.89	
CD _{0.05}						
Seed Sources (S)	0.101			0.095		
D.B.H. classes (D)	NS			NS		
SXD	NS			NS		

data it was Banjar seed source which registered significantly maximum mean total seedling dry weight of 3.53 g followed that of Garsa (3.35 g) seed source. However significantly lowest mean total seedling dry weight of 1.83 g was recorded for Kandaghat seed source. Data further revealed that different D.B.H. classes and interaction of seed source and D.B.H. class exerted non significant variation on total dry weight of seedling.

After 6 months of sowing, the data revealed significant variation among different seed sources for total mean seedling dry weight. While D.B.H. class and interaction of seed source and D.B.H. class exerted non significant variation on total seedling dry weight of seedling. However significant highest mean total dry weight of seedling registered 7.66 g for Banjar seed source, followed by Garsa (7.44g) among different seed sources and significant lowest mean total dry weight of seedling registered 4.25 g for Kandaghat seed source.

4.5 ESTIMATION OF GENOTYPIC AND PHENOTYPIC CORRELATION ALONG WITH GENETIC PARAMETERS

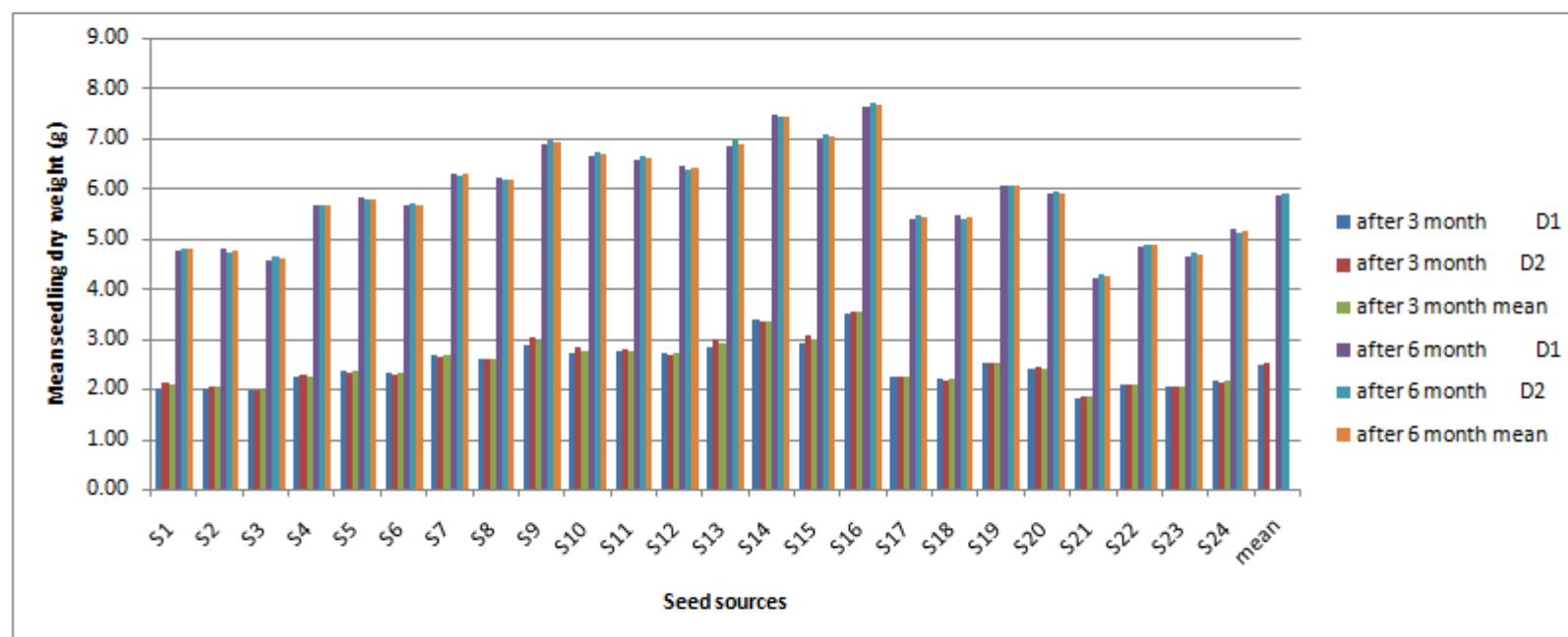
This part of study was carried out to estimate phenotypic and genotypic correlation coefficients along with variability and genetic parameters namely, genotypic coefficient of variability, phenotypic coefficient of variability, heritability, genetic advance and genetic gain on morphometric traits, germination parameters, oil content and progeny performance traits (Table 22-25).

4.5.1 Estimation of genotypic and phenotypic correlation coefficients

4.5.1.1 Estimation of genotypic and phenotypic correlation coefficients among different morphometric traits, germination parameters and oil content of *Sapindus mukorossi*

The data presented in Table 22 revealed phenotypic and genotypic correlation coefficients on morphometric traits, germination parameters and oil content. Phenotypic and genotypic correlation coefficients were worked out for seven characters. Out of 28 correlations among morphometric traits, germination parameters and oil content, all 28 were found significantly correlated at both genotypic and phenotypic levels. Morphometric traits (100 fruits weight, 100 seed weight, seed diameter, kernel weight), germination percentage, germination

Fig. 23. Variation in mean seedling dry weight (g) of *Sapindus mukorossi* among seed sources in two different diameter classes



energy and oil content % was found positively significant with each others at 5% and 1% level of significance.

Table 22. Phenotypic and genotypic correlation among different morphometric traits, germination parameters and oil content (%) of *Sapindus mukorossi*

Characters		100 fruits weight (g)	100 seed weight (g)	Seed diameter (mm)	Kernel weight (mg)	Germination percentage	Germination energy	Oil content (%)
100 fruits weight (g)	G	1.000	0.698	0.771	0.655	0.539	0.585	0.462
	P		0.680	0.758	0.643	0.514	0.495	0.443
100 seed weight (g)	G		1.000	0.970	0.763	0.922	0.842	0.824
	P			0.963	0.757	0.890	0.730	0.808
Seed diameter (mm)	G			1.000	0.843	0.836	0.769	0.761
	P				0.843	0.809	0.657	0.747
Kernel weight (mg)	G				1.000	0.578	0.587	0.568
	P					0.560	0.500	0.557
Germination percentage	G					1.000	0.803	0.892
	P						0.668	0.853
Germination energy	G						1.000	0.754
	P							0.621
Oil content (%)	G							1.000
	P							
Where, G= Genotypic correlation, P= phenotypic correlation								

4.5.1.2 Estimation of genotypic and phenotypic correlation coefficients among different progeny performance traits of *Sapindus mukorossi*

Phenotypic and genotypic correlation coefficient was estimated separately on progeny performance at intervals of 3 and 6 months after sowing and the data presented in Table 23.

A critical analysis in Table 23 exhibited that phenotypic and genotypic correlation coefficients worked out for seven characters viz., shoot length, root length, seedling height, collar diameter, leaf area, number of leaves and seedling dry weight exhibited that out of 28 correlation coefficients worked out, all 28 were found positively significantly correlated with each other. Both 3 months and 6 months related data exhibit positively significant correlation among different progeny performance traits at 5% and 1% level of significance.

Table 23. Estimation of genotypic and phenotypic correlation coefficients among different progeny performance traits of *Sapindus mukorossi*

Traits		3 months after sowing							6 month after sowing						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7
Shoot length	G	1.000	0.806	0.987	0.728	0.747	0.471	0.961	1.000	0.986	0.993	0.845	0.897	0.448	0.954
	P		0.724	0.955	0.695	0.727	0.331	0.812		0.914	0.985	0.819	0.872	0.379	0.928
Root length	G		1.000	0.962	0.851	0.823	0.517	0.914		1.000	0.989	0.912	0.938	0.436	0.981
	P			0.897	0.758	0.795	0.311	0.902			0.970	0.827	0.903	0.333	0.965
Seedling height	G			1.000	0.796	0.892	0.470	0.943			1.000	0.862	0.936	0.439	0.985
	P				0.773	0.810	0.347	0.911				0.840	0.904	0.368	0.964
Collar diameter	G				1.000	0.881	0.608	0.990				1.000	0.887	0.452	0.883
	P					0.682	0.360	0.815					0.831	0.284	0.859
Leaf area	G					1.000	0.386	0.987					1.000	0.366	0.958
	P						0.274	0.886						0.338	0.934
No of leaves	G						1.000	0.473						1.000	0.429
	P							0.322							0.338
Seedling dry weight	G							1.000							1.000
	P														

Significant at the 0.05 level

Where,

1= Shoot length, 2= Root length, 3= Seedling height, 4= Collar diameter, 5= Leaf area, 6= Number of leaves, 7= Seedling dry weight

G= Genotypic correlation, P= phenotypic correlation

4.5.2 Variability estimate and genetic parameters

Significant variation was observed among different seed sources and between D.B.H. classes with regards to Morphometric traits, germination parameters oil content and progeny performance traits. Therefore the data was calculated for variability estimation and genetic parameters for above different characters.

Variability and genetic parameters were worked out with regard to estimate of coefficient of variability (phenotypic and genotypic), heritability (broad sense), genetic advance and genetic gain (genetic advance as percent of mean).

The results obtained for variability and genetic parameters are presented in the ensuring tables and describing as follows

4.5.2.1 Morphometric traits, germination parameters and oil content (%) of *Sapindus mukorossi*

Partition of total variance into different components as depicted in Table 24 showed that the highest genotypic coefficient of variability was observed in 100 fruits weight (19.22) followed by germination energy (18.14) and minimum value in seed diameter (7.75). In the case of phenotypic coefficient of variability, maximum value was shown by germination energy (21.21) followed by 100 fruits weight (19.56) and minimum value was shown by seed diameter (7.75).

Table. 24. Variability and genetic parameters for morphometric traits, germination parameters and oil content (%) of *Sapindus mukorossi*

Traits	Coefficient of variability		Heritability (broad sense)	Genetic Advance	Genetic gains (%)
	Genotypic	Phenotypic			
100 fruits weight (g)	19.22	19.56	0.966	150.5	38.91
100 seed weight (g)	13.11	13.20	0.985	44.61	26.80
Seed diameter (mm)	7.75	7.75	0.999	2.21	15.98
Kernel weight (mg)	14.10	14.11	0.999	121.73	29.03
Germination percentage	9.72	10.03	0.940	13.62	19.41
Germination energy	18.14	21.21	0.731	11.39	31.94
Oil content (%)	16.98	17.31	0.963	5.18	34.30

In respect of genetic parameter (Table 24) kernel weight and seed diameter (0.999) showed maximum heritability and minimum value was shown by germination energy (0.731). Genetic advance was found to be maximum in 100 fruits weight (150.50) followed by kernel weight (121.73) and minimum in seed diameter (2.21). Genetic gain was maximum for 100 fruits weight (38.91%) and minimum was for seed diameter (15.98%).

4.5.2.2 Progeny performance traits

At the interval of 3 months after sowing, with regard to coefficient of variance (Table 25) the maximum coefficient of genotypic variation 28.70 was shown by leaf area, followed by number of leaves (22.57) and minimum coefficient of genotypic variation 9.62 shown by collar diameter. However the maximum coefficient of phenotypic variation for leaf area (31.71) was observed and minimum for collar diameter (11.51). Maximum heritability was shown by seedling dry weight (0.961) and minimum value for heritability was shown by shoot length (0.532). Maximum genetic advance was shown by number of leaves (16.78) while minimum recorded for collar diameter (0.63). Maximum genetic gain was shown by leaf area (53.47%) and minimum value was for collar diameter (16.71%).

At the interval of six month, analysis of Table 25 showed maximum value of genotypic coefficient of variability in leaf area (25.93) followed by number of leaves (25.46) and minimum in root length (12.03), while genotypic coefficient of variability in number of leaves (31.71) followed by leaf area (27.78) and minimum in root length (12.56). In respect of genetic parameters seedling dry weight (0.992) showed maximum heritability, followed by seedling height (0.911) and minimum in collar diameter (0.707). Genetic advance was found to be maximum in number of leaves (31.17) followed by seedling height (10.44) and minimum in collar diameter (1.33). Genetic gain was maximum for seedling height and leaf area (49.85%) and minimum value was for collar diameter (21.30%).

Table 25. Variability and genetic parameters for seedling growth parameters of *Sapindus mukorossi*

Traits	3 months after sowing					6 month after sowing				
	Coefficient of variability		Heritability (broad sense)	Genetic Advance	Genetic gains (%)	Coefficient of variance		Heritability (broad sense)	Genetic Advance	Genetic gains (%)
	Genotypic	Phenotypic				Genotypic	Phenotypic			
Shoot length	17.78	23.97	0.532	4.27	26.26	12.96	13.94	0.815	10.44	23.43
Root length	18.68	21.22	0.775	4.18	33.87	12.03	12.56	0.917	8.16	23.73
Seedling height	18.81	21.22	0.786	9.82	34.34	12.46	13.06	0.911	19.34	24.50
Collar diameter	9.62	11.51	0.699	0.63	16.71	12.39	14.74	0.707	1.33	21.38
Leaf area	28.70	31.71	0.819	4.08	53.47	25.93	27.78	0.871	5.12	49.85
No. of leaves	22.57	30.67	0.541	16.78	34.20	25.46	31.71	0.645	31.17	42.10
Seedling dry weight	17.63	17.98	0.961	0.89	35.74	16.08	16.14	0.992	1.97	33.50

Chapter-5

DISCUSSION

Natural variation occurs as a product of evolution and serves as raw material, which is renewable and utilizable involving basic tools such as to start with selection and thereby to manipulate the variability in tree species. Presence of vast natural variability is a characteristics feature of forest tree species. Thus provenance research involving selection of best provenance of seed sources suited best to a specific site of locality help the forest to maximize the productivity of forest. Variation in nature is an evolutionary product and serves as a base for population improvement. In any plant improvement programme, there are many series of activities which will ultimately determine the amount of genetic improvement. Selection of right seed source assumes the first importance in planting works because choice of the seed source is one of the major factor affecting establishment and productivity. The present study was an attempt in this regard. The results obtained from the present investigations entitled **“Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh”** have been discussed in this Chapter. The data of practical utility generated during this study and assessed through several parameters have been discussed in the light of available literature under the following heads:

- 5.1 Variation in fruit and seed characteristics of *Sapindus mukorossi*
- 5.2 Variation in seed viability and germination parameters of *Sapindus mukorossi*
- 5.3 Variation in oil content and oil physico-chemical traits of *Sapindus mukorossi*
- 5.4 Variation in progeny performance traits of *Sapindus mukorossi*
- 5.5 Correlation studies, variability analysis and genetic parameters

5.1 VARIATION IN FRUIT AND SEED CHARACTERISTICS OF *Sapindus mukorossi*

Various fruit and seed morphological characters, viz., 100 fruit weight, 100 seed weight, rind weight, kernel weight, fruit-kernel weight ratio and seed diameter were studied during the course of investigation and analysis of variance

attributed significant difference in these traits among different seed sources and significant or non-significant difference between D.B.H. classes. Banjar seed source registered significant maximum 100 fruit weight, 100 seed weight, rind weight, seed diameter, kernel weight and fruit-kernel weight ratio.

The result of the present study are corroborated with the findings of Mir (2011) who reported significant variation among different seed sources for fruits and seed characters. Thakur *et al.*, (2008) also reported wide range of variation in fruit and seed characters in *Emblica officinalis*, *Sapindus mukorossi* and *Syzygium cumini* from different sources in Himachal Pradesh. These finding lend in the support to the results obtained by various workers in different species for fruit and seed traits of various seed sources within available literature (Bahar and Singh, 2007). Ruan and Huang (2006) reported in *Sapindus mukorossi* that fruits and seed traits varied significantly among different seed sources. On the basis of overall performance significant variation was observed among seed sources in *Albizia lebbeck* for seed quality parameters (Radhakrishnan and Vanangamudi, 2004).

Significant variation among different seed source in *Sapindus mukorossi* was found in fruit weight, seed weight and seed size. It is possible that the variation in fruit and seed traits between different seed sources is due to resources availability at the time of fruiting. This in turn could be due to different environment at the geographic origins of each seed and seasonal variables (Murali, 1997).

The variation observed in fruit and seed traits can be attributed due to genetic makeup and adaptation of diverse environment through the distribution when collected from respective seed sources were harvested from trees of approximately the same age and height (Salazar and Quesada, 1987). Edaphic factors like that of fertility and moisture content of soil and climatic conditions of soil prevalent in seed sources are the factor affecting the fruits and seed traits (Mathur *et al.*,1984).

The extent of variation observed in fruit and seed characters could be due to genetic or environmental factors or a combination of both (Arya *et al.*,1992),

seasonal variation of respective seed sources spread over an immense geographical area experiencing varied environmental conditions (Devagiri *et al.*,1998), and might have attributed to difference in physiographic, edaphic and climatic factors (Mathur *et al.*,1985).

5.2 VARIATION IN SEED VIABILITY AND GERMINATION PARAMETERS OF *Sapindus mukorossi*

Seed viability shows no significant variation among different seed sources though maximum seed viability was recorded for Banjar (89.83%) seed source and minimum (82.00%) for Nahan and Shilly seed sources. Viability of seed is much affected by the stage of maturity reached at the time of its collection (Bonner, 1974), its moisture content and the temperature to which it is exposed (Mathur *et al.*, 1984).

The analysis of variance showed that there is a wide range of variation in the germination parameters depending upon seed sources, while no significant variation showed by D.B.H. classes. Germination per cent varied significantly among seed sources. The maximum germination was recorded for Banjar seed sources (83.83%), whereas minimum germination was recorded for Kandaghat (59.00%), Patka (59.83%) and Shilly (60.33%) seed sources.

Germination capacity in the present study also differs significantly due to seed sources variation. The highest germination capacity was recorded in Banjar (83.55%) seed source while minimum in Kandaghat (64.17%) and Patka (64.83%) seed sources.

Similarly, germination energy also varied significantly among seed sources. The maximum germination energy was recorded for Banjar (48.67%), Garsa (47.83%), Panarsa (46.83%), Jogindra Nagar (45.67%) and Bhuntar (45.33%) seed sources, while minimum germination energy was recorded for Kandaghat (28.17%), Shilly (28.50%), Jachh (29.17%), Nagrota Bagwan (29.17%), Patka (29.50%), Jwalamukhi (30.17%), Nahan (30.33%), Pandoh (31.00%), Naina Tikkar (31.17%), Trimuth (31.33%), Thadi Subhathu (32.17%) and Sarahan (32.17%) seed sources. Number of days taken to initiate germination also differs significantly due to seed sources variation.

The maximum number of days taken to initiate germination was recorded in Kandaghat (29.33 days), Shilly (28.17 days), Patka (28.00 days), Nagrota Bagwan (27.50 days), Simble Ghatta (26.83 days), Trimuth (26.67 days) and Tornu Kamni (26.17 days) seed sources while minimum in Banjar (19.33 days), Garsa (20.83 days) and Jogindra Nagar (22.17 days) seed sources.

The findings in the present investigation in *Sapindus mukorossi* indicate that germination behaviour is better in large and heavier seeds than the smaller and lighter ones, which are also in conformity with the results of research works for *Sapindus mukorossi* (Mir, 2011; Attri, 2011), *Jatropha curcas* (Singh and Saxena, 2009; Kaushik *et al.*, 2007.), *Sapindus trifoliatus* (Girish *et al.*, 2001) and for *Pinus wallichiana* (Ghildiyal and Sharma, 2005), where they have observed significant variation among different seed sources. This may be attributed to the larger food reserves with greater nutrient pool present in the endosperm (Kandya, 1978; Tripathi and Khan, 1990).

Germination parameters showed significant variation among seed sources, which arise probably due to genetic influence and the climatic conditions prevailing on a particular locality. Seed size or seed weight has controlling influence upon parameters, i.e., larger seed size and heavier seed take less time to initiate germination than smaller ones, thus enhance the completion of germination because of more food reserves in endosperm (Baldium, 1992; Dunlapp and Barnette, 1983). Thus among different seed sources, the significant variation in germination percentage, germination energy, germination capacity found maximum larger seed size and heavier seed, while maximum number of days taken to initiate germination in smaller and lowest seed. These significant results may be ascribed to the significant difference in seed size and weight observed among different seed sources of *Sapindus mukorossi*. The present results are in line with the finding of Bhagat *et al.*, (1993) who reported that in *Asculus indica* medium and bigger seeds perform better in germination parameters. In *Leucaena leucophala* the germination was faster in large seeds than in small seeds (Pathak *et al.*, 1981).

5.3 VARIATION IN OIL CONTENT AND OIL PHYSICO-CHEMICAL TRAITS OF *Sapindus mukorossi*

5.3.1 Oil content

The present investigation in soapnut revealed that the oil contents were significantly affected by different seed sources. On seed basis, maximum oil content was recorded in Garsa (18.92%) and minimum oil content was recorded for Kandaghat (10.52%) seed sources. However D.B.H class does not show distinct variation for seed oil content. Kaushik (2003) reported that oil yield and germination is maximum when fruits are harvested at fully maturity. Jones and Miller (1992) reported that oil yield improves with drier climate. The variation among different seed sources for content might be also because of different edapho-climatic factors. Burley *et al.*, (1971) conducted a study on variation in seed sources of *Eucalyptus camaldulensis* and reported that oil glands density varied significantly among different seed sources rather than latitude of seed sources.

The present study draws support from these reports as oil content exhibit significant variation among different seed sources with finding of Mir (2011) who studied seed sources variation among different seed sources in *Sapindus mukorossi* and reported significant variation in seed oil content among different seed sources with conformity with Luna *et al.*, (2008) who reported seed sources variation in oil content while working on *Jatropha curcas*, Ruan and Huang (2006) also reported significant variation in *Sapindus mukorossi*, Seghal *et al.*, (1989) in *Pinus roxburghii* and Ginwal *et al.*, (2004) in *Jatropha curcas*.

5.3.2 Oil physico-chemical traits

The present study revealed that there was no significant variation among different seed sources and between D.B.H classes in oil physico-chemical traits such as viscosity, saponification value, specific gravity and refractive index. Mir (2011) studied seed sources variation in *Sapindus mukorossi* and reported no significant variation in viscosity, saponification value, specific gravity and refractive index among different seed sources.

Gupta (2006) while studying on seed sources variation in *Prunus armeniaca* and also reported in oil physico-chemical traits such as relative viscosity, saponification value, specific gravity and refractive index from seed samples of different sources does not vary significantly. Sophia (2004) studied seed sources variation in *Juglans regia* for oil quality parameters reported non-significant variation in specific gravity and saponification value of oil sample recovered from walnut sample from different seed sources.

Viscosity is the measure of a fluid's resistance to flow. Viscosity found non-significant among different seed sources and D.B.H. classes. Maximum viscosity value (22.807) recorded in oil sample of Bhuntar seed source, while minimum value (22.017) recorded in oil sample of Jachh seed source.

Saponification value is a measure of an average molecular weight or chain length of all the fatty acid present. It allows the comparison of the fatty acid chain length. However, no significant variation was observed among the seed sources and D.B.H. classes in saponification value of oil samples, but the oil recorded from seed of Nagrota Bagwan recorded maximum value 196.99 mg KOH/g, whereas, minimum value 154.74 mg KOH/g was recorded in oil samples recovered from seeds of Banjar seed sources means that the amount of fatty acids in oil of Nagrota Bagwan seeds oil as compare to other seed stands. More saponification value means more moles of KOH per 1 g of oil were used to saponify the oil. Ruan and Huang (2006) reported non-significant variation in saponification value among different seed sources while working on seed sources variation in *Sapindus mukorossi* and found range between 173-196 mg KOH/g.

Specific gravity is the measure of the density of a substance compared to the density of water at room temperature. More specific gravity means less feasibility for oil to be used as biodiesel because it indicates increase in density. No significant variation has been observed among different seed sources and D.B.H. classes in specific gravity of oil samples. But the oil recovered from seeds showed mean viscosity value range from 0.903 to 0.904.

Refractive index is the ratio of the viscosity of light in vacuum to the velocity of light in medium. It increases in amount of unsaturation. Impurities

which are fatty acid, mono and triglyceride oxidation products, conjugated olefinic bonds etc. causes positive deviation. Specific gravity observed between 1.467 and 1.468, however no significant variation observed among different seed sources and D.B.H. classes in specific gravity of oil samples.

Conclusively all the results of the oil physico-chemical traits, viz., viscosity, saponification value, specific gravity and refractive index of oil samples recovered from the seeds of sources studied under present investigation are in conformity with that of Mir (2011) in *Sapindus mukorossi* reported non-significant variation in these traits among different seed sources and , observed viscosity range (22.02-22.77), saponification value (144.98-187.07), specific gravity (0.9025-0.9035) and refractive index(1.4674-1.4676). These findings are accordance with the finding of Farooq *et al.*, (2006) in *Moringa oleifera*, Ibanez and Usubillaga (2006) in *Coespeletia moritziana* and Sayeed *et al.*, (2004) in *Mesua ferrea*.

5.4 VARIATION IN PROGENY PERFORMANCE TRAITS OF *Sapindus mukorossi*

Various progeny performance traits viz., shoot length, root length, seedling height, collar diameter, number of leaves, leaf area and seedling dry weight were studied during the course of investigation and analysis of variance attributed significant differences in these traits among different seed sources and non-significant difference between D.B.H. classes and interaction of seed sources and D.B.H. class (SxD). Progeny performance traits of soapnut seedlings were observed at intervals, viz., 3 months and 6 months (months after sowing). All these traits showed significant variation at 3 months and 6 months of intervals among different seed sources. These resulted are parallel findings with Gera *et al.*, (2004) reported significant among different seed sources variation while studying on *Albizia procera*. Thapliyal and Dhiman (1997) while studying on geographical variation in seed and seedling characteristics in *Pinus roxburghii* reported significant seed sources variation in seed and seedling traits. Vakshasya *et al.*, (1992) also reported significant seed sources variation in *Dalbergia sissoo* on seed and seedling traits.

Variation in *Sapindus mukorossi* with respect to the seedling traits could be due to the fact that this species grow over a wide range of rainfall, temperature, altitude, and soil type of India. Similar type of research work report also observed in *Albizia procera* (Gera *et al.*, 2004). Variation in relation to habitat has also been reported in *Albizia lebbek* (Kumar and Toky, 1993) and *Pinus glauca* (Khalil, 1986). The seed source and provenance variation in nursery and field is essentially genetic in origin (Snieszko and Stewart, 1989).

Conclusively Banjar and other seed sources which have larger and heavier seeds showed better performance than Kandaghat and other seed sources which have smaller and lower seeds on various progeny performance traits. Large sized seeds of soapnut exhibited superior growth characteristics than medium and small sized. Seedling and growth characteristics are independent processes and are governed by the genetic make up, environment and seed traits (Pathak *et al.*, 1984). Growth parameters have good positive relationship with seed size and weight. Maximum height and collar diameter in *Jatropha curcas* (Singh and Saxena, 2009). Shoot length and root length in *Azadirachta indica* (Uniyal *et al.*, 2007). Seedling height and collar diameter in *Castanea sativa* (Cicek and Tilki, 2007). Maximum height and collar diameter in *Buchanania lanzan* (Nandeshwar *et al.*, 2005). Root length and shoot length in *Hardwickia binata* (Ponnammal *et al.*, 1993). Height and diameter in *Terminalia invorensis* (Oni and Bada, 1992). Shoot length in *Cryptocarya alba* (Chacon *et al.*, 1998). Seedling height growth and seedling diameter in *Santalum album* (Effendi and Sinaga, 1994). Seedling height in *Salvadora persica* and *Jatropha curcas* (Dagar *et al.*, 2004). Maximum total dry weight was found in seedlings raised from large seed in *Jatropha curcas* (Singh and Saxena, 2009), *Castanea sativa* (Cicek and Tilki, 2007) and *Dalbergia miscolobium* (Sasaki and Felipe, 1999).

5.5 CORRELATION STUDIES, VARIABILITY ANALYSIS AND GENETIC PARAMETERS

Variation refers to observable differences in an individual for a particular trait. These differences may be particularly due to genetic effects and partially owned to environmental trappings. The combined reflection of both is the phenotypic effect. The observed value the trait measured on an individual is the

phenotypic value of that individual. The relative magnitudes of these components determine the genetic properties of any particular species (Jain,1982). Therefore, the effective tree improvement programme depends upon the nature and magnitude of existing genetic variability and also the degree of transmission of the traits.

The efficiency of the selection on the magnitude of variability present in the material depends on the extent to which desirable characters are heritable.

5.5.1 Estimation of genotypic and phenotypic correlation coefficients among different morphometric, germination, oil content and progeny performance traits

Estimation of genotypic and phenotypic correlation between various traits may provide necessary information in a breeding programme, when selection is based on two and more characters. The intensity and direction of association among characters may be measured by genetic coefficients or correlation and genotypic and phenotypic coefficient of correlation depending on the type of materials studied. It is clear from the Table 21 and Table 22 that phenotypic correlation coefficients were lower than the corresponding genotype ones. This suggests that it could be either due to the modifying effect of environment or the strong inherent association of characters at genetic level.

The 100 fruit weight, 100 seed weight, seed diameter, kernel weight, germination percentage, germination energy and oil content exhibited positive and highly significant correlation with each other at genotypic as well as phenotypic level. However at 3 and 6 months intervals shoot length, root length, seedling height, collar diameter, Leaf area, number of leaves, seedling dry weight also exhibited positive and highly significant correlation with each others. This suggests that there exists a strong inherent association between these characters. The above finding supports the results of Manga and Sen (1996) in *Prosopis cineraria*, Mohapatra (1996) in *Acacia catechu*, Srivastava (1995) in *Bauhinia variegata* and Chauhan and Varma (1993) in *Acacia catechu*.

5.5.2 Variation estimates and genotypic parameters

Burton (1952) suggested the study of genotypic coefficient of variability together with heritability estimate would give the best picture of progress to be

achieved though selection if phenotypic coefficient of variability are higher than genotypic coefficient of variability it means that the characters have interacted with the environment to some degree. Johnson *et al.*, (1955) pointed out that heritability estimates along with genetic gain is more useful than heritability alone. Perusal of Table 23 with regard to coefficient of variance showed the maximum coefficient of phenotypic variation for germination energy followed by 100 fruits weight and oil content and minimum for seed diameter. However the maximum coefficient of genotypic variability was observed for 100 fruits weight followed by germination energy and oil content while minimum for seed diameter. Seed diameter and kernel weight showed maximum heritability followed by 100 seed weight and minimum value was shown by germination energy. Genetic advance was found to be maximum in 100 fruits weight followed by kernel weight and minimum in seed diameter. Genetic gain was maximum for 100 fruit weight and minimum value was for seed diameter.

At three months after sowing analysis of Table 24 showed maximum value of phenotypic and genotypic coefficient of variability for leaf area followed by number of leaves and minimum value was shown by collar diameter. Maximum heritability was shown by seedling dry weight and minimum value for heritability was shown by shoot length. Maximum genetic advance was shown by number of leaves while minimum recorded for collar diameter. Maximum genetic gain was shown by leaf area and minimum value was for shoot length.

At 6 months after sowing, Table 30 showed that the highest phenotypic coefficient of variability was observed in number of leaves followed by leaf area and minimum was observed in root length. In case of coefficient of genotypic variability maximum values was recorded for leaf area followed by number of leaves and minimum value was for root length. Among heritability values maximum values was recorded for seedling dry weight and minimum for number of leaves. For genetic advance maximum value recorded was for number of leaves and minimum was for collar diameter. Maximum genetic gain was recorded in leaf area and seedling height while minimum value was for collar diameter.

In present case high heritability with low genetic advance is associated with seedling dry weight and seed diameter. This further confirms that the expressions is possibly controlled by intra and inter allelic interactions. All traits were more over genetically controlled as revealed by high heritabilities. Phenotypic coefficient of variability is higher than genotypic coefficient of variability for all traits it means that the characters have interacted with the environment to some degree.

These results support the findings of Anand (2003) in *Bauhinia variegata*, Gera *et al.* (2002) in *Dalbergia sissoo*, Manga and Sen (1998) in *Prosopis cineraria*, Mohapatra (1996) in *Acacia catechu*, Srivastava (1995) in *Bauhinia variegata*, Gupta (1993) in *Grewia optiva*, and Khosla *et al.*, (1982) in *Santalum album*.

Chapter-6

SUMMARY AND CONCLUSION

The present investigations entitled “**Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh**” was conducted in the laboratory and experimental farm of 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 the years 2011-2013. To evaluate various morphometric, oil content, physico-chemical and progeny performance traits. The study was aimed to fulfill the following objectives:

- To study extent of variation in morphometric traits.
- To study variation in chemical characteristics.
- To study extent of variation in progeny performance traits.

The study was comprised of four separate experiments

1. Variation studies in fruits and seeds morphometric traits
2. Variation studies in seed viability and germination
3. Variation studies in oil content and oil physico-chemical traits
4. Variation studies in progeny performance traits

Seeds for present study were collected from 24 different sites in the state of Himachal Pradesh and from each selected district, four seed sources were selected. From each seed source, two diameter classes, i.e., 10-40 cm D.B.H. (D₁) and 40-70 cm D.B.H. (D₂) were selected. Three trees were selected from each diameter classes. Seeds were sown at experimental farm of the Department of Tree Improvement and Genetic Resources and rest of the seeds were evaluated in the laboratory for fruits and seeds morphometric traits, oil content, physico-chemical traits and laboratory germination traits. In the first experiment, i.e., fruits and seeds morphometric traits variation studies, physical characteristics of fruits and seeds traits were recorded in the laboratory. Data pertaining to fruits

and seeds traits viz., 100 fruits weight, 100 seeds weight, rind weight, seed diameter, kernel weight, fruit- kernel weight ratio of all seed sources from their respective samples were recorded. The second experiment for testing composite seed sample of each site for viability, germination percentage, germination energy, germination capacity and number of days taken for initiation in germination were recorded in laboratory conditions. The seeds from different seed sources and both D.B.H classes in three replications were sown in germinator. In third experiment, oil content variation study on seed weight basis was conducted and data recorded for all seed sources. In addition to this, various oil physico-chemical traits like that of viscosity, saponification value, specific gravity and refractive Index from oil sample of each seed source and D.B.H. class were also recorded. In fourth experiment, progeny performance traits for shoot length, root length, seedling height, collar diameter, leaf area, number of leaves and seedling dry weight were recorded for respective seed sources and D.B.H. class in experimental field condition. The findings of the study have been summarized as under.

- Morphometric traits with respect to 100 fruits weight, 100 seeds weight, rind weight, seed diameter, kernel weight, fruit- kernel weight ratio differed positively significant among the seed sources. However Banjar seed source registered maximum 100 fruits weight (571.00 g), 100 seeds weight (226.05 g), rind weight (3.45 g), seed diameter (17.03 mm), kernel weight (613.48 mg), while on the other hand Nahan seed source recorded maximum (11.72) fruit- kernel weight ratio.
- Seed sources differed significantly for all laboratory germination traits except seed viability. Seeds of Banjar seed source excelled over the other seed sources in respect of seed viability, recording mean maximum value (89.83%), germination percentage (83.83%), germination capacity (88.00%), germination energy (48.67%), while minimum mean number of days taken to initiate germination (19.33 days). However mean maximum number of days taken to initiate germination recorded for Kandaghat (29.33 days) seed source.

- All the seed sources differed significantly for oil content, while non-significant variation recorded for oil physico-chemical traits, like viscosity, saponification value, specific gravity and refractive Index. Maximum mean oil content percentage was recorded for Garsa (18.91 %) seed source, while maximum mean viscosity (22.80) for Bhuntar seed source. Maximum mean saponification value (196.98 mg KOH/g) was recorded for Nagrota Bagwan seed source. Such specific gravity and refractive index mean value ranged 0.903-0.904 and 1.467-1.468, respectively for all seed sources.
- Progeny performance traits for all respective seed sources recorded at 3 months and 6 months interval after seed sowing in nursery. Progeny performance traits for shoot length, root length, seedling height, collar diameter, leaf area, number of leaves and seedling dry weight revealed significant variation among different seed sources. At 3 months of interval, Banjar seed source recorded maximum mean shoot length (23.35 cm), root length (18.47 cm), seedling height (41.82 cm), collar diameter (4.97 mm), leaf area (11.08 cm²) and seedling dry weight (3.53 gm), however mean maximum number of leaves 72.67 was recorded for Sarahan seed source. At the interval of 6 months after sowing, maximum mean shoot length (57.30 cm), seedling height (98.80 cm), collar diameter (7.67 mm), leaf area (14.38 cm²) and seedling dry weight (7.65 gm) recorded for Banjar seed source, while maximum mean root length (42.20 cm) and number of leaves (112.00) recorded for Garsa and Sarahan seed source, respectively.
- All morphometric traits, oil content, physico-chemical traits, laboratory germination traits and progeny performance traits didn't show distinct significant variation between D.B.H. classes.
- High heritability with low genetic advance is associated with seedling dry weight and seed diameter. All traits were more over genetically controlled as revealed by high heritabilities. Phenotypic coefficient of variability is higher than genotypic coefficient of variability for all traits. Highly positive significant genotypic and phenotypic correlation was shown by all traits.

- Variability and genetic estimates among morphometric traits, oil content, physico-chemical traits, and laboratory germination traits showed that 100 fruits weight had maximum genotypic coefficient of variability. Germination energy had maximum phenotypic coefficient of variability, while seed diameter and kernel weight had maximum heritability, 100 fruits weight had maximum genetic advance and genetic gain both among different morphometric traits, oil content and laboratory germination traits. All these traits showed high heritability in the present investigation.
- All traits exhibited positive and highly significant correlation with each other at genotypic as well as phenotypic level. All phenotypic correlation coefficient were lower than their corresponding genotypic correlation coefficient. This suggests the presence of strong inherent association between the characters at genetic level or the modifying effect of the environment.
- Variability and genetic estimates among progeny performance traits at the interval of 3 months after sowing, with regard to coefficient of variance the maximum coefficient of genotypic variation 28.70 shown by leaf area. However the maximum coefficient of phenotypic variation was observed for leaf area (31.71). Maximum heritability was shown by seedling dry weight (0.961). Maximum genetic advance was shown by number of leaves (16.78) and maximum genetic gain was shown by leaf area (53.47%). At the interval of six month, among progeny performance traits showed maximum value of genotypic coefficient of variability in leaf area (25.93), while genotypic coefficient of variability in number of leaves (31.71). In respect of genetic parameters seedling dry weight showed maximum heritability (0.992). Genetic advance was found to be maximum in number of leaves (31.17). Genetic gain was maximum for leaf area (49.85%).

CONCLUSIONS

On the basis of present findings the following conclusions are drawn:-

- The analysis of variance revealed significant variation for fruits and seed morphometric traits, laboratory germination traits, oil content and

progeny performance traits except seed viability and oil physico-chemical traits for viscosity, saponification value, specific gravity and refractive Index. However all morphometric traits, oil content, physico-chemical traits, laboratory germination traits and progeny performance traits did not show distinct significant variation between D.B.H. classes.

- Seed weight is found reliable parameter for selection of best individuals.
- Over all Banjar seed source was found to be superior followed by Garsa seed source.
- Seed sources which have higher seed weight and seed diameter showed better performance than others, those seed with lower seed weight and seed diameter comparatively.
- Positive significant genotypic and phenotypic correlation was found between all traits, which suggest that selection for any one of these will be reliable for others also.
- Highly positive significant genotypic and phenotypic correlation was shown by all traits.
- High heritability with low genetic advance is associated with seed diameter.
- All traits were more over genetically controlled as revealed by high heritabilities.
- Phenotypic coefficient of variability is higher than genotypic coefficient of variability for all traits.

Chapter-7

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Title of Thesis : “Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh”
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Admission Number : F-2011-18-M
Major Advisor : Dr. H. P. Sankhyan
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ABSTRACT

In order to select better seed sources for improved genetic gain and quality production of *Sapindus mukorossi*, twenty four seed sources and two D.B.H. classes from Himachal Pradesh were evaluated on the basis of fruits and seeds morphometric traits, laboratory germination, oil content and physico-chemical and progeny performance traits. The present study entitled, “Morphometric and Chemical Variability in Soapnut (*Sapindus mukorossi* Gaertn.) in Himachal Pradesh” was carried out in the experimental field and laboratory of the Tree Improvement and Genetic Resources, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during 2011-13. The study revealed significant variation among different seed sources for all traits, except seed viability, and oil physico-chemical traits for viscosity, saponification value, specific gravity and refractive index while, all morphometric, oil content, physico-chemical, laboratory germination and progeny performance traits did not show significant variation between D.B.H. classes. Seed sources which have higher seed weight and seed diameter showed better performance than others, those seed with lower seed weight and seed diameter comparatively. Over all Banjar seed source was found to be superior followed by Garsa seed source for all traits. All traits were more over genetically controlled as revealed by high heritabilities. High heritability with low genetic advance is associated with seed diameter. Phenotypic coefficient of variability is higher than genotypic coefficient of variability for all traits which means that the characters have interacted with the environment to some degree of extent. Positive significant genotypic and phenotypic correlation was found among fruits weight, seeds weight, kernel weight, seed diameter, germination traits, oil content and progeny performance traits, which suggest that selection for any one of these, will be reliable for others too and phenotypic correlation coefficients were lower than the corresponding genotype ones for these traits.

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APPENDIX-I

1. ANOVA for variation in fruits and seeds morphometric traits

100 Fruit weight

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	569.543		
Seed source (S)	23	786,422.246	34,192.272	173.063
D.B.H. class (D)	1	65.304	65.304	0.331
Interaction S X D	23	2,201.545	95.719	0.484
Error	94	18,571.645	197.571	
Total	143	807,830.282		

100 Seed weight

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	76.941		
Seed source (S)	23	67,105.477	2,917.629	411.483
D.B.H. class (D)	1	5.435	5.435	0.766
Interaction S X D	23	346.483	15.064	2.125
Error	94	666.509	7.091	
Total	143	68,200.844		

Rind weight

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	0.007		
Seed source (S)	23	50.006	2.174	3,224.721
D.B.H. class (D)	1	0.008	0.008	12.290
Interaction S X D	23	0.152	0.007	9.831
Error	94	0.063	0.001	
Total	143	50.237		

Seed diameter

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	-0.001		
Seed source (S)	23	161.837	7.036	9,038.099
D.B.H. class (D)	1	0.013	0.013	16.204
Interaction S X D	23	0.209	0.009	11.675
Error	94	0.073	0.001	
Total	143	162.131		

Kernel weight

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	15.218		
Seed source (S)	23	486,059.486	21,133.021	4,195.068
D.B.H. class (D)	1	262.689	262.689	52.146
Interaction S X D	23	6,994.370	304.103	60.367
Error	94	473.533	5.038	
Total	143	493,805.297		

Fruits-kernel weight ratio

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	0.006		
Seed source (S)	23	284.012	12.348	45,021.511
D.B.H. class (D)	1	0.310	0.310	1,130.156
Interaction S X D	23	5.125	0.223	812.476
Error	94	0.026	0.000	
Total	289.479	289.479		

2. ANOVA for variation in laboratory germination traits

Seed viability

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	516.083	22.438	0.758
D.B.H. class (D)	1	8.028	8.028	0.271
Interaction S X D	23	285.639	12.419	0.420
Error	96	2,840.000	29.583	
Total	143	3,649.750		

Germination percentage

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	6,677.306	290.318	97.906
D.B.H. class (D)	1	1.361	1.361	0.459
Interaction S X D	23	23.306	1.013	0.342
Error	96	284.667	2.965	
Total	143	6,986.639		

Germination capacity

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	5,920.639	257.419	148.273
D.B.H. class (D)	1	5.444	5.444	3.136
Interaction S X D	23	13.889	0.604	0.348
Error	96	166.667	1.736	
Total	143	6,106.639		

Germination energy

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	6,607.826	287.297	13.609
D.B.H. class (D)	1	0.063	0.063	0.003
Interaction S X D	23	13.771	0.599	0.028
Error	96	2,026.667	21.111	
Total	143	8,648.326		

Number of days taken to emergence

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	722.556	31.415	4.018
D.B.H. class (D)	1	1.361	1.361	0.174
Interaction S X D	23	17.306	0.752	0.096
Error	96	750.667	7.819	
Total	143	1,491.889		

3. ANOVA for oil content and physico-chemical traits variation

Oil content

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	949.755	41.294	31,176.589
D.B.H. class (D)	1	-0.031	-0.031	-23.716
Interaction S X D	23	0.112	0.005	3.669
Error	96	0.127	0.001	
Total	143	949.963		

Viscosity

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	5.361	0.233	0.233
D.B.H. class (D)	1	0.066	0.066	0.066
Interaction S X D	23	0.460	0.020	0.020
Error	96	95.915	0.999	
Total	143	101.801		

Saponification value

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	14,830.034	644.784	1.097
D.B.H. class (D)	1	-0.113	-0.113	-0.000
Interaction S X D	23	33.479	1.456	0.002
Error	96	56,440.151	587.918	
Total	143	71,303.550		

Specific gravity

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	0.000	0.000	2.215
D.B.H. class (D)	1	0.000	0.000	0.001
Interaction S X D	23	0.000	0.000	0.019
Error	96	0.000	0.000	
Total	143	0.000		

Refractive index

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-calculated values
Seed source (S)	23	0.000	0.000	49.379
D.B.H. class (D)	1	0.000	0.000	889.813
Interaction S X D	23	-0.000	-0.000	-38.052
Error	96	0.000	0.000	
Total	143	0.000		

4. ANOVA for Variation in progeny performance traits

Shoot length

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	74.340			74.368		
Seed source (S)	23	1,467.879	63.821	8.965	4,757.770	206.860	29.032
D.B.H. class (D)	1	0.538	0.538	0.076	1.042	1.042	0.146
Interaction S X D	23	5.359	0.233	0.033	14.744	0.641	0.090
Error	94	669.139	7.118		669.765	7.125	
Total	143	2,217.256			5,517.688		

Root length

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	71.780			72.095		
Seed source (S)	23	816.206	35.487	22.998	2,476.484	107.673	69.739
D.B.H. class (D)	1	1.258	1.258	0.815	0.590	0.590	0.382
Interaction S X D	23	3.734	0.162	0.105	7.524	0.327	0.212
Error	94	145.047	1.543		145.132	1.544	
Total	143	1,038.025			2,701.825		

Seedling height

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	39.559			253.770		
Seed source (S)	23	4,432.623	192.723	24.397	14,050.410	610.887	64.271
D.B.H. class (D)	1	3.436	3.436	0.435	2.925	2.925	0.308
Interaction S X D	23	14.202	0.617	0.078	40.787	1.773	0.187
Error	94	742.536	7.899		893.461	9.505	
Total	143	5,232.357			15,241.353		

Collar diameter

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	0.053			1.929		
Seed source (S)	23	21.142	0.919	16.170	94.685	4.117	16.727
D.B.H. class (D)	1	0.002	0.002	0.029	0.095	0.095	0.385
Interaction S X D	23	0.111	0.005	0.085	0.406	0.018	0.072
Error	94	5.344	0.057		23.135	0.246	
Total	143	26.651			120.250		

Number of leaves

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	852.542			985.847		
Seed source (S)	23	22,052.271	958.794	9.229	58,429.660	2,540.420	12.970
D.B.H. class (D)	1	7.563	7.563	0.073	0.063	0.063	0.000
Interaction S X D	23	108.604	4.722	0.045	871.104	37.874	0.193
Error	94	9,765.458	103.888		18,412.153	195.874	
Total	143	32,786.438			78,698.826		

Leaf area

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	2.996			2.930		
Seed source (S)	23	717.644	31.202	29.459	1,037.533	45.110	42.960
D.B.H. class (D)	1	0.335	0.335	0.317	0.543	0.543	0.517
Interaction S X D	23	8.400	0.365	0.345	11.166	0.485	0.462
Error	94	99.561	1.059		98.704	1.050	
Total	143	828.936			1,150.877		

Seedling dry weight

Source of variation	Degree of freedom	After 3 months			After 6 months		
		Sum of squares	Mean sum of squares	F-calculated values	Sum of squares	Mean sum of squares	F-calculated values
Replication	2	0.011			0.007		
Seed source (S)	23	27.277	1.186	153.987	126.172	5.486	801.283
D.B.H. class (D)	1	0.028	0.028	3.587	0.012	0.012	1.744
Interaction S X D	23	0.141	0.006	0.793	0.134	0.006	0.848
Error	94	0.724	0.008		0.644	0.007	
Total	143	28.180			126.968		

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