SEED SOURCE VARIATION IN *Phyllanthus emblica* Linn. of HIMACHAL PRADESH

Thesis

by

POOJA SHARMA
(F-2021-31-M)

submitted to

Dr YASHWANT SINGH PARMAR UNIVERSITY
OF HORTICULTURE AND FORESTRY
SOLAN (NAUNI) HP - 173 230 INDIA

in

partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE
FORESTRY
(FOREST BIOLOGY AND TREE IMPROVEMENT)

DEPARTMENT OF TREE IMPROVEMENT AND GENETIC RESOURCES

COLLEGE OF FORESTRY

2023

Dr. Anita Kumari
Assistant Professor
(Major Advisor)

Department of Tree Improvement and Genetic Resources
College of Forestry
Dr. Yashwant Singh Parmar University of Horticulture and Forestry (Nauni) Solan (HP) - 173 230 India

CERTIFICATE-I

This is to certify that the thesis entitled**, "Seed source variation in *Phyllanthus emblica* Linn. of Himachal Pradesh**" submitted in partial fulfillment of the requirements for the award of degree of **Master of Science** in the discipline of **Forestry** (**Forest Biology and Tree Improvement)** of Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) -173230 is a bonafide research work carried out by **Ms. Pooja Sharma (F-2021-31-M)** daughter of **Shri Lalit Kumar** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Nauni (Solan)
Dated:

(Dr. Anita Kumari)
(Major Advisor)

CERTIFICATE-II

This is to certify that the thesis entitled, **"Seed source variation in *Phyllanthus emblica* Linn. of Himachal Pradesh''** submitted by **Ms. Pooja Sharma** daughter of **Shri Lalit Kumar** to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173230 India in partial fulfillment of the requirements for the degree of **Master of Science** in the discipline of **Forestry (Forest Biology and Tree Improvement)** has been approved by the student's advisory committee after the Viva-Voce Examination of the student in collaboration with an **External Examiner**.

Dr. Anita Kumari
Assistant Professor
Major Advisor

Dr. I K Thakur
External Examiner

Members of the Advisory committee

Dr. H P Sankhyan
Professor and Head
Department of TIGR

Dr. Prem Prakash
Assistant Professor
Department of SAF

Dr. H P Sankhyan
Professor and Head
Department of Tree Improvement and Genetic Resources
Dr. Y. S. Parmar, UHF, Nauni-173230, Solan (HP)

Dean
College of Forestry
Dr. Y. S. Parmar, UHF, Nauni-173230, Solan (HP)

ACKNOWLEDGEMENT

First of all, I am extremely grateful to my major advisor, ***Dr. Anita Kumari****, I don't have words to express my gratitude to my revered and esteemed major advisor for her expert guidance, keen interest and constant encouragement during the entire degree programme. To her, I owe a lot more than I can express.*

I would also like to thank my advisory committee members, ***Dr. H P Sankhyan*** *(Professor and Head), TIGR and* ***Dr. Prem Prakash*** *(Assistant professor), SAF for brilliant comments and suggestions.*

I wish to express my sincere and profound sense of gratitude and respect for ***Dr. Suman Jha****, Associate Professor, College of Forestry, Navsari Agriculture University, Gujrat for constant guidance throughout the period of my research and thesis compilation.*

The co-operation rendered by the faculty ***Dr. Atul Gupta, Dr. JP Sharma, Dr. Dushyant Kumar****,* ***Dr. Shikha Thakur*** *and* ***Dr. Lalit Thakur*** *as well as office, laboratory and field staff of the Department of Tree Improvement and Genetic Resources especially* ***Sh. Makhan Singh, Sh. Vidya Nand, Sh. Dinesh*** *and* ***Sh. Desh Raj*** *is duly acknowledged. I am also thankful to the Academic branch COF and COH for their kind help.*

*Words cannot express how grateful I am to my loving grandparents (****Sh. Jai Nand Sharma*** *and* ***Smt. Banti Devi****), parents (****Sh. Lalit Sharma*** *and* ***Smt. Reena Devi****), sister (****Ambika Sharma****), brother (****Sumit Sharma****) and other family members (****Anu di, Niju****) for all of the sacrifices that you they made on my behalf.*

I extend my sincere thanks to my seniors specially ***Sukirti di, Dr. Krishan Lal Gautam sir, Anchal di, Mohit Sir, Rizika di, Shreya di, Akshiptika ma'am, Shweta di, Satyam Sir and Sumit Sir*** *for their help during my research work. Thanks, are also due to my friends (****Dinku, Tmaa, Isha, Svina, Anjali, Oshmi, Sugandhi, Swati, Anku, Anshul, Kushagra, Mitu, Pranchal, Dikshi*** *and* ***Vishal****), juniors (****Akash, Anjalika, Bandana, Divyansh, Kanchan and Piyush****) and my roommates* ***(Kiran, Amita, Gargi, Srishti*** *and* ***Ritika****) who are the fulcrum of my existence.*

Most Importantly, I am indebted to God for his eternal support in guiding me through the good and testing times.

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

Place: Nauni, Solan
Date: **(Pooja Sharma)**

CONTENTS

ABBREVIATIONS USED

%	:	Per cent
=	:	Equal to
×	:	Multiplication
°C	:	Degree Celsius
ANOVA	:	Analysis of Variance
cm^2	:	Centimeter square
cm	:	Centimeter
df		Degree of Freedom
et al.	:	Co-workers
g	:	Gram
ha	:	Hectare
HP	:	Himachal Pradesh
i.e.	:	That is
kg	:	Kilogram
Linn.	:	Linnaeus
m^2	:	Meter square
mm	:	milimeter
Min	:	minimum
m^2	:	Meter square
MSS	:	Mean Sum of Square
PC	:	Principal Component
viz.	:	*Videlicet*
&	:	And

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Chapter-1

INTRODUCTION

Forests are a unique gift of nature to humankind and constitute one of the prized assets of a nation and rightly termed as an 'index of prosperity of a nation'**.** It's composition and diversity can contribute substantially to the ecological and economic development of any country. Nature has bestowed India with an enormous wealth of medicinal plants due to which the country is often referred as 'Medicinal Garden' or 'Botanical Garden' of the world (Ahmadullah and Nayar, 1999). Medicinal plants are the most precious creation of nature which is the ultimate gift for all the creatures which includes humankind also. The Indian subcontinent constitutes a rich repository of medicinal plants. It is believed that around 7000 plant species are used for medicinal purposes and these plants represent a significant source of livelihood for many forests tribal groups that are used by various indigenous health care systems.

Phyllanthus emblica (syn. *Emblica officinalis*) is one of the most important medicinal tree species. The genus *Phyllanthus* contains 350–500 species, the most of which are shrubs with a small number of herbs and trees and *P. emblica* is the one most frequently cultivated. India is the world leader in amla production. It is native to India as well as found in tropical South East Asia, Sri Lanka, Bangladesh, China and occurs mainly in the dry or moist deciduous forests. It is the first tree to have ever been created in the universe, according to ancient Indian mythology (Pria and Islam, 2019). The large numbers of wild germplasm available in the Himalayas, Uttar Pradesh, Rajasthan, Bihar, Odisha, West Bengal, Andhra Pradesh, Karnataka, Madhya Pradesh, Chotanagpur plateau and in Western Ghats. This tree can be grown up to elevation of 200 m and up to 4500 ft in the valley of Kashmir and spread across coastal, tropical, sub-tropical zones and abundantly in deciduous forests of India (Rai *et al*., 2012; Thilaga *et al*., 2013; Sai *et al*., 2002)

Aonla is also known as amritphal in Sanskrit, which literally means the fruit of heaven or nectar fruit. Different vernacular names have been given to it in different regions of India, including Amla or Aonla in Hindi, Dhatri, Dhatriphala or Amlaki in Sanskrit, Amla or Amalaki in Bengali and Oriya, Nelli in Malayalam and Tamil, Amlakamu, Usirikai Usrika in Telugu, Amolphal in Punjabi, and Aonla, Myrobalan, Indian Goosberry in english. (Gaire and Subedi, 2014). It's fruits along with those of *Terminalia bellerica* and *T. chebula* constitute the well-known ayurvedic drug 'Triphala', which is used as a purgative (Shaanker and Ganeshaiah, 1997).

Aonla is the medium sized deciduous plant. It has simple, sub-sessile and closely set along branchlets. Height of the tree ranges 6-18 meter and has a crooked trunk and spreading branches. Its unique branching architecture known as 'phyllanthoid branching' where in two types of shoots, viz. indeterminate and determinate, are borne on the tree. The indeterminate shoot is called branch which grow continuously and form the basic framework of plant, whereas determinate shoot is called branchlet are small and short-lived (Pathak, 2003). They emerge in group (3 to 5) from the nodes of indeterminate shoot. Branchlets may either be floriferous or vegetative. The floriferous branchlets bear staminate and pistillate flowers on the axil of leaves. Racemose inflorescence is characterized by inconspicuous unisexual flowers with pedicel of short length. Male flowers are yellowish green to deep pink in colour and appear in cluster at the basal part of branchlet. Female flowers are light green and are borne at the distal end. Both types of flowers are spatially separated along the axis of branchlets. Aonla also shows temporal variation in flower maturation *i.e.* protandry as male phase precedes female phase. Different climatic conditions and genotype lead to variation in the ratio of male and female flowers (Wali *et al*., 2015). Botanically drupaceous fruit of aonla has translucent spherical epicarp, fleshy mesocarp and stony endocarp surrounding almost six seeds. The fruit is spherical green light green at first but when they mature become dull greenish yellow. The mature fruits are tough and resist being delicately touched. Its wood has a rough texture. When exposed to the sun or extreme heat it wraps and splits. Wood is reddish and has a grey bark. Dormancy in aonla begins in November with the cessation of shoot growth and commencement of leaf shedding. It continues for 4-8 weeks and during this period most of the leaves shed and dormancy of trees gets established.

Both light and heavy soils can support the growth of aonla except for completely sandy soil. But the optimum soil for a better yield is well-drained fertile loamy soil. The young plants are protected from the scorching hot winds and from frosty winter months as they die easily up to the age of 3 years. However, at maturity it become frost-hardy and heat tolerant. It is generally propagated through seeds and requires optimum sunlight. Suitable sunshine is needed and the monsoon season is used to irrigate it. Seven years after the day of planting, it starts to produce fruit berries. For optimum growth, annual precipitation of 630-800 mm has given good yield. Aonla is typically propagated through seeds although trees grown from seeds have long gestation periods and delayed germination owing to seed dormancy produce fruits of lower quality. Dormancy may be due to physiological factors affecting embryo or morphological factor such as hard, thick testa or due to incorrect storage or handling (Mousavi *et al*., 2011). To overcome dormanc, such seeds may require special treatments such as scarification, soaking in water, stratification or seed treatments with growth regulators.

Best harvesting time of aonla fruits is February when the fruits have maximum ascorbic acid content. The amla fruit tissue contains ascorbic acid, proline, alanine and lysine to treat conditions like excessive salivation, nausea, vomiting, internal body heat, liver tonic, and menstrual irregularities. Due to its antioxidant properties, it is used in hair shampoos, conditioners and also have potential in preventing ulcers, diabetics, enhances memory and anti-inflammatory properties. Supplements containing aonla extract may be beneficial for those receiving radiation treatment and they also shield cancer cells from the radiation's intended destruction. Aonla tonic avoids indigestion, regulates acidity, and acts as a natural anti-aging agent. It also has a haematinic and lipolytic activity that is helpful in treating scurvy and jaundice (Sachan *et al*., 2013). According to the two main classic texts on Ayurveda, Sushruta Samhita and Charaka Samhita, aonla is regarded as "the best among rejuvenator" and "the best among the sour fruit”. It’s role in ecological perspective is that the plant materials of amla can be used as effective bio absorbent for removal of lead and zinc from aqueous solutions (Sripriya and Vijayalakshmi, 2013).

Nowadays there is great pressure on the forest resource to meet the requirement of timber and other forest products in the country. To reduce this pressure initiatives like plantation forestry, social forestry and other afforestation approaches have been started as alternative strategies to prevent large scale decline in this valuable resource. For this there is a need to select best possible species which are multipurpose and at the same time fast growing to meet the requirements of the country. However, in India large scale afforestation has been carried out in the recent past, the result on survival and growth performance in the field was poor due to lack of information on exact propagation and cultural techniques in the nursery. This result in fifty percent failure in the field establishment was due to poor quality seedlings and choice of species. The ultimate success of the various plantation programmes depends upon the right choice of species and quality of planting stock.

Genetic variation is a necessary component for long-term stability of the forest ecosystem. The geographical areas and environment in which parent trees grow and within which their genetic constitution has been developed through natural and artificial selection, result in variation among natural populations of a species. Variability studies is a necessary component for developing tree improvement strategies. Variation in the tree is mainly caused by three factors: the genetic differences among trees, the environment in which tree grows and the interaction between tree genotype and the environment in which they grow.

The knowledge of genetic variability and association of traits is considered to provide considerable help in genetic improvement of the species. Selection and propagation of genotypes with most desirable phenotypes is most important in achieving maximum uniformity in desirable characters that are strongly influenced by the genetic control and have broad spatial variability. The quantitative estimation of variability would suggest the scope for improving the desirable characters through selection.

P. emblica is an important medicinal tree growing in traditional agroforestry systems, woodlots and forest (Singh *et al*., 2012). The breeder can maximize the overall productivity by studying the variance in seed sources of the species and choosing best provenance for seed source. Instead of their multiple benefits *P. emblica* is underutilized and thus it is necessary to discover the variability and choosing the candidate plus tree for further research by using information of the genetic variability and heritability. Hence, the present investigation was envisaged to evaluate the seed source variation in different parameters collected from various regions of Himachal Pradesh.

Objectives

1. To study the variability in fruit and seed characters.
2. To study the variation for germination and seedling growth characteristics.

Chapter-2

REVIEW OF LITERATURE

The vast phenotypic and genetic variations present in forest tree populations are associated with location or source of seed as trees cover a wide range of environmental conditions. It is impossible to operate a breeding programme for forest tree improvement until sustainable variations exist in that species (Zobel and Talbert, 1984). In the last decades, there has been a definite trend towards the greater use of phenotypically superior trees *i.e.* plus trees, as seed source. The analysis of population variation is a requisite step in every programme for improving and breeding trees. It enables the identification of the relative performance of various traits and evaluating its economic value. The vast phenotypic and genetic variations present in forest tree populations are linked with location or source of seed as trees cover a wide range of environmental conditions. Genetic variability among different traits is of primary interest to improve forest trees (Zobel and Talbert, 1984). The tree populations exhibit high genetic variability and in particular, forest tree species possess greater variability, almost double than that of other plants (Hamerick *et al*., 1979). These variations can be grouped into geographical source (provenances), stands, sites and individual trees. These studies enable in analysing the natural patterns of variation, comparison of desirable and undesirable traits which have great significance in breeding or tree improvement programme and preserving these variations for future use. There is a paucity of research on phytosociology, natural regeneration pattern, extent and pattern of variation in fruit, seed, and nursery features within and between populations of the species.

Phyllanthus emblica is one of the most important medicinal tree species and of high commercial value *i.e.* generally propagated through seeds. Since amla has not yet been the subject of systematic research on site features, natural regeneration, or natural variation. Already existing relevant information with respect to seed source variation in seed and seedling characteristics, germination parameters and seedling characteristics for forest trees are briefly reviewed here under. The same is described under the following headings:

2.1 Variation in morphological traits

2.2 Variation in fruit and seed traits

2.3 Variation in seed germination and seedling characteristics

2.1 VARIATION IN MORPHOLOGICAL TRAITS

Sharma *et al*. (2021) demonstrated an experiment in order to evaluate variations in morphometric characteristics of white mulberry (*Morus alba* L.). The research revealed high estimates of heritability for leaf area, lamina length and green leaf yield. As well, significant and positive correlations were found among basal diameter, petiole length, lamina width, lamina length and leaf area. Petiole length and crown area also exhibited significant and positive correlation with green leaf yield. The best performance was shown by clones Tr10, S146 and Mandaley with respect to various morphometric characters will have implications for genetic resources conservation and tree improvement.

Ojo and Ezekiel (2019) studied the effect of provenance variations on the growth and development of *Terminalia ivorensis*. They evaluated genotypes for the observed parameters The results revealed significant differences among the different provenances at P>0.05 with the remarkable difference in the growth parameters (plant height, leaf count, leaf area and collar diameter). The variation was observed across the composition of nutrients in the provenance. Best genotypes for selection and screening of superior individuals within the populations for genetic resources conservation and tree improvement was also done.

Sharma *et al.* (2017) conducted an experiment to investigate the plus tree variation of shisham (*Dalbergia sisso*) in different agro-ecological regions of Haryana. They had selected 45 plus trees from three agroecological regions. By investigated correlation between the traits, it was observed that seeds from the dry subtropical region were determined to be more promising. However, significant differences in morphological traits were discovered, as well as a significant positive correlation between the traits such as total height, clear bole height, diameter at breast height, crown spread and straightness was observed.

Rao and Subramanyam (2009) evaluated seven varieties of aonla in rainfed area at Horticultural Research Station. They recorded, highest variability in plant height (4.2 m), number of branches (12.6), plant spread (39.9 m^3) and no. of fruits (861.6) in NA-10 followed by Kanchan (plant height 3.9 m and plant spread 32.9 m^3), NA-7 (no. of branches 11.1) and NA-6 (no. of fruits 817.6), highest stem girth (73.2 cm) and fruit yield (76.1 kg) per tree was recorded in Kanchan followed by NA-10 (65.5 cm and 74.8 kg yield).

Aulakh *et al*. (2006) investigated the performance of five aonla cultivars, including Banarasi grafted, Banarasi seedling, Chakaiya, Francis, and Kanchan in the Shivalik foothills of Punjab. Between these cultivars, cultivar Banarasi seedling (10 m) and Kanchan (7.3 m) had the highest and lowest plant heights, respectively. The maximum plant height (3.46 m) was found in NA 7, followed by NA 6 (3.21 m), NA 10 (3.11 m), and Krishna (3.10 m). The aonla cultivars growing in the Shivalik foothills of Punjab had stem girths ranging from 78-106 cm. It was measured as having a maximum in Banarasi seedlings (106 cm) and a minimum in Banarasi grafted trees (78 cm). Under rain-fed circumstances in Andhra Pradesh, Kanchan had the largest stem girth (73.2 cm), followed by NA 10 (65.5 cm), while Chakaiya had the smallest stem girth (33 cm).

2.2 VARIATION IN FRUIT AND SEED TRAITS

Bhalchandra *et al*. (2022) studied the variability of *Myrica esculenta* Buch-Ham. ex D. Don distributed in three districts of Himachal Pradesh. They reported that in terms of tree size, Serbharal population was superior to other populations. Serbharal population had maximum tree height (24.40 m) whereas minimum in Shilly (12.20 m) population. The maximum tree diameter (87 cm) was also recorded in Serbharal population whereas minimum (63 cm) in the Jaunaji population. In Tutu (10.65 cm) and Rajgarh (3.24cm) populations, maximum leaf length and leaf breadth was recorded, respectively, whereas minimum leaf length and leaf breadth were found in Shogi population *i.e.* (7.63 cm) and (2.40 cm), respectively. The mother tree variance was higher as compared to the population and within tree variance for all the tree morphological traits. The mother tree repeatability co-efficient was higher for all the tree morphological traits ranging from 0.81 for leaf breadth, 0.86 for leaf length and 0.82 for petiole length. Population repeatability co-efficient was low for all the parameters except tree height where it was found moderate (0.38).

Chandravanshi *et al*. (2022) studied physico-chemical characterstics of fruits of *Phyllanthus emblica in* Madhya Pradesh. The result showed variation in fruit morphology (fruit diameter, fruit length), TSS and pulp percentage. It was concluded that the maximum physico-chemical characteristics of aonla genotypes *i.e.* fruit weight, fruit diameter, fruit length and TSS were recorded with JA 114.

Javaid *et al.* (2022) investigated variability in fruit and seed characteristics of candidate plus trees of *Toona ciliata* in Jammu subtropics. The research revealed significant differences in the morphological traits in fruit and seed characters of *T. ciliata* with fruit length ranged from 16.88 to 25.60 mm, fruit breadth ranged from 8.23 to 11.78 mm, fruit weight ranged from 151.70 gm to 365.00 gm and seeds per capsule ranged between 19.67 and 28.33. Hundred seeds weight varied greatly between seed sources ranging from 0.12 to

0.36 g. The result concluded that the CPT-1, CPT-11, CPT-12, CPT-22, and CPT-6 with large sized fruits and with greater number of seeds can be used for commercial raising of quality planting material and the variability component can be exploited for further selection and improvement for further genetic improvement in the species.

Kumar *et al*. (2021) evaluated aonla genotype comprising of nine promising cultivars (NA 6, NA 7, NA 10, NA 20, Krishna, BSR 1, Gujarat 1, Chakaiya and CHES 1) released from the different parts of the country. They observed variation in plant shape as spreading (CHES 1, Chakaiya, Krishna, NA 6, NA 7, NA 10, BSR 1); drooping (NA 20) and upright (G1) in different cultivars of aonla. The recorded traits like plant height (4.90-6.70 m), plant spread-EW (4.47-7.15 m), plant spread-NS (4.44-7.53 m), stem girth (46.45-95.37 cm), plant volume (86.8-283.9 m3) and plant canopy area (15.59-42.35 m^2). Variation in traits like TSS (9.17-18.32 °B), acidity (1.92-2.63%), TSS: acidity ratio (4.09-7.71), ascorbic acid (323-567 mg/100 g pulp), fruit weight (5.89-55.43 g), fruit length (1.87-3.33 cm), fruit breadth (2.28-3.70 cm) and yield (36-102 kg/plant and 10.00-28.34 MT/ha) was also observed. Fruit shape was observed as flattened round (CHES 1, Chakaiya, NA 6, NA 10, G 1, BSR 1), triangular (Krishna), oval (NA 7) and round (NA 20). Free base (cavity at stem end) was observed as absent (CHES 1), shallow (Chakaiya, NA 6, NA 20, G 1), deep (Krishna), flat (NA 7, NA 10, BSR 1) and fruit apex was observed as flat (CHES 1, Chakaiya, Krishna, NA 7, NA 10, NA 20), papillate (NA 6, BSR 1) and depressed (G 1).

Singh *et al.* (2021) evaluated 11 aonla (*Phyllanthus emblica*) genotypes under semi-arid conditions in Haryana. The evaluated genotypes had significant variability for the observed parameters in number of male flowers, female flowers and total number of flowers on 10 cm length of indeterminate branch, sex ratio (male/female), fruit weight and pulp percent, TSS and TSS: acid ratio, total sugars, reducing sugars and non-reducing sugars content shows high variation, ascorbic acid and tannin content also showed variability in the selected genotype.

Sankhyan *et al*. (2020) studied the variability in morphological descriptors among different populations of *Grewia optiva* Drummond (Beul) in Himachal Pradesh. They selected fifteen populations of superior plus trees (20-30 cm diameter) of *Grewia optiva* Drummond (Beul) for study in three districts for leaf parameters (length, width, area), plant characteristics (plant height, plant diameter plant crown, number of primary branches, number of secondary branches and primary branches angles) and fruit parameters (fresh weight of 100 fruits, dry weight of 100 fruits, fruit length, fruit width and fruit thickness). All the quantitative, qualitative and pseudo qualitative traits were recorded. The population site (Bharnoi-MN5) has proved the superior population on the basis of overall scoring index of useful desired traits. However, the population site *i.e.* Balt-MN4 and Old Kangra-KR3 were statistically at par and both populations are ranked at number 2. Hence, these populations are significantly proved the best sources for selection and screening of superior individuals within the populations, on the basis of natural phenotypically observations and scoring index on each individual traits, so as to get improved genetic gain and establishment of gene bank of superior families and best genotypes of the families for genetic resources conservation and tree improvement.

Karthik *et al*. (2019) studied the germinating potential and the biochemical parameters of *Phyllanthus amarus* seeds in 100 plants (per location). It was observed that the number of seeds in the field-collected plants varies from 50 to 150, *P amarus* showed variability in germination and its germination rate reduces drastically with time that depend on both selection of viable seeds and condition of storage.

Plathia *et al*. (2018) studies the variability of seedling origin (*Syzygium cumini* (L.) Skeels) germplasm growing in subtropical region of Jammu. The surveys were conducted for characterization and evaluation of genetic diversity of Jamun for different horticultural traits. The experiment was undertaken during the entire reproductive phase to assess the distribution range and to record the range of genetic variability of different horticultural traits on the selected 40 trees. The mature fruits were harvested and analysed for different fruit traits. The research results of evaluated Jamun genotypes showed wide variability for studied characteristics.

Devi *et al*. (2018) studied the variability studies in morphometric characters on *Quercus leucotrichophora* A. natural populations in Himachal Pradesh for best phenotypes. In order to select best sites for improved genetic gain and quality production of *Q. leucotrichophora*, eight sites and three D.B.H. classes from Himachal Pradesh were evaluated on the basis of morphometric traits. The research result revealed significant variation among different sites for traits viz., tree height, clean bole height, crown width, leaf length, leaf width, leaf area. Whereas, among the different diameter classes all the traits showed significant variation except number of primary branches, leaf area, leaf width. For all traits, over all site S_8 (Salooni-Chamba) was found to be superior followed by site S_6 (Manikaran-Kulu). Diameter class D_3 (>60 cm) excelled in morphometric traits. The result concluded that superiority of S_8 (Salooni) and S_6 (Manikaran) populations from large diameter class D_3 (>60 cm dbh) for obtaining seed for further testing and obtaining best tree improvement.

Kumar *et al*. (2016) evaluated aonla varieties for their vegetative and fruit characters at KVK, Panchmahal, Vejalpur (Godhra), Gujarat, under rainfed hot semi-arid ecosystem during 2013–14. The varieties showed the variability in growth habit as tall drooping, upright spreading, tall semi-spreading and tall upright as well as the plant height varied from 3.64 to 5.69 m in all varieties. The trunk colour (grey and whitish green), leaf apex (obtuse and acute), leaf shape (oval oblong and elliptical) and the size of leaves *i.e.* length and width ranged between 1.28 cm × 0.24 cm and 48 cm × 0.33 cm, respectively. The time of fruit setting and time of fruit maturity differed considerably among all varieties. The highest fruit setting (51.95%) and fruit retention (26.40%) were recorded in NA 7, whereas it was lowest in Francis (36.56% and 11.43%). Size of fruits varied as small, medium and large. The highest fruit weight was found in NA 7, while it was lowest in Anand 2. The qualitative characters, *viz*. fruit juice content (41.56–71.62%), acidity (2.04–2.16%), pulp content (24.57–31.76 g), vitamin C content (348.42–543.82 mg/100 g), TSS (9.74–11.75%), TSS: acid ratio (4.05–5.66 g) and stone weight (1.96–2.09 g) were also observed. The stone in fruits also varied with respect to its shape (oval, oval round and round) and size of seed as small, medium and large.

Singh *et al*. (2016) conducted an experiment on variability in morphological and physico-chemical traits of 39 selected aonla genotypes collected from north-eastern region of India. The variability in fruit morphology (fruit weight, fruit length, fruit breadth, fruit girth), stone weight and specific gravity observed among the studied genotype. The fruit weight ranged between 1.39-10.59 g being maximum in T26. The highest fruit length was observed in genotype T25 (2.53 cm), The fruit breadth was observed maximum in T26 (2.57 cm), The stone weight per fruit ranged between 0.28 -1.50 g. The highest stone weight was recorded in T26 (1.50g) followed by T14 (0.95 g) and it was recorded the lowest in T18 (0.28 g) followed by T20 (0.29 g). The specific gravity ranged between 1.01- 1.42, whereas the maximum value of the same was recorded in T35 (1.42).

Sudrajat (2016) investigated the genetic variability of fruit, seed, and seedling characteristics among 11 populations of white jabon in Indonesia. The study results revealed the significant differences among populations for all the characteristics studied, except the radicle length. Higher genotypic variance and genotypic coefficient of variance for all fruit, seed, and seedling characteristics were found than corresponding environment variance and environment coefficient of variance. High heritability values coupled with high genetic gain were found for fruit weight, seedling height, root collar diameter, sturdiness index, leaf number, leaf length, and leaf width. These traits appear to be under strong genetic control and scope exists for exploitation of heritable additive genetic components for breeding and improvement in white jabon.

Mkwezalamba *et al.* (2015) studied the phenotypic variation in fruit morphology among provenances of *Sclerocarya birrea* (A. Rich.) Hochst. This study assessed for fruit traits at fifteen years of age. However, there were significant ($P<0.001$) variations among the provenances in number of fruits, fruit weight, pulp weight, seed weight, fruit length, and diameter. Magunde provenance from Mozambique had the highest mean number of fruits and Moamba provenances from Malawi. Mozambique was the most outstanding in the other parameters measured attaining the mean fruit weight of 20.89 ± 0.25 g and 25.67 ± 0.67 g, pulp weight of 25.70 ± 0.08 g and 21.55 ± 0.83 g, seed weight of 4.81 ± 0.35 g and 4.12 ± 0.18 g, fruit length 2.61 ± 0.14 cm and 2.33 ± 0.07 cm, and fruit diameter of 2.33 ± 0.15 cm and 1.97 ± 0.08 cm, respectively. The result reported no significant correlation between number of fruits and the other fruit traits. However, there were significant ($P<0.05$) and strong positive relationships between fruit length and diameter ($r = 0.775$) and fruit weight and pulp weight ($r=0.987$).

Pandey *et al*. (2014) assessed variability in twenty-eight genotypes of aonla. The research concluded that genotypes showed considerable variability with respect to morphological and physico-chemical characters. The fruit weight varied from 13.40 to 54.33 g, fruit diameter (2.87 to 4.81 cm), fruit length (2.51 to 4.04 cm), stone length (1.21 to 2.02 cm), stone weight (0.97 to 2.23 g), stone breadth (1.08 to 1.70 cm), pulp stone ratio (8.27 to 34.47), pulp weight (12.43 to 52.80 g), pulp percentage (89.21–97.16) and stone percentage (2.84–10.79). Biochemical constituents varied as, vitamin ‘C’ content (347.67 – 632.33 mg/100 g pulp), TSS ranged from (10.17–17.40 ^{o}B), acidity (2.07–2.97%), TSS acid ratio (3.96–8.29%), sugar acid ratio (1.88–4.21%), tannin content (2.80–7.08%), reducing sugars (2.43–4.35%) and total sugar (4.98–8.85%), in different germplasm accessions evaluated. Therefore, the seven aonla genotypes, *viz*., T_5, T_7, T_{10}, T_{17}, T_{20}, T_{26} and T_{28} were selected as most promising and these might be used as superior trees for clonal propagation.

Patil *et al*. (2014) investigated seed source variation on fruit and seed traits of *Zanthoxylum rhetsa* a medicinal tree under high exploitation in central western ghats, India. They collected seeds in order to evaluate fruit length, fruit width and fruit test weight. The result revealed fruit length (6.09 mm), fruit width (4.19 mm), fruit test weight (21.29 g) was found highest in Sirsi. Seed length (2.84 mm), seed width (1.75 mm), test weight (10.40 g) and seed volume (0.037 mm) were also found highest. However, Kumta seed source recorded the least for both fruit and seed parameters.

Arthanari *et al*. (2013) studied seed source variation on pod and seed parameters in *Caesalpinia sappan* Linn. They investigated 15 seed sources of *Caesalpinia sappan* assembled from Kerala and Tamil Nadu. The result revealed that pod traits expressed variability and maximum expression was with seed number per pod and the minimum with pod width. Superior variability expression was with Nagercoil for pod length (9 cm), pod width (3.8 cm), pod fresh weight (10.3 g), seed number per pod (4.7) and pod to seed ratio (25%). Pariyaram recorded highest seed length (1.7cm) with seed width (0.9 cm), germination per cent (80%) and mean daily germination (4%) among various seed sources while Palakkad recorded highest 100 seed weight (71.9 g).

Munthali *et al*. (2012) studied within and between provenance variability in fruit and seed characteristics of five populations of *Adansonia digitata* L. (baobab) selected from four silvicultural zones and assessed that morphometric traits could delineate populations from different zones into land races. Fruits were characterized from 55 trees that cover wide geographical area. 6 fruit traits and 3 individual seed traits were assessed. The results revealed highly significant differences ($P \leq 0.001$) in fruit, pulp, and seed weight, fruit length and width, number of seed, seed length, individual seed weight and width. Mean fruit weight ranged from 125.8 ± 3.25 to 162.9 ± 3.25 g, seed weight ranged from 38.6 ± 2.5 to 66 ± 2.01 g and pulp weight ranged from 28.7 ± 1.33 to 41.4 ± 1.33 g. Single seed weight showed promised evidence of divergence of populations into ecotypes.

Shankar and Synrem *(2012)* examined the morphological variability in fruits and seeds traits of *Prunus nepaulensis* in three provenances at Shillong, to study the effect of provenance variation on fruit and seed traits. According to the study, the seed and fruit weight was found to be a more variable and environmentally controlled trait, while the dimensions of fruits and seeds were found to be least variable and genetically controlled.

Singh *et al*. (2012) estimated genetic variability in *Phyllanthus emblica* Linn. of four sites in Uttarakhand. The study revealed that morpho-chemical characters of *P. emblica* exhibited considerable genetic variability in fruit morphology, especially those based on fruit weight, which has high genotypic variation, higher heritability and greater potential for genetic gain. Vitamin C had moderate genetic variance, moderate heritability but greater genetic gain. Selection can therefore be effective based on these two characters and their phenotypic expression should be an indication of their high genotypic potential. Highest phenotypic and genotypic variance was found in fruit weight. However, the lowest values (0.016 and 0.011) were found in fruit length and fruit diameter, respectively. The heritability (broad-sense) values were highest (0.99) for sugar content whereas, lowest (0.42) for fruit diameter.

Yadav and Yadav (2010) investigated the performance of eight aonla cultivars: Krishna, Kanchan, Chakaiya, NA 7, Balwant Bold, Banarasi, Francis, and NA 10 in Mathura, Uttar Pradesh.The fruit's length and diameter, which ranged from 2.90 to 4.80 cm and 2.60 to 4.30 cm, respectively, in cultivars from Chakaiya to Balwant Bold, showed a broad range of variance. Similar, under sub-tropical circumstances in Punjab, cultivar Krishna had maximum fruit length (3.34 cm) and fruit breadth (3.88 cm), followed by NA 6 and NA 7, while Kanchan had minimum values (2.90 and 3.18 cm).

Arzani *et al*. (2008) studied the morphological variation between Persian walnut (*Juglans regia*) genotypes from central Iran. They studied 58 mature Persian walnut (*Juglans regia*) seedlings growing at six sites and evaluated to determine their morphological variation and to identify promising individuals. The traits investigated included phenological characteristics, such as budbreak and nut maturity time, and nut characteristics, such as nut and kernel weight, kernel ratio, shell thickness, yield efficiency and fruit bearing habit were also investigated. The average fruit characteristics: nut weight, kernel weight, kernel ratio and shell thickness were in the range of 6.0–15.2 g, 2.6–9.1 g, 38.4–79.6%, and 0.4–1.4 mm, respectively. The promising genotypes were AA_{33}, AA_{35}, AA_{115}, AA_{116}, and BA_{150} because these trees had larger nuts (AA_{116}), heavier nuts (15.2 g, AA_{33}), heavier kernels (9.1 g, AA_{33} and AA_{115}), higher kernel ratio (79.6%, AA_{35}), and later budbreak (BA_{150}). Significant correlations were found between nut weight and nut length (0.57), nut width (0.68), nut thickness (0.67), kernel weight (0.75), and shell thickness (0.32); whereas a negative correlation was found between shell thickness and kernel ratio (0.34). The promising genotypes can be exploited for further selection and improvement.

Rao *et al*. (2008) conducted an extensive wild germplasm exploration survey and 32 high yielding candidates plus trees (CPTs) of *Jatropha curcas* were selected from different locations from a latitudinal and longitudinal spread for evaluating genetic association, and variability in seed and growth characters. The significant trait distinction was observed in all the seed characters viz., seed morphology and oil content as were observed in growth characters viz., plant height, and female to male flower ratio and seed yield in the progeny trial. Broad sense heritability was high in general and exceeded 80% for all the seed traits studied. Female to male flower ratio showed near to 100% heritability followed by yield and plant height (87.73). The path analysis concluded that female to male flower ratio had the highest positive direct relationship with seed yield (0.789 kg).

Goulart *et al.* (2007) studied morphological variation within and among five populations located in the vegetation types and in transitional sites in order to evaluate variability in fruit and seed morphology among and within populations of *Plathymenia* (Leguminosae - Mimosoideae) in areas of the Cerrado, the Atlantic Forest, and transitional Sites. Thirteen morphological traits of fruits, seeds, and of the membranous endocarp were obtained from thirty fruits and twenty seeds from each of nine to 10 individuals per population. The result showed significant variation in all traits while comparing individuals within populations, and most traits varied significantly among populations as well. Some traits differed significantly between forest and Cerrado populations, while transition sites showed intermediate patterns and higher within-population variation.

Sharma and Badiyala (2006) investigated the variability studies in common fig in Hamirpur district of Himachal Pradesh. They surveyed and evaluated the existence of variability in different traits. The high variability was found for fruit weight, yield and leaf size. On the basis of different characters, the population has been categorized into three strains from small to large fruited types. Large fruited ones had longer fruit ripening period whereas small fruited strains reported to have short fruit ripening period. The fruit weight and yield observed for the strains were 11.6 kg, 21.0 kg, 36.8 kg and 11.0 kg, 19.4 kg, 37.6 kg/tree respectively.

Samadia (2005) studied genetic variability studies in Lasora (*Cordia myxa Roxb.*). They started two extensive explorations during 2000 and 2001 for the surveys and collections of lasora variability in Rajasthan. They collected germplasm from 95 sites having varied agro-climatic conditions. The ANOVA revealed that there were high and significant differences among the thirty groups of lasora population. The result showed wide range of variability for important traits on plant growth, leaf size, fruit size, fruit quality and yield components. The estimation of PCV and GCV for fruit weight and leaf size was high and therefore, good scope for improvement through selection. Genotypes with large sized leaves are potential source of bigger sized fruits and genotypes with small sized leaves are potential source of small sized fruits.

Abdelkheir *et al*. (2003) investigated the provenance variation in seed and germination traits of *Acacia karroo*. They studied the intraspecific variations in seed morphometric and germination traits among ten provenances of *Acacia karroo* obtained from its natural habitat in Southern Africa. Seeds from each provenance were sown under controlled conditions and their germination traits were evaluated for about four weeks. The result showed significant variation in seed and germination traits.

Gowda *et al. (2002)* studied the variability and standardization of propagation techniques in *Terminalia chebula.* the investigations also focused on identification of elite trees with superior quality fruits and also to know the best provenance for quick and maximum germination of seeds with different treatments. The RAPD characterization of *T. chebula* genotypes for five provenances was evaluated to know the genetic relatedness among the population. To know the germination capacity of the *T. chebula* seeds, in vitro seed germination studies were also conducted under controlled conditions. The result showed significant differences in tree height, fruit weight, fruit length, fruit breadth, seed weight, seed length and seed breadth.

2.2 Variation in seed germination and seedling characteristics:

Baby *et al*. (2022) conducted an experiment to assess the effect of different seed priming treatments and growing conditions on seed germination and seedling vigour of aonla with 16 treatment combinations. The experiment results indicated that the combination of seed priming and growing condition with GA3 @ 500 ppm for 24 hours + poly house recorded minimum number of days to germinate, maximum germination percentage (81.30%), height of seedling, vigour index, chlorophyll content and survival percentage.

Javaid *et al*. (2022) studied variability in fruit and seed characteristics of candidate plus trees of *Toona ciliata* in Jammu subtropics. They selected 22 CPTs in subtropical and intermediate zone of Jammu region based on their phenotypic superiority. Fruits samples were collected from selected CPTs during the first and second weeks of June with collection starting from lower altitudes up to higher altitudes. The traits studied were fruit length and breadth, seed length and width, number of seeds per fruit, and hundred fruit and seed weight. The result revealed significant differences in the morphological traits in fruit and seed characters of *T. ciliata* with fruit length (16.88 to 25.60 mm), fruit breadth (8.23 to 11.78

mm), fruit weight (151.70 gm to 365.00 gm), seeds per capsule (19.67 and 28.33) and 100 seeds weight (0.12 to 0.36 g). The maximum seed length with wings was 10.44 mm, minimum seed length with wings was 12.61 mm. the seed length without seed wings varies from 4.83 mm to 6.82 mm and for seed width without seed wings ranged between 2.2 mm to 3.08 mm. The study concluded that the CPTs viz. CPTs viz. CPT-1, CPT-6, CPT-11, CPT-12 and CPT-22 with large sized fruits with a greater number of seeds can be used for commercial raising of quality planting material.

Parab *et al*. (2022) studied the effects of physical treatments and gibberellic acid on germination success of aonla seed. Twenty seeds were used for each experimental unit. The result indicated that mechanical scarification using sand paper is found to be the most effective for better seed germination (days taken to first germination, germination percentage and survival percentage) and seedling growth (length of seedling, total dry matter of seedling, Vigour Index). Among GA3 concentration, GA3 @400 ppm recorded higher values for seed germination and seedling growth parameters of aonla. The treatment combination of scarification with sand paper + GA3 @400 ppm showed better germination and seedling growth. Therefore, it is concluded that the combination of scarification with sand paper + GA3 @400ppm was found most suitable for seed germination and seedling growth of aonla.

Singh and Kaur (2021) studied the effect of pre-sowing treatment on seed germination and seedling vigour of aonla. They revealed that treatment ensured early germination with an increase in seed germination and improvement in the seedling growth with an increase in root formation and vigour index.

Lalitha *et al*. (2020) studied the effect of chemicals on seed germination and seedling growth of aonla with 11 treatments in Navsari. The results of experiment showed that aonla seeds treated with GA3 @ 500 mg/l (T10) gave the highest germination percentage and maximum seedling growth viz. number of leaves, seedling diameter and seedling height, 180 days after sowing. Highest leaf area, fresh weight of shoot and root, dry weight of shoot and root, shoot: root ratio, vigour index and survival percentage were also noted higher in treatment GA3 @ 500 mg/l (T10) at 180 days after sowing.

Chauhan *et al*. (2019) studied seeds of twenty candidate plus trees of *Melia dubia* selected from South Gujarat region of India. The result reported significant variation among CPTs for the germination and related vigour attributes was recorded. NAU-12 seeds showed the highest germination of 38.05%, mean daily germination 0.51%, germination value 1.72 and germination index 1432.5. However, initiation of germination process was recorded in NAU-9 and NAU -17 after 23.50 and 38.25 days of sowing, respectively. The result concluded that seeds of CPTs like NAU-12, NAU-9 and NAU-17 performed better on germination and vigour traits.

Verma *et al*. (2019) studied the influence of pre-sowing seed treatment and growing conditions on growth performance of Indian gooseberry. They conducted experiment in three growing conditions viz. Open condition (C1), net house (C2), poly house condition (C3) and six treatments of seed *i.e.* water soaking (S1), GA3 200 ppm (S2), GA3 400ppm (S3), GA3 600ppm (S4), Thiourea 0.5% (S5) and Thiourea 1% (S6) having 18 treatment combinations. Between different growing conditions poly house and among the seed treatment, GA3 (600ppm) were proved most promising as compare to others. The C3-S4 treatment combination (poly house and 600 ppm GA3) was proved most superior over rest of the treatment combinations with respect to growth parameters and physiological parameters like height of shoots (35.14 cm), number of leaves per seedling (103.73) and girth of stem (1.80 mm) at 120 DAS respectively, among the various treatment combinations. However, the fresh weight of shoots (3.00 g), dry weight of shoots (0.69 g), dry weight of roots (0.21 g), fresh weight of roots (0.59 g), seedling vigour, leaf area duration (5785.00 cm^2/day), leaf area index (0.347), energy interception (0.50) and light transmission ratio (30.67), recorded at 120 DAS were found to maximum in C3-S4 treatment combination.

Suman *et al*. (2018) studied the variation in growth traits of different clones of *Morus alba*. Variability among different morphometric traits were studied among fifteen selected clones of *Morus alba*. The research revealed, significant differences among clones with respect to various morphometric characters viz, basal diameter, number of primary branches, crown spread, lamina length, petiole length, lamina width, leaf area and green leaf yield clones Tr10, S146, S36, S799 and Mandaley showed higher values. These clones can be further used for provenance interaction trials etc. and therefore recommended the evaluated genotypes for improvement programme.

Fredrick *et al*. (2015) assessed provenance variation in seed morphological characteristics, germination and early seedling growth of *Faidherbia albida.* They evaluated six provenances namely Chinzombo, Wagingombe, Taveta, Maseno, Lake Koka and Awassa. The result revealed highly significant differences among provenances in all studied parameters except for seedling height at 2 to 5 months. Highest variation among provenances in seed characters was observed in seed weight while seed thickness had the lowest variation. However, the overall mean germination among provenances was 70.2% varying from 32.7 to 93.3%. Significant correlation was reported between collar diameter and seed length and between collar diameter and temperature. There were significant differences ($p \leq 0.05$) among provenances with regards to mean seed length, width, thickness and weight. The mean seed length varied from 7.03 to 9.29 mm. Seeds collected from Chinzombo (9.29 mm) and mean seed diameter varied from 4.59 to 6.06 mm. Wagingombe seeds had highest values (6.06 mm) compared to the other provenances with the lowest being for seed collected from Awassa (4.59 mm). Awassa recorded the highest seed germination capacity (93.3%) and was lowest for Taveta (32.7%) provenances. Germination energy at day nine was highest (62.5%) for Maseno provenance and lowest (32.2%) for Lake. The overall mean leaf number after 1 to 5 months ranged from 7.41 to 58.65.

Azad *et al. (2013)* studied the effects of variation in seed sources and pre-sowing treatments on seed germination of *Tamarindus indica i.e.* a multi-purpose tree species in Bangladesh. They collected seeds from various locations in Bangladesh and applied four pre-sowing treatments *i.e.* control, immersion in cold water (4°C for 24 h), immersion in hot water (80°C for 10 min) and scarification with sand paper. The germination of the seeds was carried out in poly-bags with a mixture of topsoil and cow dung in the ratio of 3:1. The fresh seeds had an average length of 1.35 ± 0.26 cm, width of 1.07 ± 0.20 cm and thickness of 0.69 ± 0.11 cm. The findings showed that pre-sowing treatments had an impact on the germination of seeds. The cold-water treatment (81.67%) and scarification with sand paper (82.33%) considerably enhanced the germination percentage when compared to the control (58.33%) and hot water treatment (59.00%). Germination started in all treatments on average 5 to 7 days after the start of the treatments, and it took 13 to 19 days to complete. Scarification with sand paper yielded the highest germination success rate (82.33%). The result showed significant differences ($p < 0.05$) in germination closing dates, seed germination periods and germination percentages among the treatments but no significant difference among seed sources. However, the effect of the interaction between seed source variation and pre-treatment differed significantly in seed germination closing dates and germination percentages and recommended cold water treatment for seed germination.

Azad *et al.* (2012) examined the seed morphology and seed germination techniques of *Albizia procera* in order to evaluate the source variation in seeds and pre-sowing treatment effects on seed germination. Mature seeds of *A. procera* were collected from five different districts and treated with four pre-sowing treatments, *i.e.* control, immersion in cold water (4°C for 24 h) and immersion in hot water (80°C for 10 min and 100°C for 1 min). The fresh seeds had an average length, width and thickness of seeds as 0.502 ± 0.485, 0.420 ± 0.060 and 0.191 ± 0.118 cm, respectively. The germination of the seeds was carried out in poly-bags with a mixture of topsoil and cow dung in the ratio of 3:1. The results showed that pre-sowing treatments affected the rate of germination of seeds, which significantly increased the germination percentages of seeds in hot water treatments compared with those in control (60.60%) and the cold water treatment (63.53%).The result showed significant differences ($p < 0.05$) in germination closing dates, seed germination periods and germination percentages among the treatments but no significant difference among seed sources. The study also revealed that the interaction between seed source variation and treatment effect significantly differed in seed germination starting dates, closing dates, germination percentages and rates of germination. The hot water treatment is recommended for seed germination of *A. procera*.

Gupta *et al*. (2012) studied the genetic variability and correlation study in *Acacia catechu* seed source in Himachal Pradesh. It was conducted in Himachal Pradesh to estimate the genetic variability for the phenotypic characters, seed traits and nursery traits of khair selected from ten different seed sources. The seedling height, number of branches, tree diameter and seed germination had high coefficient of variability, heritability and genetic advance indicating importance of these desired traits for selection purposes. Nursery traits had high heritability, genetic advance and genetic gain suggesting their importance for the success of improvement through selection. The environmental, genotypic and phenotypic correlations for all possible pairs have also been discussed. Using Euclidean cluster analysis, all the provenances were grouped in to three clusters.

Kaushik *et al*. (2012) studied the genetic parameters in seed morphology, germination, seedling growth and biochemical contents of seed traits in *Azadirachta indica* collected from different parts of Haryana, India. The 'F' values for every character under investigation were significant ($P<0.05$), demonstrating that there was enough genetic diversity for every character. Between 1.93 and 8.73 percent was the calculated coefficient of variance. From 21.29 percent for seed breadth, 88.27 percent for root length, the genetic advance as a percentage of means recorded fluctuated. In terms of genetic advance as a percentage of mean, the other parameters, collar diameter (73.56%) and shoot length, likewise displayed high values. For 100-seed weight, seed germination, shoot length, palmitic acid, stearic acid, high heritability (99.00%) and genetic increase were observed, showing additive gene activity. A substantial and positive correlation was found between seed size (length and breadth) and 100-seed weight and oil content, as well as between azadirachtin content, palmitic acid, and oleic acid. The top performing plus trees were T4 from Jhatipur of Sonipat lineage, T6 from Premnagar of Bhiwani, T6 from Kurukshetra of the Karnal and T6 from Pinjore II of Panchkula.

Shu *et al*. (2012) studied variation in seed and seedling traits among fifteen Chinese provenances of *Magnolia officinalis.* They selected provenances ranging from 336 to 1387 m in China in order to evaluate germplasm resources of *M. officinalis* by testing seed traits, seed germination, seedling traits and seedling growth rate. The result revealed significant differences among provenances in all studied traits except net assimilation rate and relative growth rate. A significant positive correlation in terms of average annual temperature and average annual rainfall, and negative correlation with latitude of seed origin. Seed weight exhibited maximum variation among provenances in seed morphometric traits. Overall average seed germination in nursery was 59.4% varying from 26.6% to 91.2%. By geographical latitude, the stem diameter decreased from east to west while seedling height fell steadily from South to North. The result concluded that geographic variation of the *M. officinalis* at the seedling stage manifests a two-way variation with the latitude and longitude. Seed of Longsheng, Wuyishan, Kaixian, Ningqiang Yangxian and Jingning provenance have been identified suitable to produce quality seedlings.

Sumbali *et al*. (2012) studied the effects of pre-sowing treatments on germination and seedling growth of *Terminalia chebula* Retz. The highest germination percentage, vigour index, germination value and germination energy followed by fruits that had been depulped and soaked in cow dung slurry for 12 hours, alternately dried for 8 hours, and again soaked for 12 hours, which were significantly different from the control treatment.

Hembrom *et al*. (2011) assessed 25 provenances of *Terminalia arjuna* (11) and *T. tomentosa* (14) for seed morphology, seedling growth and biomass attributes. They recorded variability for 13 seed and seedling traits in both the species. In *T. arjuna* and *T. tomentosa*, the weight of a single seed varied from 1.15 to 4.52 g and 0.87 to 2.76 g, respectively. The highest germination percentage (83.33) was recorded in *T. arjuna* seeds from Chakradharpur, Jharkhand. The highest amount of fresh biomass was produced by *T. tomentosa* seedlings from Kharsawan, Jharkhand (2.03 g). The highest root shoot ratio (3.08:1), a crucial factor in the initial establishment of seedlings, was seen in *T. tomentosa* seedlings from Ranka

(Jharkhand). Between 669.80% (*T. arjuna*) and 580.80% (*T. tomentosa*), the vigour index fluctuated. The emergence index, germination rate, germination speed, root length, and vigour index were all found to be significantly correlated. Based on the vigour index, root/shoot ratio, and trees of T. *tomentosa* from Baharagoda and *T. arjuna* from Chakradharpur and Garwha have been identified for propagation purposes.

Raddad and Luukkanen (2007) investigated the eco-physiological and genetic variability in seedling traits and of eight *Acacia senegal* provenances in Sudan. The genetic variation in seed number per kg, seed weight and seedling traits was compared among eight *A. senegal* seed sources originating from the East and West in Sudan. Seed variables showed significant differences and showed considerable variation in seed weight and seed number in Eastern provenances. They had the smallest seed weight but the highest seed number, while the western provenances had the largest seed weight but lowest seed number. Seedling branch number, root length, root to shoot ratio and shoot dry weight differed significantly among the provenances 12 weeks after germination. Seedling variables, such as root nodule and branch numbers showed high positive correlations and this could be used for early selection. The variability was greater between provenance groups than within them, suggesting that selection among groups would yield genetic gain.

Loha *et al.* (2006) studied the patterns of genetic variation in *Cordia africana*. They collected seed samples from six natural populations in Ethiopia and examined for variations in seed morphometric traits, seed germination, and seedling growth at nursery stage. Analysis of variance revealed significant differences among provenances in all studied attributes except root collar diameter after 4 months of growth. A significant positive correlation showed by seed weight with altitude and negative correlation with temperature of seed origin. Germination energy was correlated with longitude and rainfall and seedling parameters and geo-climatic variables of seed origin were fairly correlated. A significant inter-trait correlation was found between seed length and seed weight, between root collar diameter at the age of 4 months and seed length and weight, as well as between seedling height after 4 and 8 months of growth. The research concluded that the observed patterns of variation will have implications for genetic resources conservation and tree improvement.

Singh *et al.* (2006) examined the variability in seed and seedling traits of *Celtis australis*, a multipurpose tree in Central Himalaya, India. They collected seeds from 13 different provenances and significant ($p < 0.05$) variations were observed for traits among provenances. Among various characters, seed weight exhibited maximum variation between seed populations compared to other morphological traits. The significant ($p < 0.01$) positive correlation between growth performance of seedlings and altitude of the seed source was recorded. Across the provenances, shoots had the highest proportion of total biomass (42.3%), followed by leaves (32.6%) and roots (24.6%). The different provenances showed significant differences in seedling growth.

Chapter-3

MATERIALS AND METHODS

The current study entitled **"Seed source variation in *Phyllanthus emblica* Linn. of Himachal Pradesh,"** was conducted in 2021–2023 in the Department of Tree Improvement and Genetic Resources, College of Forestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan. The descriptions of the materials and methods used, the sites selected for the experiments, and the methodology chosen for the study are explained under the following headings.

3.1 Study area and experimental site

3.2 Experimental procedure

3.3 Statistical analysis

3.1 STUDY AREA AND EXPERIMENTAL SITE

3.1.1 Location: Twelve naturally occurring *Phyllanthus emblica* populations were selected from four regions of Himachal Pradesh viz. Hamirpur, Kangra, Bilaspur and Mandi. Details of the natural populations are given in (Table 1).

Table 1. Physical description of sites (Populations)

Populations	Regions	Latitude (E)	Longitude(N)	Altitude (m)
Khaggal	**Hamirpur**	31º43’37”	76º24’93”	711
Rangas	**Hamirpur**	31°42’43”	76°21’48”	614
Pahlu	**Hamirpur**	31º36’25”	76º31’54”	654
Jachh	**Kangra**	31º16’22”	76º52’56”	489
Kathal	**Kangra**	31º15’32”	76º51’21’’	430
Ganoh	**Kangra**	31º14’92”	76º52’48”	292
Beri	**Bilaspur**	31º22’55”	76º49’19”	650
Panjgain	**Bilaspur**	31º27’41”	76º50’48’’’	718
Kasol	**Bilaspur**	31º22’41”	76º52’58’’	673
Slapper	**Mandi**	31º24’54”	76º50’55’’	601
Jarol	**Mandi**	31º27’30”	76º83’58’’	1029
Baroti	**Mandi**	31º26’55”	76º48’22’’	626

3.1.2 Climate

The selected locations had a subtropical environment with cold winters. In summer, temperature reaches maximum up to 42°C, while in winter up to 1°C. The monsoon occurs from July to September. Just before the monsoon, in April, May and June, as well as in October and November, there are drought-like conditions that might occasionally pose a major fire risk.

3.2 EXPERIMENTAL PROCEDURE

3.2.1 Variation in fruit and seed characters

3.2.1.1 Fruit Collection

Fruits of *Phyllanthus emblica* were collected from twelve natural populations in Himachal Pradesh. Five mature trees were selected from each population. The selected trees were kept at least 100 m apart from each other to ensure maximum genetic variation within the population. The mature fruits were collected randomly from each tree in month of December, 2022. The following observations were recorded-

OBSERVATIONS RECORDED

1. Morphometric traits

- **Tree height (m)** - It is straight line distance from leading tip to ground level. The tree height was taken with the help of Ravi's Altimeter.
- **Tree girth (m)** - Tree girth above 15 cm were selected for study with the help of measuring tape at height of 1.37 m.

Fruit characteristics

- **Fresh fruit weight (g) -** Individual fruit weight was recorded by using electronic balance.
- **Fresh fruit length (mm) –** Individual fruit length was measured by using digital vernier calliper.
- **Fresh fruit breadth (mm) –** Individual fruit breadth was measured by using digital vernier calliper.
- **Fruit length/weight ratio:** It was calculated using the following formula-

$$\text{Fruit length/breadth ratio} = \frac{\text{Fruit length}}{\text{Fruit breadth}}$$

3. **Stone characteristics**

- **Stone weight (mm)** - Individual stone weight was recorded for each genotype using electronic balance.
- **Stone length (mm) –** Individual stone length was measured by using digital vernier calliper.
- **Stone breadth (mm) –** Individual stone breadth was measured by using digital vernier calliper.

4. **Pulp characteristics**

- **Pulp weight (g) –** Pulp was extracted from fruit and was measured by electronic weighing balance.
- **Pulp thickness (mm) –** It was calculated using the formula i.e., fruit breadth subtracted by stone breadth.

5. **Seed characteristics**

- **Seed extraction -** Seed were extracted from dried stone by breaking them manually, or with the help of hammer.
- **Hundred seed weight (g) -** From each tree hundred seeds were randomly selected and weighed by using electronic balance.

3.2.2 Nursery Experiment

The nursery trial of *Phyllanthus emblica* was raised in the glasshouse 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. The area has subtropical climate with cold winters and moderate summers. The average maximum temperature in May surpasses 32.1 and the average lowest in January is 0.7. Frost incidence in the winter is fairly frequent. Western disturbances often cause winter precipitation.

Altitude: 1250 m amsl

Latitude: 30º0’51’’N

Longitude: 76º0’11’’E

(Source: Survey of India, Toposheet No. 55F/1)

Table 2. Meteorological data of nursery site (2023)

Month	Temperature (°C)			Relative humidity (%)	Total rainfall (mm)
	Maximum	Minimum	Mean		
February, 2023	22.78	5.56	14.17	52.48	7.2
March, 2023	23.58	8.04	15.81	63.77	130.6
April, 2023	26.62	10.50	18.56	51.14	114.3
May, 2023	27.90	13.20	20.55	58	154
June, 2023	29.30	17.40	23.35	65	15.4

Source: Metrological Observatory, Department of Environment Sciences, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, HP 173 230

3.2.3 Seedling traits

3.2.3.1 Germination (%) -The seeds collected from each genotype were sown in polybags under glass house conditions and germination percentage was recorded after one month.

3.2.3.2 Growth parameters - Various growth parameters were studied as below after 4 months of seed sowing.

- **Seedling height (cm)**- Height was measured from collar region up to apex of leading shoot with the help of scale.
- **Shoot length (cm)**- Length was measured from first leaf from the bottom up to apex of leading shoot with the help of scale.
- **Internodal length (cm)**- Length was measured in between two nodes of seedling. Their average was recorded as internodal length of seedling.
- **Collar diameter (mm)** - Collar diameter was measured with the help of digital vernier calliper.
- **Number of leaves / seedling** - Total number of leaves per plant were counted.
- **Leaf area (cm^2)** - It was measured by using leaf area meter. Three leaves were collected from lower, middle and upper part of plant. Their average was recorded as leaf area of seedling.

3.4 STATISTICAL ANALYSIS

3.4.1 Genetic estimation and correlation

The experimental data of all the tree characters studied were subjected to the statistical analysis for proper interpretation. The data of mother trees was analysed statistically using random nested model as follows:

$$Y_{ijklm} = \mu + p_i + m\,(p)j_{(i)} + e_{ijk}$$

Where:

μ	=	grand mean
p_i	=	effect of ith natural population (i=1,2.....p)
$m\,(p)_{j(i)}$	=	the jth mother tree effect within each ith natural population
e_{ijk}	=	the interaction of the kth observation and jth mother tree in the ith natural population

3.4.2 Genetic parameter estimation: REML Variance components for population, mother tree or family within population and within family were estimated in JMP Pro 10 (JMP Pro 10; SAS Institute Inc., Cary, NC, USA).

3.4.3 Repeatability –

We couldn't accurately measure genetic variance between and within populations because genetic effects can't be isolated from environmental effects in natural populations when parental origin and environmental influences aren't controlled. As a result, we are unable to calculate the heritability coefficient at the population or individual tree level. In this case, we use the repeatability coefficient, which may be considered as the top limit of the genetic-phenotypic variance relationship (Falconer and Mackey, 1996). These coefficients also show the proportion of within-population variation that contributes to total variance and the proportion of between-tree variation that contributes to total population variation.

Mother tree repeatability: $\sigma_m^2 = \frac{\sigma_n^2}{\sigma_m^2 + \sigma_{\omega(m)}^2}$

Where,

σ^2_m	=	Mother tree variance
$\sigma^2_{w(m)}$	=	Within mother tree variance

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

$$h^2 = \frac{Vg}{Vp} \times 100$$

Where;

h^2	=	heritability (broad sense)
V_p	=	phenotypic variance
V_g	=	genotypic variance

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

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

Where;

k	=	Selection differential at five percent selection intensity i.e., 2.06 (Allard, 1960)

3.4.6 Genetic gain: It was calculated by the method suggested by Johnson *et al.* (1955) as under:

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

3.4.7 Correlations: Correlations were computed to examine inter-character relationships among fruit, seed, germination and seedling traits following (Panse and Sukhatme,1967) as:

$$r = \frac{Cov[x_1, x_2]}{\sqrt{v(x_1) \cdot v(x_2)}}$$

where,

r	=	Correlation coefficient,
Cov	=	Covariance for any two traits x1 and x2, respectively,
V	=	Variances for any two traits x1 and x2, respectively.

The data was analyzed using JMP Pro 10 (JMP Pro 10; SAS Institute Inc., Cary, NC, USA)

3.4.8 Principal component and Cluster analysis:

Relationships among the accessions were investigated by Principal Component Analysis (PCA). PCA was performed using JMP pro 10 software. Means of mother trees or families were used to create a correlation matrix to extract standardized principal component (PC) scores. Scatter plots of the first 2 PCs were created with JMP 9 pro. To determine the PCs accounting the greatest amount of variation, the eigen values of the 2 PCs were compared for each trait. Cluster analysis was also performed to cluster genotypes into similarity groups using the method of UPGA (Unweighted Pair Group Average) using ward method (Ward, 1963).

Chapter-4

RESULTS AND DISCUSSION

In the current study twelve seed sources from Hamirpur, Kangra, Bilaspur and Mandi regions were examined for morphometric, fruit, seed, seedling characterstics and genetic estimates. The results are presented as per the following segments.

4.1 Morphometric characteristics

4.2 Fruit and seed characteristics

4.3 Nursery performance of open pollinated families

4.4 Multivariate analysis

4.1 MORPHOMETRIC CHARACTERISTICS

4.1.1 Variation among regions for tree height and tree girth

The data revealed that Kangra region had maximum (10.77 m) tree height whereas minimum (6.17 m) was observed in Mandi region. The maximum tree girth (0.66 m) was recorded in Hamirpur region whereas minimum (0.28 m) in Bilaspur region (Table 3).

Table 3. Variation among regions for tree height and tree girth in *Phyllanthus emblica*

Regions	Tree height (m)	Tree girth (m)
Bilaspur	6.17	0.33
Hamirpur	8.88	0.66
Kangra	10.77	0.62
Mandi	6.82	0.28
C D $_{0.05}$	**2.08**	**0.22**

4.1.2 Variation among populations for tree height and tree girth in *Phyllanthus emblica*

The data revealed that Kathal population in Kangra region had maximum (11.28 m) tree height whereas minimum (5.41 m) in Jarol, Mandi region. The maximum tree girth (0.83 m) was recorded in Rangas, Hamirpur region whereas minimum (0.28 m) in Beri, Bilaspur region (Table 4). These results are in confirmation with result of Singh (2016) in *P. emblica* hybrid where tree height was ranged from 4.83-6.62 m and tree girth from 46.40-95.33 cm.

Table 4. Variation among populations for tree height and tree girth in *Phyllanthus emblica*

Regions	Populations	Tree Character	
		Tree height (m)	Tree girth(m)
Bilaspur	**Beri**	6.77	0.23
	Kasol	6.22	0.37
	Panjgain	5.53	0.39
Hamirpur	**Khaggal**	8.29	0.68
	Pahlu	7.99	0.48
	Rangas	10.36	0.83
Kangra	**Ganoh**	9.94	0.62
	Jachh	11.09	0.65
	Kathal	11.28	0.61
Mandi	**Barot**	7.62	0.29
	Jarol	5.41	0.30
	Slapper	7.44	0.25
CD $_{0.05}$		**2.12**	**0.14**

4.2 FRUIT AND STONE CHARACTERISTICS

4.2.1 Variation among regions for fruit length, fruit breadth, fruit weight and fruit length/breadth ratio in *Phyllanthus emblica*

The data presented in table 5 concluded that maximum fruit length (20.14 mm) was recorded in Mandi region and minimum (18.52 mm) in Bilaspur region. Maximum fruit breadth (22.28 mm) was found in Hamirpur region and minimum fruit breadth (21.20 mm) in Kangra. The maximum fruit weight (6.33 g) was recorded in Mandi and minimum fruit weight (5.79 g) in Kangra region. Maximum fruit length/breadth ratio was recorded in Kangra and Mandi region *i.e.* 0.92 and minimum in Bilaspur region (0.86).

Table 5. Variation among regions for fruit length, fruit breadth, fruit weight and fruit length/breadth ratio in *Phyllanthus emblica*

Regions	Fruit Length (mm)	Fruit breadth (mm)	Fruit weight (g)	Fruit (length/breadth) ratio
Bilaspur	18.52	21.49	5.86	0.86
Hamirpur	20.01	22.28	6.21	0.90
Kangra	19.39	21.20	5.79	0.92
Mandi	20.14	21.86	6.33	0.92
CD $_{0.05}$	**0.16**	**0.17**	**0.09**	**0.01**


a) *Phyllanthus emblica* tree

Plate 1: Measurement for girth at dbh of mother tree

4.2.2 Variation among populations for fruit length, fruit breadth, fruit weight and fruit length/breadth ratio in *Phyllanthus emblica*

Appraisal of table 6 revealed that in Rangas populations traits like fruit length (22.39 mm), fruit breadth (24.63 mm), fruit weight (7.43 g) was found maximum. In Beri populations fruit length (17.73 mm) and fruit length/breadth ratio (0.85) were recorded minimum. In Jachh population fruit breadth (20.09 mm) and fruit weight (5.24 g) were recorded minimum among other populations. However, fruit length/breadth ratio (1.10) was recorded highest in Baroti population. Singh *et al.* (2016) reported in fruit length (1.26- 2.53 cm), fruit breadth (1.27-2.57 cm) and fruit weight (1.39 - 10.59 g) range in *P. emblica*. Kaur and Dhaliwal (2013) found fruit length & fruit width *i.e.* 2.90 cm and 3.18 cm, respectively in Kanchan variety in *P. emblica*. Bakshi *et al.* (2015) also found that diameter and length of amla fruits ranged from 2.84 to 4.42 cm and 2.64 to 3.73 cm, respectively, in Neelam and Desi cultivars.

Table 6. Variation among populations for fruit length, fruit breadth, fruit weight and fruit length/breadth ratio in *Phyllanthus emblica*

Regions	Population	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Fruit length/breadth ratio
Bilaspur	**Beri**	17.73	21.03	5.57	0.85
	Kasol	18.45	21.24	5.70	0.87
	Panjgain	19.38	22.19	6.30	0.88
Hamirpur	**Khaggal**	18.92	21.52	5.71	0.88
	Pahlu	18.73	20.71	5.49	0.90
	Rangas	22.39	24.63	7.43	0.91
Kangra	**Ganoh**	19.60	21.88	6.14	0.90
	Jachh	19.19	20.09	5.24	0.96
	Kathal	19.37	21.64	6.00	0.90
Mandi	**Baroti**	21.21	21.11	6.30	1.01
	Jarol	18.84	21.71	6.04	0.87
	Slapper	20.37	22.76	6.64	0.90
	$C.D_{0.05}$	**0.28**	**0.30**	**0.16**	**0.01**

4.2.3 Variation among regions for stone length, stone breadth, stone weight, pulp weight and pulp thickness in *Phyllanthus emblica*

The data presented in table 7 concluded that maximum stone length (11.50 mm), stone breadth (10.49 mm) and stone weight (0.95 g) was recorded in Hamirpur region. The minimum stone breadth (9.46 mm), stone weight (0.86 g) was recorded in Bilaspur region. Maximum pulp thickness (6.01 mm) was observed in Bilaspur region whereas minimum (5.39 mm) in Kangra region. Maximum pulp weight (5.41 g) was found in Mandi region while minimum pulp weight (4.88 g) in Kangra region.

Table 7. Variation among regions for stone length, stone breadth, stone weight, pulp weight and pulp thickness in *Phyllanthus emblica*

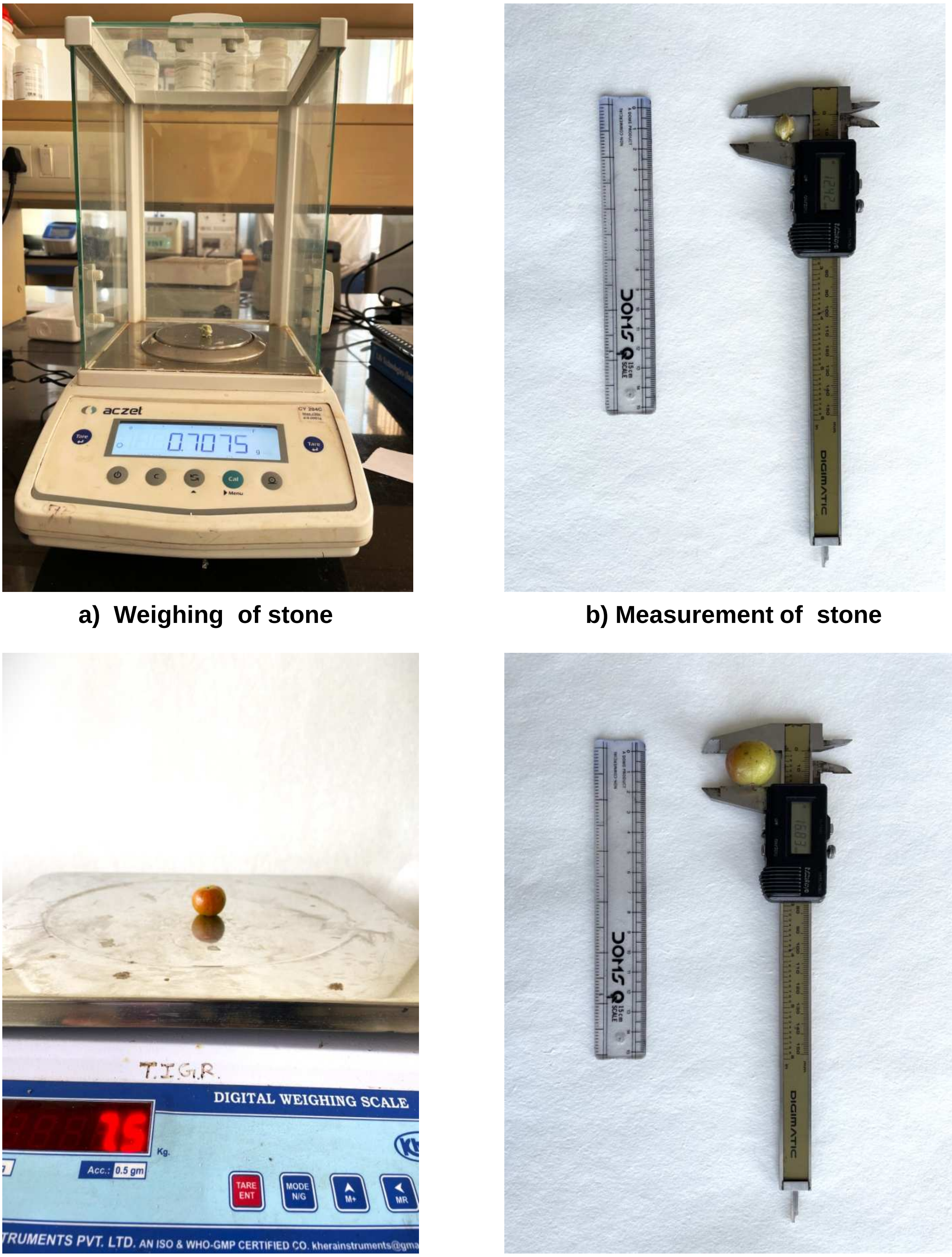
Regions	Stone length (mm)	Stone breadth (mm)	Stone weight (g)	Pulp weight (g)	Pulp thickness (mm)
Bilaspur	10.49	9.46	0.86	4.99	6.01
Hamirpur	11.50	10.49	0.95	5.26	5.90
Kangra	10.40	10.43	0.91	4.88	5.39
Mandi	11.02	10.03	0.92	5.41	5.92
$CD_{0.05}$	**0.13**	**0.14**	**0.01**	**0.09**	**0.06**

4.2.4 Variation among populations for stone length, stone breadth, stone weight, pulp weight and pulp thickness in *Phyllanthus emblica*

In Rangas population traits like stone length (12.66 mm), stone weight (1.06 g), pulp weight (6.37 g) and pulp thickness (6.39 mm) were found maximum (Table 8). Among populations stone breadth (12.89 mm) was recorded maximum in Ganoh. However, in Jachh population stone length (9.93 mm), stone breadth (8.91 mm), stone weight (0.84 g) and pulp weight (4.40 g) recorded minimum. Singh *et al*. (2016) reported stone weight from 0.28 to 1.50 g in *P. emblica* hybrid. Hazarika (2019) reported pulp weight (7.26–3.92 g), pulp-stone ratio (1.63–6.98), pulp percentage (60.27–84.81%), stone length (9.27–12.80 mm) and stone weight (0.58–2.94 g) in *P. emblica*. Pandey *et al*. (2014) also found that stone weight of aonla fruits varied from 0.97 g to 2.23 g in 28 aonla genotypes.

Table 8. Variation among populations for stone length, stone breadth, stone weight, pulp weight and pulp thickness in *Phyllanthus emblica*

Regions	Population	Stone length (mm)	Stone breadth (mm)	Stone weight (g)	Pulp weight (g)	Pulp thickness (mm)
Bilaspur	**Beri**	10.25	9.31	0.86	4.71	5.86
	Kasol	10.31	9.26	0.86	4.85	5.99
	Panjgain	10.91	9.81	0.88	5.42	6.19
Hamirpur	**Khaggal**	11.44	10.3	0.92	4.79	5.61
	Pahlu	10.4	9.33	0.87	4.62	5.69
	Rangas	12.66	11.84	1.06	6.37	6.39
Kangra	**Ganoh**	10.79	12.89	1.05	5.09	4.50
	Jachh	9.93	8.91	0.84	4.40	5.59
	Kathal	10.48	9.48	0.85	5.14	6.08
Mandi	**Baroti**	11.22	10.4	0.98	5.31	5.36
	Jarol	10.58	9.56	0.86	5.18	6.08
	Slapper	11.25	10.12	0.9	5.74	6.32
	$CD_{0.05}$	**0.22**	**0.24**	**0.02**	**0.15**	**0.1**



a) Weighing of stone

b) Measurement of stone

c) Weighing of fruit

d) Measurement of fruit

Plate 2: Measurement of stone and fruit of *Phyllanthus emblica*

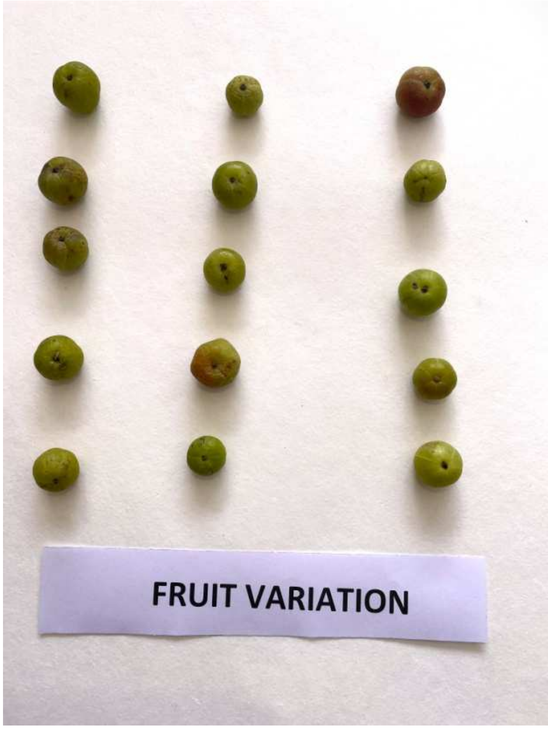
4.2.5 Variance component, repeatability, genetic advance and genetic gain for fruit, stone and pulp characteristics

Table 9 revealed that variation due to region was found maximum in fruit length (0.2681 mm) and minimum in fruit length/breadth ratio (0.0003). Variation due to population was found maximum in stone breadth (0.8905 mm) and minimum for fruit length/breadth ratio (0.0009). Variation due to mother tree was found maximum in fruit breadth (1.7384 mm) and minimum in fruit length/breadth ratio (0.0016). Variation due to environment factors was found maximum in fruit breadth (1.9334 mm) and minimum in fruit length/breadth ratio (0.0022). Total variation was found maximum in fruit breadth (4.5171 mm) and minimum in fruit length/breadth ratio (0.0051). The repeatability due to region was found maximum for fruit length/breadth ratio (0.0653) and minimum for pulp weight (0.0381g). The population repeatability coefficient was found maximum for pulp thickness (0.3055 mm) and minimum for stone length (0.0879 mm). The mother tree repeatability coefficient was found maximum for fruit breadth (0.4734 mm) and minimum for stone weight (0.3589 g). Genetic advance due to region was found maximum for fruit length (0.36 mm) and minimum for seed weight (0.01 g). Genetic advance due to population was found maximum for fruit breadth (0.3802 mm) and minimum for fruit length/breadth ratio (0.0126). Genetic advance due to mother tree was found maximum for fruit breadth (1.2859 mm) and minimum for fruit length/breadth ratio (0.035 g). Genetic gain due to region was found maximum for pulp thickness (0.5396 mm) and minimum for fruit weight (0.1582 g). Genetic gain due to population was found maximum for pulp thickness (4.3604 mm) and minimum for stone length (0.7051 mm). Genetic gain due to mother tree was found maximum for pulp weight (11.5594 g) and minimum for fruit length/breadth ratio (3.892). This variation was supported by Sofi and Singh (2012) in *Dalbergia sissoo* and Tchokponhoué *et al*. (2020) in *Synsepalum dulcificum* where heritability by using repeatability coefficient for fruit parameters was found 0.66 for fruit breadth and 0.74 for fruit length. Singh *et al*. (2012) observed that fruit weight exhibits high genotypic variation, higher heritability and higher potential for genetic gain in *P. emblica*.

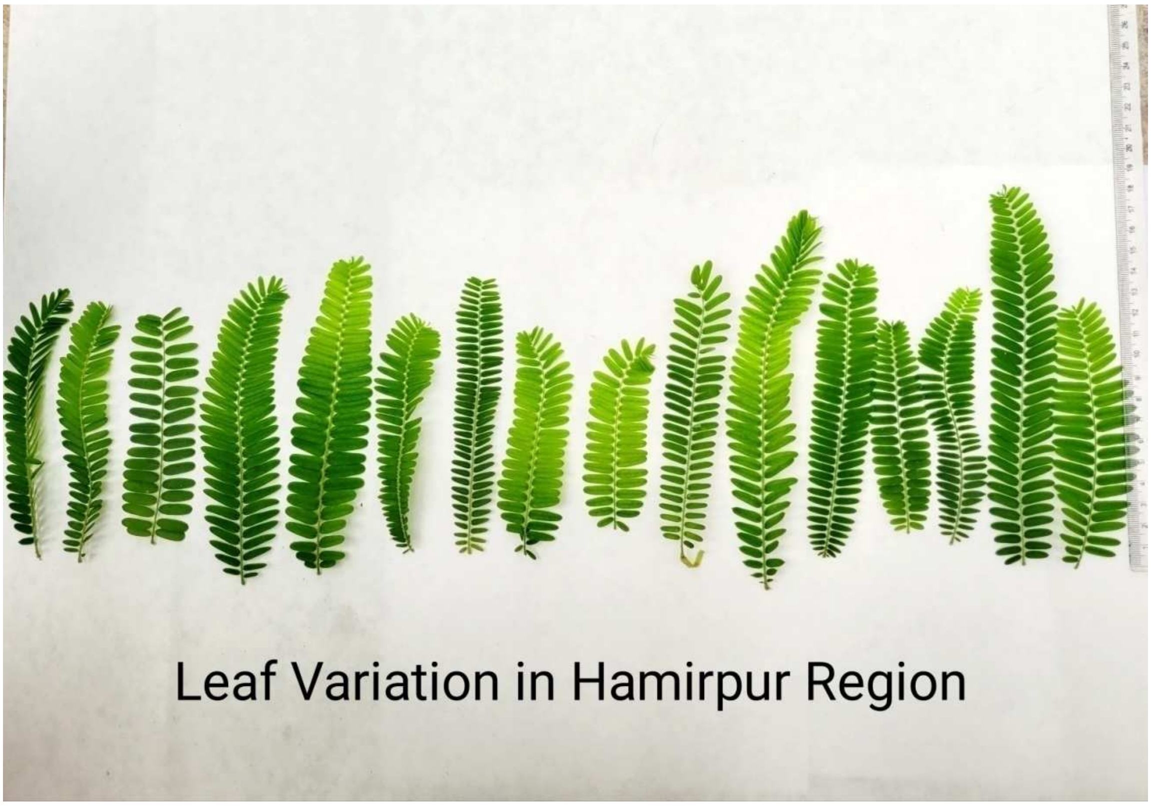
Table 9. Variance components, heritability, genetic advance and genetic gain for fruit, stone and pulp characteristics

Random effect	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Stone length (mm)	Stone breadth (mm)	Stone weight (g)	Fruit length/breadth ratio	Pulp weight (g)	Pulp thickness (mm)
Vr	0.2681	0.1784	0.0484	0.1088	0.1825	0.0009	0.0003	0.0408	0.0422
Vp	0.8226	0.6669	0.172	0.1787	0.8905	0.0034	0.0009	0.1366	0.1615
Vt(p)	1.4761	1.7384	0.449	0.7863	0.8352	0.0059	0.0016	0.4052	0.1568
Ve	1.7434	1.9334	0.5693	1.0684	1.2621	0.0106	0.0022	0.489	0.2102
V_T	4.3102	4.5171	1.2387	2.1422	3.1703	0.0208	0.0051	1.0715	0.5707
Rr	0.0622	0.0395	0.0391	0.0508	0.0576	0.041	0.0653	0.0381	0.074
Rp	0.2035	0.1537	0.1445	0.0879	0.298	0.1707	0.1987	0.1325	0.3055
Rmt	0.4585	0.4734	0.4409	0.424	0.3982	0.3589	0.4238	0.4531	0.4273
GAr	0.0663	0.0343	0.0177	0.0345	0.0507	0.0025	0.0024	0.0158	0.0313
GAp	0.3802	0.2586	0.1234	0.0765	0.5793	0.0205	0.0126	0.1009	0.2529
GAt	1.1475	1.2859	0.6086	0.7744	0.7498	0.057	0.035	0.5942	0.3486
GGr	0.3398	0.1582	0.2928	0.3181	0.5015	0.2718	0.2722	0.308	0.5396
GGp	1.9478	1.1911	2.0404	0.7051	5.736	2.2566	1.3955	1.9631	4.3604
GGmt	5.8786	5.923	10.0598	7.1376	7.4233	6.2662	3.8921	11.5594	6.0103

Vr- variation due to region, Vp- variation due to population, Vt(p)– variation due to tree (region and population) , Ve– variation due to environment, , V_T – Total Variance, Rr- repeatability due to region, Rp- repeatability due to population, Rmt- repeatability due to mother tree, GAr- genetic advance due to region, GAp- genetic advance due to population, GAt- genetic advance due to tree region and population, GAt- genetic advance due to tree, GGr- genetic gain due to region, GGp- genetic gain due to population, GGmt- genetic gain due to mother tree.



a)



b)

Plate 3 : a) Fruit variation and b) leaf variation of *Phyllanthus emblica*

4.3 Nursery performance of open pollinated families

4.3.1 Variation among populations for germination percent and hundred seed weight in *Phyllanthus emblica*

Seed germination *i.e*. emergence of radicle through seed coat is an important factor in the distribution as well as survival of species. Table 10 revealed that Rangas population in Hamirpur region recorded highest seed germination percentage (56%) followed by Khaggal population (50.67%) in Hamirpur region. However, the lowest germination percentage (36.66%) was noted in Jachh population in Kangra region. Lalitha *et al*. (2020) also observed maximum germination percentage (53.97 %) in control conditions and Baby *et al*. (2022) noted maximum (53.42 %) germination percentage in poly house condition in *P. emblica*. Dhankhar and Singh (1996) reported germination percentage of 50.76 -75.98 % after 35 days of sowing in *P. emblica*. Kumari (2004) also supported present evidences where seed germination was reported (39.55-42.65%) in *P. emblica*. These results are also supported by Waiboonya *et al*. (2019), Rajamanickam and Balakrishnan (2004) and Mawalagedera *et al.* (2014) in *P. emblica*. Hundred seed weight was found maximum in Rangas population (3.678 g) while minimum in Jachh population (1.858 g). Bansal *et al*. (2021) also found seed weight ranged from 1.4 g to 2.2 g in *P.emblica.*

Table 10. Variation among populations for germination percentage and hundred seed weight in *Phyllanthus emblica*

Regions	Populations	Germination percentage (%)	100 seed weight (g)
Bilaspur	Beri	45.67	2.908
	Kasol	46.67	3.058
	Panjgain	41.33	3.07
Hamirpur	Khaggal	50.67	3.182
	Pahlu	41.33	2.18
	Rangas	56.00	3.678
Kangra	Ganoh	44.67	3.156
	Jachh	36.66	1.858
	Kathal	40.67	2.632
Mandi	Barot	40.33	2.968
	Jarol	41.67	3.02
	Slapper	38.67	2.862
	$C.D_{0.05}$	**4.96**	**0.481**

4.3.2 Variation among regions for seedling height, shoot length, collar diameter, number of leaves, leaf area and internodal length in *Phyllanthus emblica*

Table 11 revealed that Hamirpur region showed maximum seedling height (14.39 cm), shoot length (11.95 cm), collar diameter (2.22 mm), leaf number (10.28), leaf area (20.62 cm^2) and internodal length (1.76 cm). Kangra region exhibit minimum seedling height (10.96 cm), leaf area (14.42 cm^2) and internodal length (1.23 cm). While Mandi region, exhibited minimum shoot length (8.75 cm), collar diameter (1.68 mm) and leaf number (8.12).

Table 11. Variation among regions for seedling height, shoot length, collar diameter, number of leaves, leaf area and internodal length in *Phyllanthus emblica*

Regions	Seedling height (cm)	Shoot length (cm)	Collar diameter (mm)	Leaf number	Leaf area (cm^2)	Internodal length (cm)
Bilaspur	11.37	9.13	1.77	8.77	15.95	1.24
Hamirpur	14.39	11.95	2.22	10.28	20.62	1.76
Kangra	10.96	8.91	1.92	8.77	14.42	1.23
Mandi	10.97	8.75	1.68	8.12	14.50	1.35
C $D_{o,o5}$	**0.34**	**0.32**	**0.06**	**0.22**	**0.52**	**0.05**

4.3.3 Variation among populations for seedling height, shoot length, collar diameter, number of leaves, leaf area and internodal length in *Phyllanthus emblica*

Table 12 concluded that seedling height (15.48 cm) was found maximum for Rangas and minimum for Jachh and Jarol population *i.e.* 10.69 cm. Maximum shoot height (12.78 cm) was found in Rangas and minimum was found for Jarol (8.51 cm). Collar diameter (2.37 mm) and leaf number (10.41) was found maximum in Khaggal population & minimum collar diameter (1.63 mm) and leaf number (7.92) for Baroti population. Leaf area was found maximum in Rangas (22.84 cm^2) and minimum in Jachh population (13.76 cm^2). Internodal length was found maximum in Khaggal population (1.90 cm) and minimum for Jachh (1.16 cm). Baby *et al*. (2022) reported the seedling height (35.20 cm) in *P. emblica*. The investigation was also supported by Lilabati and Sahoo (2016) where germination percentage (32.86% - 84%), shoot length (8.50-19.22 cm), number of leaves (10.00-16.33) and collar diameter varied considerably in *E. officinalis*. Verma *et al*. (2019) reported seedling height (13.19-33.43 cm) and collar diameter (1.63-1.73 mm) in *P. emblica*.

a) Trial establishment

b) Seedling of aonla

Plate 4 : Germination stages of *Phyllanthus emblica*

Table 12. Variation among populations for seedling height, shoot length, collar diameter, number of leaves, leaf area and internodal length in *Phyllanthus emblica*

Regions	Population	Seedling height (cm)	Shoot length (cm)	Collar diameter (mm)	Leaf number	Leaf area (cm^2)	Internodal length (cm)
Bilaspur	**Beri**	11.44	9.22	1.83	8.71	16.74	1.29
	Kasol	11.36	9.02	1.81	8.91	16.02	1.22
	Panjgain	11.32	9.14	1.67	8.70	15.07	1.20
Hamirpur	**Khaggal**	14.52	12.17	2.37	10.41	21.96	1.90
	Pahlu	13.18	10.91	2.04	10.07	17.06	1.52
	Rangas	15.48	12.78	2.26	10.35	22.84	1.87
Kangra	**Ganoh**	10.92	8.77	1.95	8.75	14.81	1.22
	Jachh	10.69	8.88	1.90	8.72	13.76	1.16
	Kathal	11.26	9.09	1.90	8.84	14.69	1.29
Mandi	**Baroti**	10.76	8.63	1.63	7.92	14.03	1.28
	Jarol	10.69	8.51	1.68	8.01	14.13	1.29
	Slapper	11.47	9.12	1.72	8.43	15.34	1.47
	$CD_{0.05}$	**0.59**	**0.55**	**0.10**	**0.39**	**0.90**	**0.08**

4.3.4 Variance component, heritability, genetic advance and genetic gain for seedling characteristics

Variation due to region was found maximum in leaf area (4.091 cm^2) and minimum in collar diameter (0.029 mm). Variation due to population was found maximum in seedling height (0.178 cm) and minimum in internodal length (0.009 cm). In leaf area variation due to tree *i.e.* regions and populations (1.992 cm^2), variation due to environment (12.987 cm^2) and total variance (20.791 cm^2) was found maximum. The heritability due to region was found maximum for internodal length (0.206 cm) and minimum in leaf number (0.131). The heritability due to population was found maximum in leaf area (0.103 cm^2) and minimum in leaf number (0.010 mm). The heritability due to tree was found maximum in collar diameter (0.118 mm) and minimum in shoot length (0.097 cm). Genetic advance due to region was found maximum for leaf area (0.820 cm^2) and minimum for collar diameter (0.053 mm). Total genetic advance was found maximum for leaf area (0.387 cm^2) and minimum for internodal length (0.028 cm). Genetic gain due to region was found maximum for internodal length (5.437 cm) and minimum for leaf number (0.1990). Genetic gain due to population was found maximum for leaf area (1.700 cm^2) and minimum for leaf number (0.036). Genetic gain due to mother tree was found maximum for leaf number (2.906) and minimum for seedling height (1.373 cm). These studies are in conformation with the findings of Cornelius

(1994) who concluded that in forest tree species, low to moderate heritability are largely due to environment, epistatic and dominant non-additive genes.

Table 13. Variance component, heritability, genetic advance and genetic gain for seedling characteristics

Random Effect	Seedling height (cm)	Shoot length (cm)	Collar diameter (mm)	Leaf number	Leaf Area (cm^2)	Internodal length (cm)
Vr	1.453	1.242	0.029	0.440	4.091	0.032
Vp	0.178	0.102	0.004	0.028	1.720	0.009
Vt(p)	0.622	0.513	0.020	0.512	1.992	0.013
Ve	5.558	4.782	0.146	2.380	12.987	0.100
VT	7.811	6.639	0.199	3.359	20.791	0.155
hr	0.186	0.187	0.149	0.131	0.197	0.206
hp	0.028	0.019	0.022	0.010	0.103	0.075
hmt	0.101	0.097	0.118	0.177	0.133	0.117
GAr	0.462	0.430	0.053	0.179	0.820	0.076
GAp	0.024	0.012	0.003	0.003	0.278	0.015
GAt	0.164	0.143	0.034	0.261	0.387	0.028
GGr	3.876	4.433	2.764	1.990	5.009	5.437
GGp	0.205	0.128	0.146	0.036	1.700	1.074
GGmt	1.373	1.475	1.797	2.906	2.362	2.002

Vr- variation due to region, Vp- variation due to population, Vt(p)– variation due to mother tree,Ve– variation due to environment, , V_T – total Variance, hr- heritability due to region, hp- heritability due to population, hmt- heritability due to mother tree, GAr- genetic advance due to region, GAp- genetic advance due to population, GAt- genetic advance due to tree region and population, GAt- genetic advance due to tree, GGr- genetic gain due to region, GGp- genetic gain due to population, GGmt- genetic gain due to mother tree

4.4 Multivariate Analysis

4.4.1 Correlation

For studying the inter-dependence between two traits, correlation is an important statistical tool. It provides a proportional relationship between traits that form a basis for selection. In tree improvement and breeding programme, correlated characters have major significance as it provides opportunity to improve more than one character simultaneously.

4.4.1.1 Correlation between fruit length, fruit breadth, fruit weight, stone weight, fruit length/breadth ratio, pulp weight and pulp thickness.

Table 14 revealed that fruit length was highly correlated with fruit weight (0.81), stone length (0.78), pulp weight (0.78), fruit breadth (0.72), stone breadth (0.62), stone weight (0.62). Fruit breadth was significantly correlated with fruit weight (0.93), stone length (0.92), pulp weight (0.78), stone breadth (0.68), stone weight (0.6), pulp thickness (0.26) and negatively correlated with fruit length/breadth ratio (-0.24).

Table 14. Correlation between fruit, stone and pulp characteristics

	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Stone length (mm)	Stone breadth (mm)	Stone weight (g)	Fruit length/breadth ratio	Pulp weight (g)	Pulp thickness (mm)
Fruit length (mm)	1								
Fruit breadth (mm)	0.72**	1							
Fruit weight (g)	0.81**	0.93**	1						
Stone length (mm)	0.78**	0.92**	0.9**	1					
Stone breadth (mm)	0.62*	0.68*	0.69*	0.71**	1				
Stone weight (g)	0.62*	0.6*	0.58*	0.68*	0.87**	1			
Fruit length/breadth ratio	0.5*	-0.24	-0.02	-0.04	0.02	0.12	1		
Pulp weight (g)	0.78**	0.92**	0.99**	0.87**	0.62*	0.49	-0.04	1	
Pulp thickness (mm)	0.26	0.56*	0.45	0.41	-0.23	-0.19	-0.34	0.51	1

(*)- Significant correlation at 0.05 level of significance

Fruit weight was highly correlated with pulp weight (0.99), stone length (0.9), stone weight (0.58), pulp thickness (0.45) and negatively correlated with fruit length/breadth ratio (-0.02). Stone length correlation was found highly significant with pulp weight (0.87), stone breadth (0.71), stone weight (0.68) and negatively correlation with fruit length/breadth ratio (-0.02). Pulp weight showed significant corelation with pulp thickness (0.51). Stone breadth showed significant correlation with stone weight (0.87), pulp weight (0.62), and negatively correlated with pulp thickness (-0.23). Stone weight showed positive correlation with pulp weight (0.49) and negatively correlated with pulp thickness (-0.19). Desirable trait *i.e.* fruit length, breadth and weight showed positive correlation with each other and with pulp weight and pulp thickness. Jayakeerthi (2016) showed correlation among fruit and stone parameters of *P. emblica*. Similar results are obtained by Prabhuraj (2002) in jamun where fruit weight had highly significant positive correlation with fruit traits, seed traits and quality parameters.

4.4.1.2 Correlation between seedling height, shoot length, collar diameter, leaf number leaf area and internodal length

Table 15 showed that seedling height was significantly correlated with shoot length (0.98), leaf area (0.92), internodal length (0.90), collar diameter (0.76) and leaf number (0.75). While shoot length was found highly correlated with leaf area (0.91), internodal length (0.88), collar diameter (0.76) and leaf number (0.74). Leaf number showed positive correlation with leaf area (0.66) and internodal length (0.61). Internodal length also displayed highly significant relation with leaf area (0.87). Similar findings were observed by Shweta (2020) in *B. vahlii* where collar diameter was found correlated with seedling height. Sukirti (2022) also observed that collar diameter showed significant positive correlation with seedling height (0.83) and leaf area (0.82) whereas number of leaves showed positive correlation with leaf area *i.e.* 0.50.

Table 15. Correlation between seedling characters

	Seedling height (cm)	Shoot length (cm)	Collar diameter (mm)	Leaf number	Leaf area (cm^2)	Internodal length (cm)
Seedling height(cm)	1.00					
Shoot length (cm)	0.98**	1.00				
Collar diameter (mm)	0.76**	0.76**	1.00			
Leaf number	0.75**	0.74**	0.64**	1.00		
Leaf area (cm^2)	0.92**	0.91**	0.76**	0.66**	1.00	
Internodal length(cm)	0.90**	0.88**	0.70**	0.61**	0.87**	1.00

(*) - Significant correlation at 0.05 level of significance

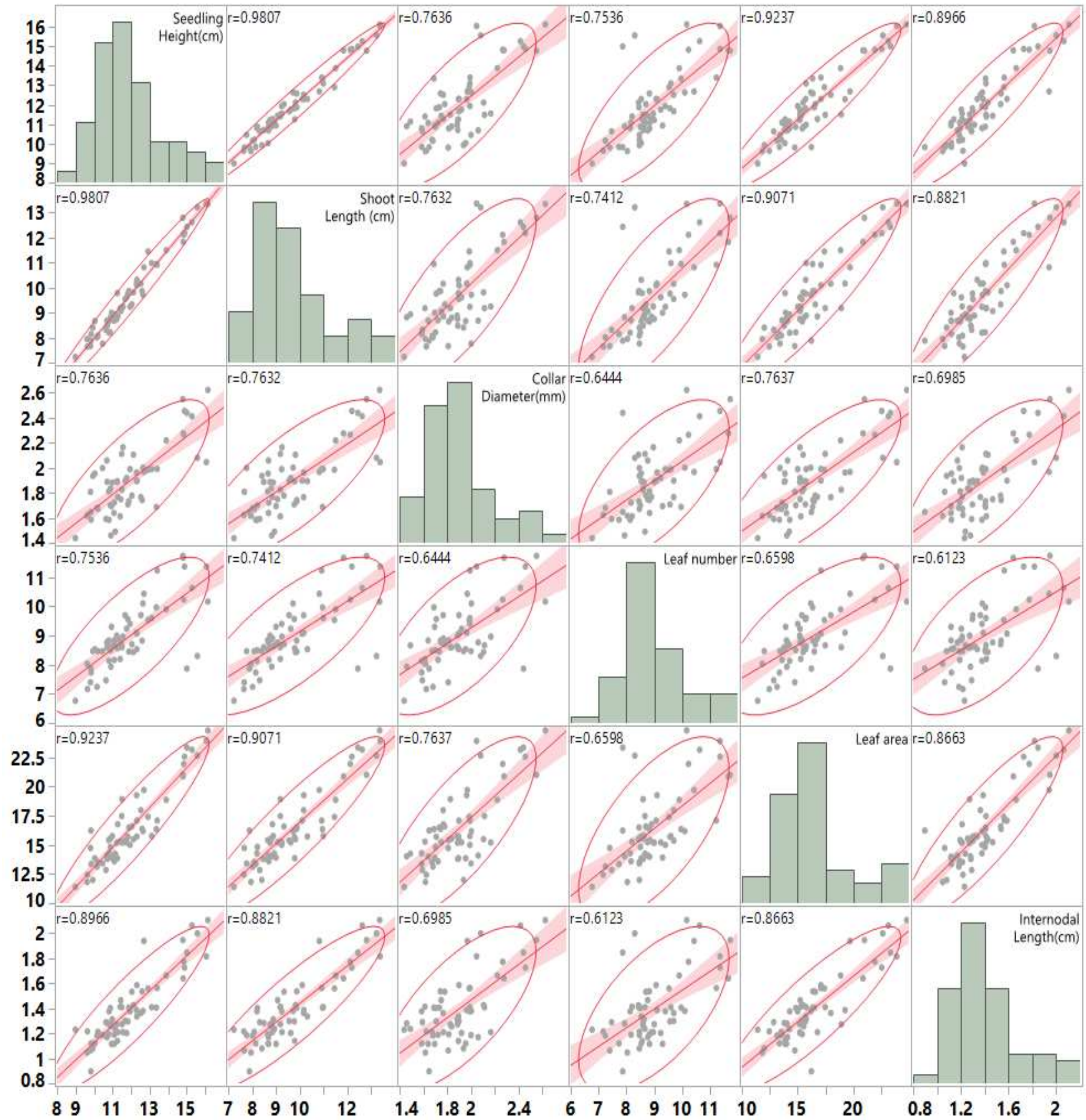


Figure 1: Graph showing correlation coefficient between seedling traits

4.4.2 Principal component Analysis

The principal component analysis is carried out to reduce the larger set of variables into a smaller set of variables that still explains the maximum amount of information present in original data set. It is a data reduction technique that is carried out to reduce the larger set of variables into a smaller set of variables. It is a complex interaction for studying all the selected characters at the same time. It helps in identification of data pattern by reducing the dimensions of number as well as to classify the relationship among the traits in complete multi-trait system. It enables breeder to identify highest variable trait in genetic diversity. The key data is extracted from the table, represented as a collection of new orthogonal variables known as principal components, and the similarity between the observations and variables is illustrated as points on a map. The importance and contribution of each component to the overall variance are determined by their eigen value. Hence it is known as dimension reduction technique. For plotting, regression, clustering and other purposes, principal components can be used in place of original variables.

Table 16 concluded that the first component explained 62.82 % of total variation. The highest value (0.966) was exhibited by fruit weight followed by pulp weight (0.936), stone length (0.933), fruit breadth (0.915), fruit length (0.899), stone breadth (0.751) and minimum by fruit length/breadth ratio. The second component displayed 20.28% of variation where the highest value was displayed by pulp thickness (0.944). The principal component 3 showed 12.28% of variation and maximum contributing trait was fruit length/breadth ratio (0.779). Similar findings were reported by Sukirti (2022) where five principal component analysis explained 91.53% of variation in traits in *T. bellerica* and Chauhan (2021) where eight fruit and seed traits were characterized into 3 principal components on the basis of PCA and first component explained 44.56% variation and second component explained 33.06 % of total variation in *Elaeagnus umbellata.* Tewari *et al.* (2019) noted that the variation for first two principal components *i.e.* PC1 and PC2 were 52.40% and 25.20%, respectively and collectively they capture 77.60% of total variance in *P. emblica*. While the third principal component (PC3) captured lesser variability (16.10%) followed by others PCs.

Table 16. Principal component analysis between fruit, stone and pulp characterstics

Trait	PC 1	PC 2	PC 3
Fruit length (mm)	0.899	-0.138	0.407
Fruit breadth (mm)	0.915	0.347	-0.188
Fruit weight (g)	0.966	0.204	0.027
Stone length (mm)	0.933	0.081	0.009
Stone breadth (mm)	0.751	-0.496	-0.426
Stone weight(g)	0.835	-0.497	-0.191
Fruit length/breadth ratio	0.194	-0.596	0.779
Pulp weight (g)	0.936	0.296	0.058
Pulp thickness (mm)	0.169	0.944	0.271
Eigen value	**5.65**	**1.83**	**1.11**
Percent variance	**62.82**	**20.28**	**12.28**
Cumulative percent (%)	**62.82**	**83.1**	**95.38**

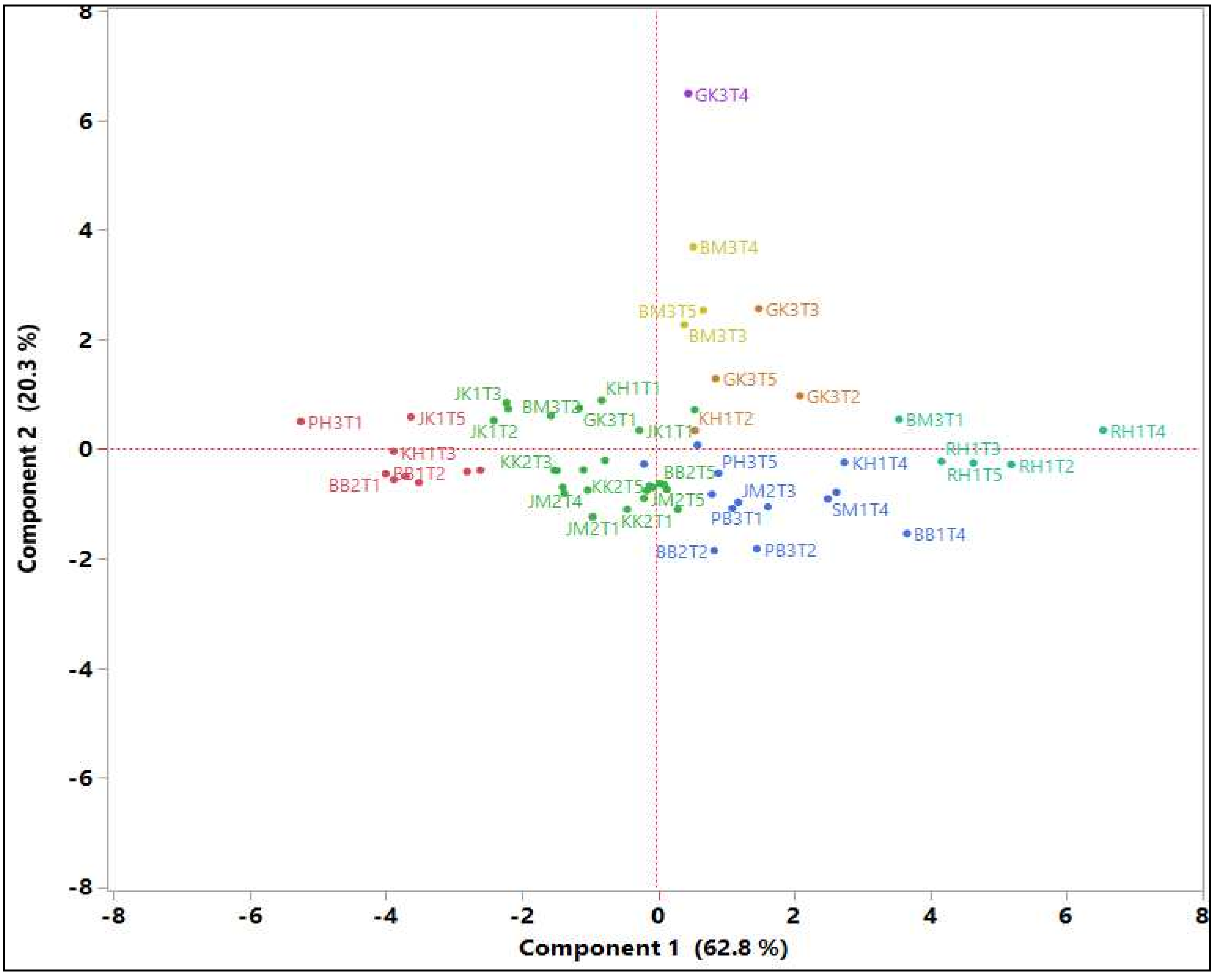


Figure 2: Scatter plot diagram of PC1-PC2 of fruit, stone and pulp characteristics showing distribution of populations

Appraisal of table 17 concluded that the first component in seedling characteristics explained 82.93 % of total variation. The highest value was exhibited by seedling height (0.98) followed by shoot length (0.97), leaf area (0.94), internodal length (0.91), collar diameter (0.85) and leaf number (0.8). The second component accounted for 7.44% of the total variation and the highest value showed by leaf number (0.57). The third component explained 5.59% of total variation and the highest value was shown by collar diameter (0.52). The fourth component accounted for 2.19% of total variation and the highest value was exhibited by internodal length (0.28). The sixth component explained 0.29% of total variation and the highest value was shown by shoot length (0.08). The fifth component explained 1.56% of total variation and the highest value showed by leaf area (0.21). The sixth component displayed 0.29% of variation. The principal component analysis is multi-variate analysis, and number of traits for analysis in present study were comparatively low. Therefore only PC1 exhibited high variation percentage.

Table 17. Principal component analysis of nursery characteristics

Trait	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Seedling height (cm)	0.98	-0.06	-0.11	-0.07	-0.11	-0.1
Shoot length (cm)	0.97	-0.06	-0.1	-0.08	-0.18	0.08
Collar diameter (mm)	0.85	0.09	0.52	0.04	-0.02	0
Leaf number	0.8	0.57	-0.16	0.05	0.06	0.01
Leaf area	0.94	-0.17	-0.01	-0.2	0.21	0.01
Internodal length(cm)	0.91	-0.27	-0.11	0.28	0.06	0.01
Eigen value	**4.98**	**0.45**	**0.34**	**0.13**	**0.09**	**0.02**
Percent variance	**82.93**	**7.44**	**5.59**	**2.19**	**1.56**	**0.29**
Cumulative Percent	**82.93**	**90.37**	**95.96**	**98.15**	**99.71**	**100**

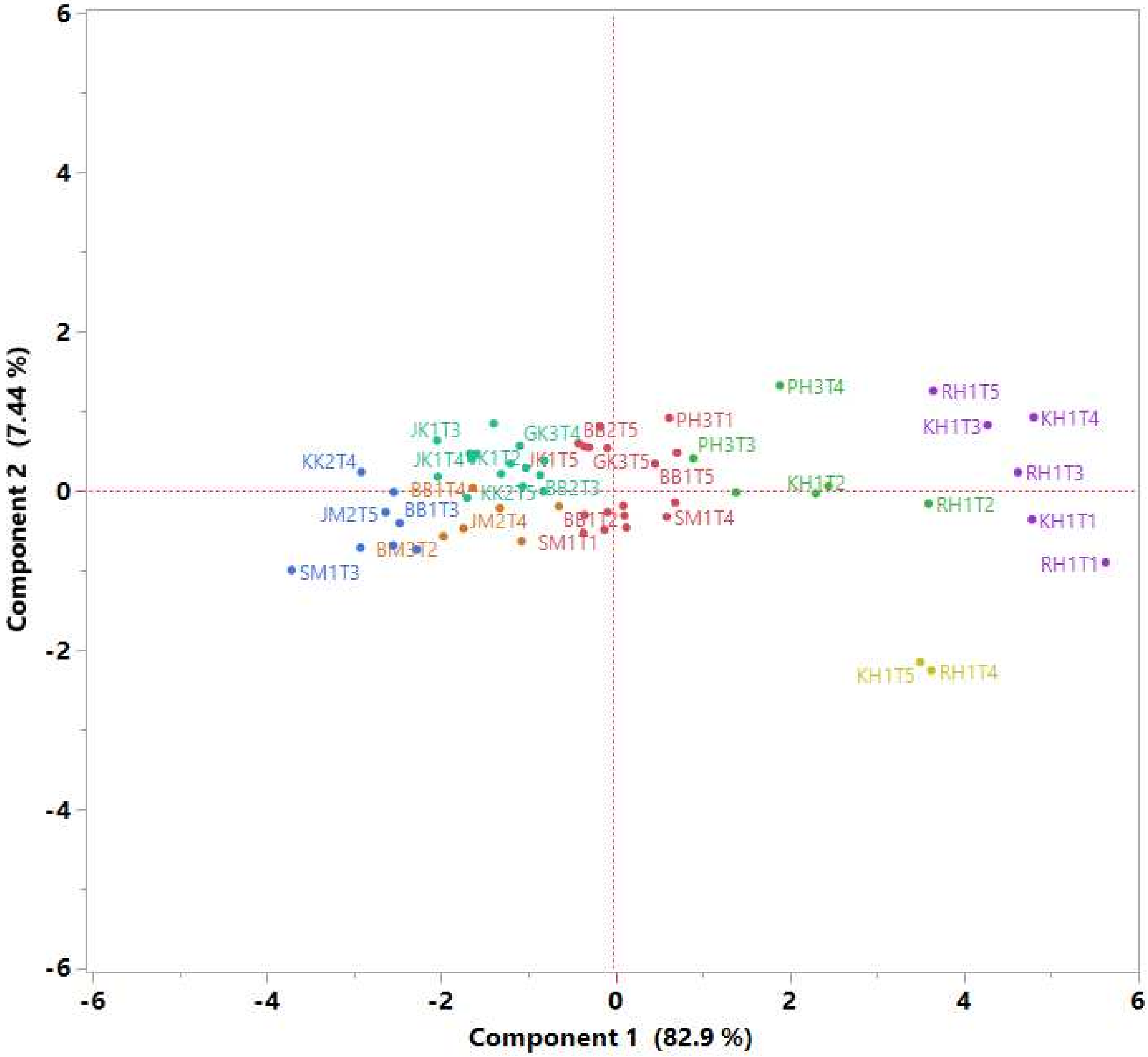


Figure 3: **Scatter plot diagram of PC1-PC2 of nursery characteristics showing distribution of population**

4.4.3 Cluster analysis

Seven clusters were identified by Ward's hierarchical cluster analysis based on Euclidean distance. The mother tree was mostly segmented by origin, similar like PCA analysis. The hierarchical cluster analysis used to generate the clusters is supported by the scatter plot of the two PCs. Some mother trees do not form clusters indicating considerable degree of diversity among populations. Hierarchical cluster produces an output called dendrogram which depicts genetic interaction in groups/cluster.

It is revealed from table 18 that cluster fifth contains maximum values for genotype with desirable traits like fruit length (22.81 mm), fruit breadth (24.97 mm), fruit weight (7.56 g), stone length (12.96 mm) and pulp weight (6.44 g). Sixth cluster reported maximum value for stone breadth (14.96 mm), stone weight (1.33 g) and seventh cluster reported maximum value for fruit length/breadth ratio (1.08). While in seedling traits (Table 19) cluster sixth and seventh showed maximum values for seedling height (15.32 cm), shoot length (12.83 cm), collar diameter (2.39 mm), leaf number (11.16), leaf area (22.72 cm^2) and internodal length (1.92 cm).

Table 18. Mean values of fruit, stone and pulp characters for the cluster separated by cluster analysis

Cluster	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Count	9	25	13	4	5	1	3
Fruit length (mm)	17.07	19.27	19.82	19.45	22.81	19.9	22.06
Fruit breadth (mm)	19.39	21.31	22.98	22.49	24.97	20.75	20.41
Fruit weight (g)	4.74	5.8	6.75	6.25	7.56	5.5	6.34
Stone length(mm)	9.32	10.46	11.61	11.61	12.96	10.16	11.12
Stone breadth(mm)	8.32	9.49	10.66	12.48	11.93	14.96	10.24
Stone weight (g)	0.82	0.86	0.92	1.03	1.12	1.33	0.94
Fruit length/breadth ratio	0.88	0.91	0.86	0.87	0.91	0.96	1.08
Pulp weight (g)	3.92	4.94	5.84	5.22	6.44	4.17	5.4
Pulp thickness (mm)	5.53	5.91	6.16	5	6.52	2.89	5.09

Table 19. Mean values of seedling characters for the cluster separated by cluster analysis

Cluster	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Count	17	6	8	6	15	6	2
Seedling height (cm)	12.1	13.47	9.81	11.09	10.76	15.32	15.28
Shoot length (cm)	9.77	11.3	7.86	8.74	8.68	12.69	12.83
Collar diameter (mm)	1.89	2.07	1.62	1.6	1.84	2.39	2.26
Leaf number	9.12	10.16	7.46	8.37	8.68	11.16	8.08
Leaf area (cm^2)	16.5	18.46	13.25	14.65	14.32	22.72	23
Internodal length (cm)	1.38	1.65	1.13	1.36	1.19	1.88	1.92

The present investigation was successfully supported by Sukirti (2022) where two cluster contained most desirable traits; Chauhan (2021) where four clusters were made and out of these cluster 3 and 4 genotypes comprised of desirable traits in *Elaeagnus umbellata*. Also, Rawale (2020) observed that, cluster II and IV contained desirable traits like seed width and seed weight in *Myrica esculenta.* Gupta *et al*. (2020) observed eight cluster in *Acacia nilotica* CPTs while Singhdoha *et al*. (2017) observed 7 cluster in 60 trees where cluster 1 was the largest having 14 CPTs in *Acacia nilotica*. Mohapatra *et al.* (2001) in *Acacia catechu* reported fifteen cluster.

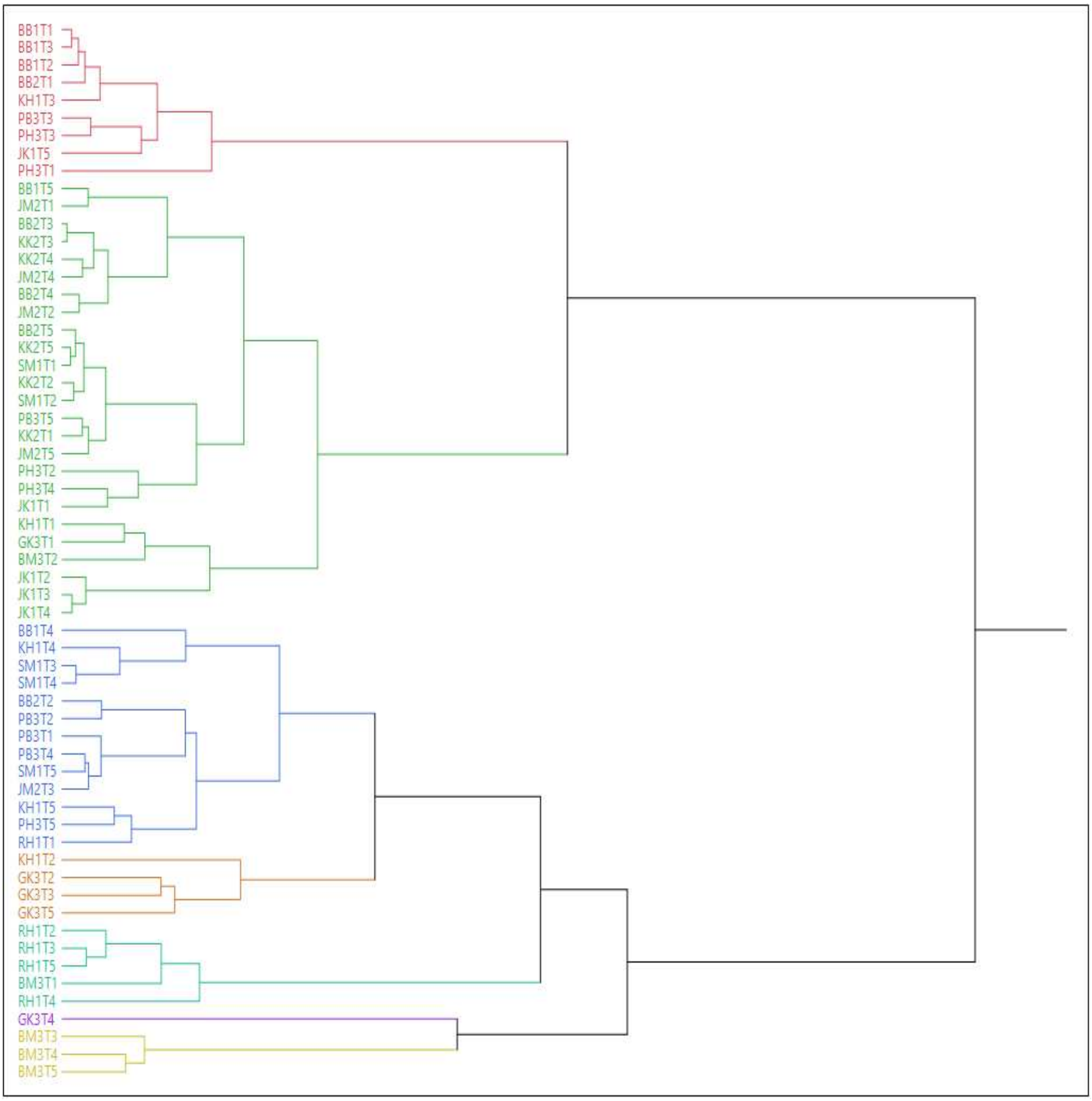


Figure 4: Dendrogram showing clusters in fruit, stone and pulp character

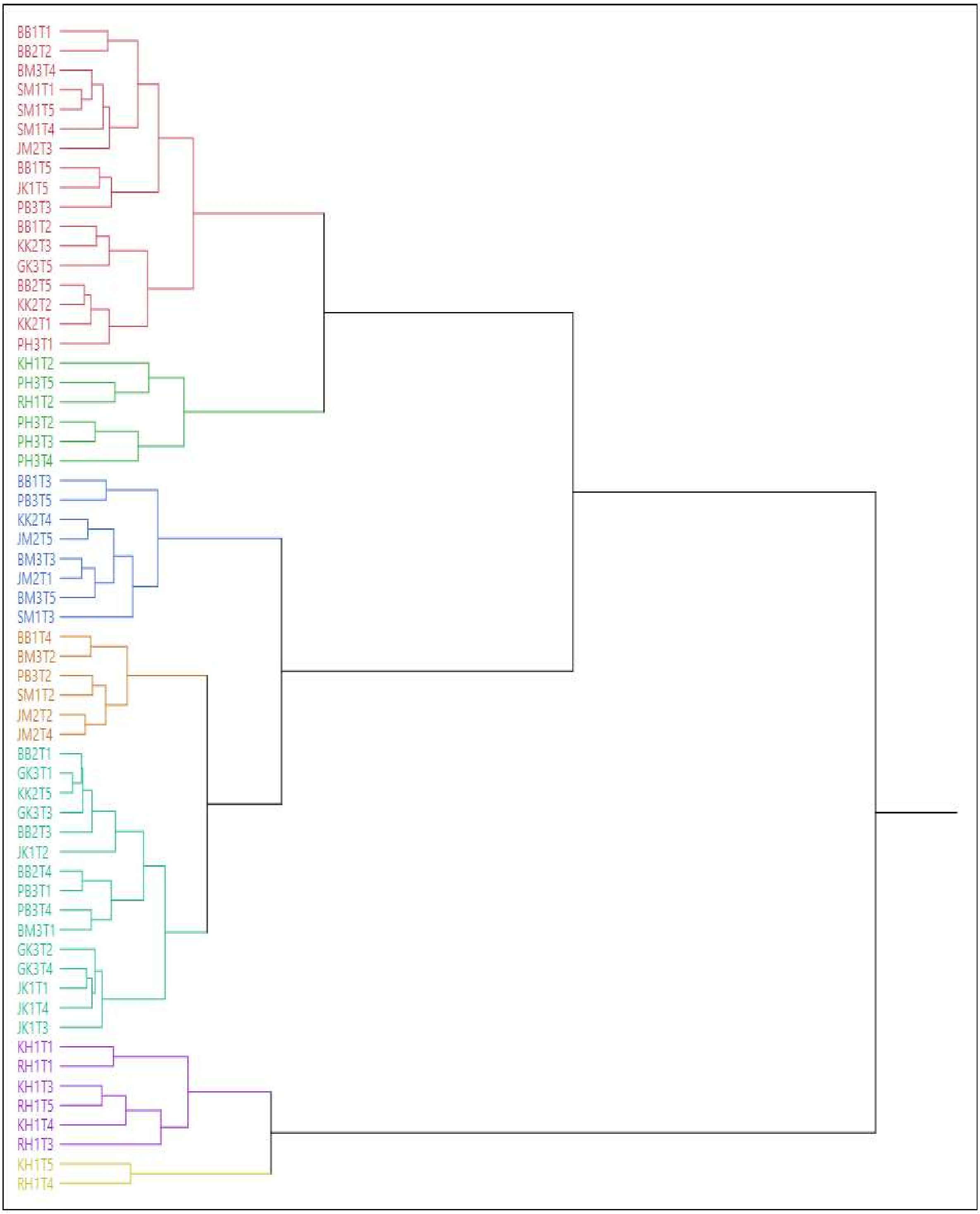


Figure 5: Dendrogram showing clusters in nursery character

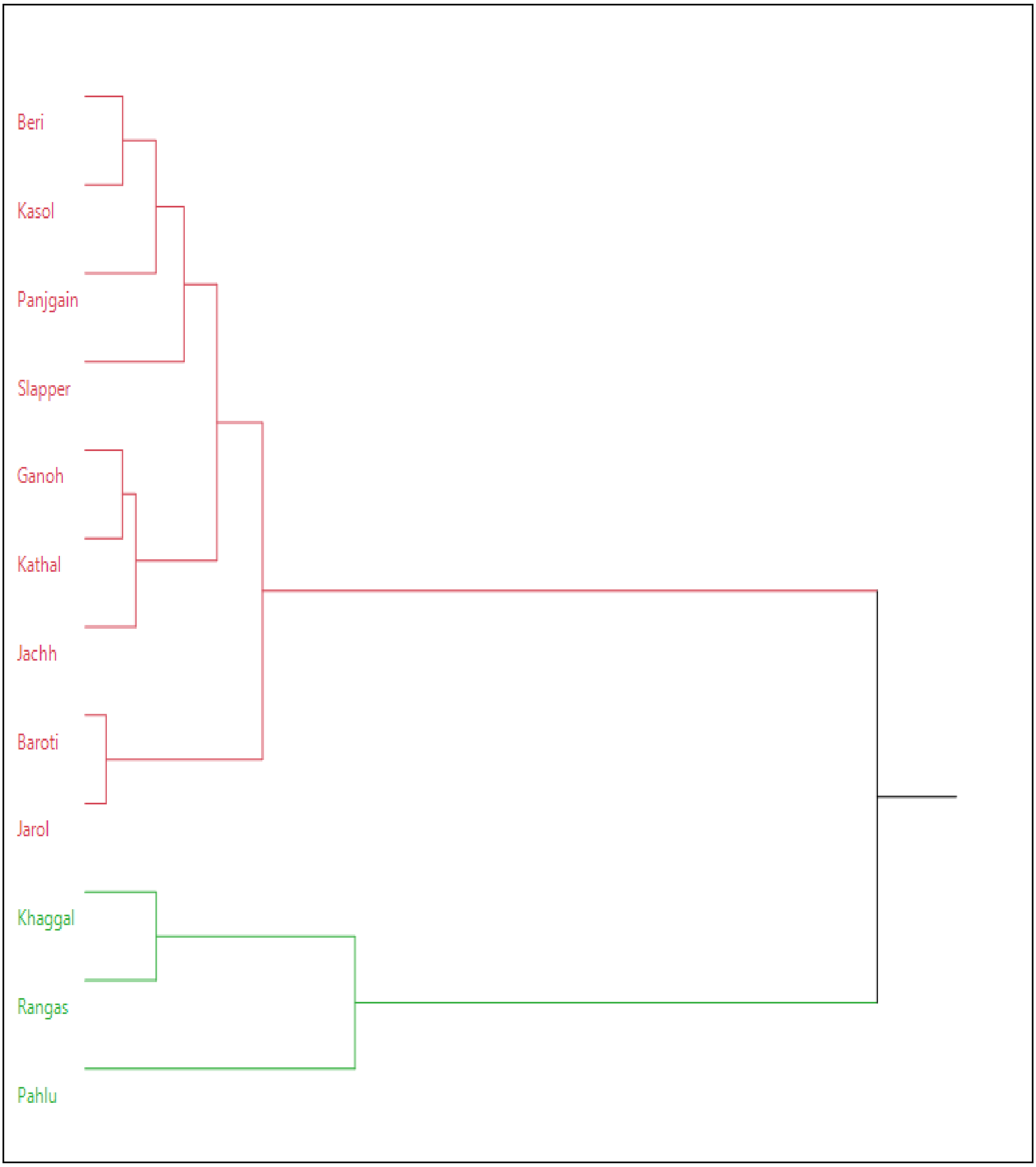


Figure 6: Dendrogram showing clusters among populations

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled **"Seed source variation in *Phyllanthus emblica* Linn. of Himachal Pradesh"** was carried out in the Department of Tree Improvement and Genetic Resources, College of Forestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni Solan, Himachal Pradesh by selecting twelve populations of 4 regions viz., Hamirpur, Kangra, Bilaspur and Mandi during 2021-2023. The key feature of this study included the important aspects of variation covering morphometric and fruit characters, stone traits and nursery stage growth performance.

The phenotypic parameters studied showed significant variation within seed sources. Among regions maximum average tree height (10.77 m) in Kangra region and the maximum tree girth (0.66 m) was recorded in Hamirpur region. Among the populations Kathal population in Kangra region recorded maximum tree height (11.28 m) whereas the maximum tree girth (0.83 m) was recorded in Rangas, Hamirpur region.

Significant variation was found in the fruit, stone and pulp traits among all the twelve natural populations. Among regions maximum fruit length (20.14 mm) was recorded in Mandi region, maximum fruit breadth (22.28 mm) was found in Hamirpur region and the maximum fruit weight was recorded in (6.33 g) in Kangra. The maximum stone length (11.50 mm), stone breadth (10.49 mm) and stone weight (0.95 g) was recorded in Hamirpur region. The maximum pulp thickness (6.01mm) was recorded in Bilaspur region and maximum pulp weight (5.41 g), fruit length/breadth ratio (0.92mm) was found in Mandi region.

Among populations in Rangas population traits like fruit length (22.39 mm), fruit breadth (24.63mm), fruit weight (7.43 g), stone length (12.66 mm), stone weight (1.06 mm), pulp weight (6.37 g) and pulp thickness (6.39 mm) were found maximum. Stone breadth (12.89 mm) was recorded maximum in Ganoh population.

Variation due to region was found maximum in fruit length (0.2681 mm) due to population it was found maximum in stone breadth (0.8905 mm), due to mother tree it was found maximum in fruit breadth (1.7384 mm) and due to environment factors it was found maximum in fruit breadth (1.9334 mm) and total variation was found maximum in fruit breadth (4.5171 mm). The repeatability due to region was found maximum for fruit length/breadth ratio (0.0653), population repeatability coefficient was found maximum for pulp thickness (0.3055 mm) and mother tree repeatability coefficient was found maximum for fruit breadth (0.4734 mm). Genetic advance due to region was found maximum for fruit length (0.36 mm), due to population it was found maximum for fruit breadth (0.3802 mm) and due to mother tree, it was found maximum for fruit breadth (1.2859 mm). Genetic gain due to region was found maximum for pulp thickness (0.5396 mm), due to population it was found maximum for pulp thickness (4.3604 mm) and due to mother tree, it was found maximum for pulp weight (11.5594 g).

In Rangas population of Hamirpur region the highest seed germination percentage (56%) and hundred seed weight (3.678 g) was recorded.

Among regions Hamirpur region showed maximum seedling height (14.39 cm), shoot length (11.95 cm), collar diameter (2.22 mm), leaf number (10.28), leaf area (20.62 cm^2) and internodal length (1.76 cm). Among populations seedling height (15.48 cm), shoot height (12.78 cm) and leaf area (22.84 cm^2) was found maximum for Rangas population. Collar diameter (2.37 mm), leaf number (10.41) and internodal length (1.90 cm) was found maximum in Khaggal population.

Variation due to region was found maximum in leaf area (4.091 cm^2), due to population it was found maximum in seedling height (0.178 cm). Leaf area contributed to maximum variation in mother tree (1.992 cm^2), in environment (12.987 cm^2) and in total variance (20.791 cm^2) among other traits. The heritability due to region was found maximum for internodal length (0.206 cm), due to population it was found maximum for leaf area (0.103 cm^2) and due to tree it was found maximum for collar diameter (0.118 mm). Genetic advance due to region and total genetic advance was maximum for leaf area *i.e.* 0.820 $cm^2$and 0.387 cm^2 respectively. Genetic gain due to region was found maximum for internodal length (5.437 cm), due to population it was found maximum for leaf area (1.700 cm^2) and due to mother tree it was found maximum for leaf number (2.906).

Desirable traits *i.e.* fruit length, breadth and weight showed positive correlation with each other and with pulp weight and pulp thickness. Among seedling characters, seedling height was found highly correlated with shoot length (0.98), leaf area (0.92), internodal length (0.90), collar diameter (0.76) and leaf number (0.75). While shoot length was found highly correlated with leaf area (0.91), internodal length (0.88), collar diameter (0.76) and leaf number (0.74). Leaf number showed positive correlation coefficient with leaf area (0.66) and internodal length (0.61). Internodal length also displayed highly significant relation with leaf area (0.87).

In fruit, stone and pulp traits, 95.38 % of variation was explained by three principal components. The first component explained 62.82 % of total variation. While the second and third component explained 20.28 % and 12.28 % of total variation, respectively. In seedling traits, first component explained 82.93 % of total variation. The second component accounted for 7.44% of the total variation, the third component explained 5.59 % of total variation, the fourth component accounted for 2.19 % of total variation, fifth component accounted for 1.29% and the sixth component explained 0.29 % of total variation.

In cluster analysis seven cluster were formed for fruit, stone, pulp and seedling characteristics. Cluster fifth contained maximum values for genotype with desirable traits like fruit length (22.81 mm), fruit breadth (24.97 mm), fruit weight (7.56 g), stone length (12.96 mm) and pulp weight (6.44 g). Sixth cluster reported maximum value for stone breadth (14.96 mm), stone weight (1.33 g) and seventh cluster reported maximum value for fruit length/breadth ratio (1.08). While in seedling traits cluster sixth and seventh showed maximum values.

CONCLUSIONS

- Kathal population recorded maximum tree height and Rangas population had maximum tree girth.
- The maximum fruit length, fruit breadth, fruit weight, stone length, stone breadth, pulp weight, pulp thickness, seedling height, shoot length, and leaf area was recorded in Rangas population. While collar diameter and leaf number were recorded maximum in Khaggal population.
- Germination percent, a desirable trait in tree breeding, was recorded maximum for Rangas population in Hamirpur region.
- Principal component 1 showed highest fruit, stone and pulp characteristics accounting for 62.82 % of variation followed by PC2 and PC 3.
- 100 % of total variation was explained by six principal components for seedling characters while principal component 1 showed highest seedling trait accounting for 82.93% variation.

- In cluster analysis cluster V, VI and VII contained maximum value for genotypes with the desirable characters. The principal component analysis and cluster analysis suggested a population-based tendency of grouping in genotype for scientific study of germplasm.
- Overall Hamirpur and Kangra regions were found best suitable as seed sources of *P. emblica*. The mother trees from populations of Rangas (Hamirpur), Khaggal (Hamirpur) and Kathal (Kangra) are suggested for further extensive studies in order to explore more variability for extending the germplasm collection for further breeding programmae.

LITERATURE CITED

Abdelkheir R M, Ibrahim A M and Khalill A A. 2003. Provenance variation in seed and germination characteristics of *Acacia karroo*. *Sudan Silva* **9(2)**:14-26.

Ahmadullah M and Nayar M P. 1999. Red data book of Indian Plants (Peninsular India): Botanical survey of India. *Calcutta, India* 4p.

Allard R W. 1960. Principles of plant breeding. John Wiley and Sons 585p.

Arthanari P, Krishnaveni K and Mariappan N. 2013. Seed Source Variation on Pod and Seed Parameters in *Caesalpinia sappan* Linn. *Tree Genetics and Molecular Breeding* **3**(4): 19-24.

Arzani K, Ardakan H M, Vezvaei A and Roozban M R. 2008. Morphological variation among Persian walnut (*Juglans regia*) genotypes from central Iran. *New Zealand Journal of Crop and Horticultural Science* **36(3)**:159-168.

Aulakh P S, Kumar G, Dhaliwal H S, Singh B and Baidwan R P S. 2006. Comparative performance of aonla *(Emblica officinalis* Gaertn.) cultivars in lower Shivaliks of Punjab. *Journal of Research, Punjab Agricultural University* **43**:312-315.

Azad M S, Biswas R K and Matin M A. 2012. Seed germination of *Albizia procera* (Roxb.) Benth. in Bangladesh: a basis for seed source variation and pre-sowing treatment effect. *Forestry Studies in China* **14**:124-130.

Azad M S, Nahar N and Matin M A. 2013. Effects of variation in seed sources and pre-sowing treatments on seed germination of *Tamarindus indica*: a multi-purpose tree species in Bangladesh. *Forest Science and Practice* **15**:121-129.

Baby G, Reddy P V K, Harshavardhan A and Salomi D R. 2022. Effect of seed priming and different growing conditions on germination and seedling vigour of Aonla (*Emblica officinalis* Gaertn.). *The Pharma Innovation Journal* **11(8)**: 1294-1297.

Bakshi P, Wali V K, Jasrotia A, Sharma A and Iqbal M. 2015. Evaluation of different aonla (*Emblica officinalis)* cultivars under rainfed conditions of lower Shivalik foothills of Himalayas. *Indian Journal of Agriculture Sciences* **85(8)**:1012-1016.

Bansal P, Butola J S and Negi A. 2022. Comparative Study of Morpho-Physical Quality Char ateristics in Wild and Planted Amla (*Phyllanthus emblica* Linn.) Fruits and Seeds. *Frontiers in Crop Improvement* **9**(VI):2704-2709.

Bhalchandra R G, Kumari A, Jha S, Thakur S and Saini P. 2022. Morphological variations in populations of *Myrica esculenta* (Kaphal) in Himachal Pradesh. *The Pharma Innovation Journal* **11(6):**1616-1619.

Burton G W and De Vane E W. 1953. Estimating heritability in Tall Fescue (*Festuca arundineae*) from replicated clonal material. *Agronomy Journal* **45(10)**:478-481.

Chandravanshi J, Pratibha, Dhakad B, Singh R, Kumar N and Sharma D P.2022. Physico-chemical study of aonla genotypes (*Emblica officinalis* Gaertn). *The Pharma Innovation Journal* **11**: 870-877

Chauhan R S, Thakur N S, Gunaga R P, Bhuva D C and Jadeja D B. 2019. Assessment of germination attributes in candidate plus trees (CPTs) of Malabar Neem (*Melia dubia* cav.). *Indian Journal of Ecology* **46(**2):335-339.

Chauhan S. 2021. Variation studies in Autumn olive (*Elaeagnus umbellata* Thunb.) in Himachal Pradesh. M.Sc. Thesis Deptt. of Tree Improvement and Genetic Resources. Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan. 87p.

Cornelius J. 1994. Heritabilities and additive genetic coefficients of variation in forest trees. *Canadian journal of forest research* **24**(2):372-379.

Devi S, Sankhyan H P, Thakur S, Sharma S S, Rana N and Chand K. 2018. Variation in seed germination and seedling traits of *Quercus leucotrichophora* A.Camus natural population in Himachal Pradesh. *Journal of Pharmacognosy and Phytochemistry* **7**(2): 749-752.

Dhankhar D S and Singh M. 1996. Seed germination and seedling growth in aonla (*Phyllanthus emblica* Linn.) as influenced by gibberellic acid and thiourea. *Crop Research-Hisar* **12**:363-366.

Falconer D S and Mackay T F. 1996. Introduction to quantitative genetics. Longman, Scientific and Technical England. 433p.

Fredrick C, Muthuri C, Ngamau K and Sinclair F. 2015. Provenance variation in seed morphological characteristics, germination and early seedling growth of *Faidherbia albida*. *Journal of Horticulture and Forestry* **7**(5):127-140.

Goulart M F, Lemos F J P and Lovato M B. 2007. Variability in fruit and seed morphology among and within populations of *Plathymenia* (Leguminosae-Mimosoideae) in areas of the Cerrado, the Atlantic Forest, and transitional sites. *Plant Biology* **8**(1):112-119.

Gowda D V, Muguli G, Rangesh P R and Deshpande R D. 2002. Phytochemical and pharmacological actions of Triphala: Ayurvedic formulation–A review. *International Journal of Pharmaceutical Sciences Review and Research* **15**(2):61-65.

Gupta S, Sahoo G and Wani A M. 2020. Estimation of genetic parameter in progenies in *Acacia nilotica* (L.). *International general of Current Microbiology and Applied Sciences* **11**:337-342

Gupta T, Prakash T and Gupta R K. 2012. Genetic variability and correlation study in *Acacia catechu* seed source in Himachal Pradesh. *Range Management and Agroforestry* **33**(1):47-52.

Hamrick J L, Linhart Y B and Mitton J B. 1979. Relationships between life history characteristics and electrophoretically detectable genetic variation in plants. *Annual review of ecology and systematics* **10**(1):173-200.

Hazarika T K. 2019. Physico-chemical characterization of wild and semi wild Indian gooseberry from Mizoram, North-East India. *Indian Journal of Horticulture* **76**(4):612-618.

Hembrom I, Kumar R, Singh M K and Vijayaprakash N B. 2011. Provenance variations in seed characteristics and germination behaviour of *Terminalia arjuna* and *Terminalia tomentosa*. *Indian Forester* **137**(2):216-220.

Javaid M, Gupta L M, Gupta M, Sood K K, Choudhary P and Gupta S K. 2022. Variability in fruit and seed characteristics of candidate plus trees of *Toona ciliata* in Jammu subtropics. *The Pharma Innovation Journal* **11**(11): 553-556.

Jayakeerthi K R. 2016. Studies on Floral Biology, Fruit set, Development and Yield of Amla (*Emblica Officinalis* Geartn). Doctoral dissertation, University of Agricultural Sciences, GKVK Bangalore 112p.

Johnson H W, Robinson H F and Comstock R. 1955. Estimates of genetic and environment variability in Soybean. *Argon* **47**(7):314-318.

Karthik S N, Raj E E, Sakthivel M, Babu G V, Sadhuvan M, Kumar M K, Kathiravan K and Palani P. *2019.* Germinating potential of *Phyllanthus amarus* seeds: evaluation of biochemical parameters. *SN Applied Sciences* **1**:1582. https://doi.org/10.1007/s42452-019-1620-z.

Kaur A and Dhaliwal H S. 2013. Studies on the performance of aonla (*Emblica officinalis* Gaerten) varieties under sub-tropical condition of Punjab. *Haryana Journal of Horticulture Sciences* **42**(1&2): 6-8.

Kaushik N, Kaushik J C and Nautiyal S. 2012. Genetic variability and correlation studies for seed morphology, seedling growth and biochemical traits in neem (*Azadirachta indica* A. Juss). *Indian Forester* **138**(1):10-16.

Kumar M, Arya R K, Kumar M, Gaur R K and Sharma S. 2021. Evaluation of aonla varieties under semi-arid conditions of Haryana. Ekin *Journal of Crop Breeding and Genetics* **7**(2): 139-144.

Kumar R, Khadda B S, Jadav J K, Rai A K, Khajuria S and Lata K. 2016. Evaluation of aonla (*Emblica officinalis*) varieties under hot semi-arid conditions of western India. *Current Horticulture* **4(**2):39-43.

Kumari A, Bhatia S K and Joon M S. 2004. Standardization of in situ patch budding time in aonla (*Emblica officinalis* Gaertn.). *Journal of Horticulture Sciences* **33(**3):234-235.

Lalitha K R, Tank R V, Chawla S L and Jena S. 2020. Effect of chemicals on seed germination and seedling growth of aonla (*Emblica officinalis* Gaertn.). *The Pharma Innovation Journal* **9**(12): 239-243.

Lilabati L and Sahoo U. 2016. Germination and Growth Behaviour of Seedlings of *Emblica officinalis Gaertn* under different light and nutrient regimes in field conditions. *Science & Technology Journal* **4**:98-104.

Loha A, Tigabu M, Teketay D, Lundkvist K and Fries A. 2006. Provenance variation in seed morphometric traits, germination, and seedling growth of *Cordia africana* Lam. *New Forests* **32**: 71-86.

Lush J C. 1940. Intersine correlation and regression of offspring on damasa methods of estimating heritability characters. *American Society of Animal Science* **33**:293-301

Mawalagedera S M U P, Perera G A D, and Sooriyapathirana S D S S. 2014. Prolonged seed dormancy in *Phyllanthus emblica* L. can be overturned by seed scarification and gibberellin pre-treatment. *Open Journal of Forestry* **4**(1):38-41.

Mkwezalamba I, Munthali C R and Missanjo E. 2015. Phenotypic variation in fruit morphology among provenances of *Sclerocarya birrea* (A. Rich.) Hochst. *International Journal of Forestry Research* **2015**:1-8.

Mohapatra K P, Chauhan K C and Dhaal S P. 2001. Genetic divergence in *Acacia catechu* Willd. *Indian journal of genetics* **61**(1):61-64.

Mousavi S R, Razaei, M and Mousavi A. 2011. A general view of seed dormancy and methods of breaking it. *Advances in Environmental Biology* **5**: 3333-3337.

Munthali C R Y, Chirwa P W and Akinnifesi F K. 2012. Phenotypic variation in fruit and seed morphology of *Adansonia digitata* L.(baobab) in five selected wild populations in Malawi. *Agroforestry systems* **85**:279-290.

Ojo M O and Ezekiel Ajayi. 2019. Effect of provenance variation on the growth and development of *Terminalia ivorensis* (A chev). *Current Journal of Applied Science and Technology* **37**:1-7.

Pandey D, Pandey G and Tripathi M. 2014. Variability in aonla (*Emblica officinalis Gaertn*.) accessions collected from Madhya Pradesh. *Progressive Horticulture* **46**(2):280-284.

Panse V G and Sukhatme P V. 1967. Statistical methods for agricultural Workers. ICAR, New Delhi. 610 p.

Parab A, Kotiyal A and Patil V. 2022. Effects of physical treatments and gibberellic acid on germination success of aonla seed. *The Pharma Innovation Journal* **11**: 3110-3114.

Pathak R K. 2003. Status Report on Genetic Resources of Indian Gooseberry-aonla (*Emblica officinalis* Gaertn.) in South and Southeast Asia. IPGRI Office for South Asia National Agriculture Science Centre (NASC) DPS Marg, Pusa Campus, New Delhi, India, 96p.

Patil J B, Shivanna H and Hegde K. 2014. Seed Source Variation on Fruit and Seed Traits of *Zanthoxylum rhetsa*-a medicinal tree under high exploitation in Central Western Ghats, India. *International Journal of Pharmacy & Life Sciences* **5**(12): 4081-4085.

Plathia M, Wali V K, Bakshi P and Sharma N. 2018. Studies on variability of seedling origin jamun (*Syzygium cumini* (L.) Skeels) germplasm growing in subtropical region of Jammu, India. *International Journal of Current Microbiology Applied Sciences* **7(**2): 3363-3368.

Prabhuraj H S. 2002. Correlation and path coefficient analysis in jamun (*Syzigium cuminii*) trees. *My Forest* **38**(2):177-182.

Pria F F and Islam M S. 2019. *Phyllanthus emblica* Linn. (Amla) - a natural gift to humans: an overview. *Journal of Diseases and Medicinal Plants* **5**:1-9.

Raddad E Y and Luukkanen O. 2007. Provenance variation in seed morphological traits and early seedling growth of *Balanites aegyptiaca* Del. *Agricultural Water Management* **8**(1):61-72.

Rai N, Tiwari L, Sharma R K and Verma AK. 2012. Pharmaco-botanical profile on *Emblica offcinalis* Gaertn. —a pharmacopoeial herbal drug. *Scientific Technical Medical Journal* **1**:29–41.

Rajamanickam C and Balakrishnan AK. 2004. Influence of seed treatments on seedling vigour in aonla (*Emblica officinalis* G.) *South Indian Horti*culture **52**(6):324-327.

Rao G R, Korwar G R, Shanker A K and Ramakrishna Y S. 2008. Genetic associations, variability and diversity in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) accessions. *Trees* **22**:697-709.

Rao K D and Subramanyam K. 2009. Growth and yield performance of aonla varieties under scarce rainfall zone. *Agricultural Science Digest* **29**(2):45-47.

Rao V R and Hodgking. 2002. Genetic diversity and conservation and utilization of plant genetic resources. *Kulwer Acadmic Publishers* **68**:1-9.

Rawale G. 2020. Seed source studies in Kaphal (*Myrica esculenta* Buch Ham.ex D. Don) in Himachal Pradesh. M.Sc. Thesis Deptt. of Tree Improvement and Genetic Resources. Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan. 76p.

Sachan, N K, Gangwar S S, Sharma R and Kumar Y. 2013. An investigation into phytochemical profile and nutraceutical value of amla (*Emblica officinalis*) fruits. *Inernational Journal of Modern Pharmaceutical Research* **2(**1):1-12.

Sai R M, Neetu D, Yogesh B, Anju B, Dipti P, Pauline T, Sharma SK, Sarada SK, Ilavazhagan G, Kumar D and Selvamurthy W. 2002. Cyto-protective and immunomodulating properties of amla (*Emblica offcinalis)* on lymphocytes: an in-vitro study. *Journal of Ethnopharmacol* **81:**5–10.

Samadia D K. 2005. Genetic variability studies in Lasora (*Cordia myxa Roxb*.). *Indian Journal of Plant Genetic Resources* **18**(03):236-240.

Sankhyan H P, Thakur S and Kumar S. 2020. Variation in morphological descriptors among different populations of *Grewia optiva* Drummond (Beul) in Himachal Pradesh. *Journal of Pharmacognosy and Phytochemistry* **9**(5):249-254.

Shaanker R U and Ganeshaiah K N. 1997. Mapping genetic diversity of *Phyllanthus emblica*: forest gene banks as a new approach for in situ conservation of genetic resources. *Current Science* **73**(2):163-168.

Shankar U and Synrem I L. 2012. Variation in morphometric traits of fruits and seeds of *Prunus nepaulensis* Steud. in Meghalaya, India. *Tropical Ecology* **53**(3):273-286.

Sharma K B, Kumari B, Johar V and Bisht V. 2017. Plus tree variation of shisham (*Dalbergia sissoo*) in different agro-ecological regions of Haryana. *Environment & Ecology* **35**(4A):2996-2998.

Sharma S K and Badiyala S D. 2006. Variability studies in common fig in Hamirpur district of Himachal Pradesh. *Indian Journal of Horticulture* **63**(2):159-161.

Sharma V, Kumari A, Thakur I K, Chandel M, Bhatia A K and Kumar A. 2021. Variations in morphometric characteristics of white mulberry (*Morus alba* L.). *Journal of Pharmacognosy and Phytochemistry* **10(**1):312-315.

Shu X, Yang X and Yang Z. 2012. Variation in seed and seedling traits among fifteen Chinese provenances of *Magnolia officinalis*. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **40(2):**274-283.

Shweta. 2020. Seed source variation in *Bauhinia vahlii* Wight & Arn. M. Sc. Thesis Department of Tree Improvement and Genetic Resources, YSP University of Horticulture & Forestry, Solan. 53p.

Singh A K, Singh P P, Singh S, Bhargava R and Makwana P. 2016. Variability in morphological and physico-chemical traits of aonla (*Emblica officinalis*) genotypes collected from north-eastern region of India. *Indian Journal of Agricultural Sciences* **86**(8):992-997.

Singh A K, Singh Sanjay, Appa Rao V V, Hiwale S S, Joshi H K and Sharma S K. 2012. Effect of organic manure and biofertilizers on soil properties and growth of aonla under rainfed condition of hot semi-arid environment. *Indian Journal of Arid Horticulture* **7(**1-2): 45–48.

Singh B, Bhatt B P and Prasad P. 2006. Variation in seed and seedling traits of *Celtis australis*, a multipurpose tree, in central Himalaya, India. *Agroforestry Systems* **67:**115-122.

Singh B, Uniyal A K, Rawat J S M and Rana D K. 2012. Estimation of genetic variability in *Phyllanthus emblica* towards a contribution in sustainable rural development. *Journal of Horticulture and Forestry* **4**(5): 92-95.

Singh N, Kumar M and Sharma J R. 2021. Evaluation of aonla (*Phyllanthus emblica*) genotypes under semi-arid conditions. *Indian Journal of Agricultural Sciences* **91(**12):1778-1782.

Singh S and Kaur A. 2021. Effect of Various Treatments on Seed Germination and Seedling Vigour of Aonla cv. Chakaiya. *Indian Journal of Agricultural Research* **55**(5):614-618.

Singhdoha A, Dhillon R S and Johar V. 2017. Estimation of genetic diversity among Superior CPTs of *Acacia nilotica*. *International Journal Current Microbiology Applied Science* **6:**1197-1202.

Sofi A H and Singh O. 2012. Variability in seed traits and genetic divergence in a clonal seed orchard of *Dalbergia sissoo* Roxb. *Journal of forestry research* **23**:109-114.

Sripriya L and Vijayalakshmi M. 2013. A study on biosorption and phytoremediation of heavy metals by leaves and bark of *Phyllanthus emblica*. *International Journal of Research in Pharmaceutical and Nano Sciences* **2**(2): 140-144.

Sudrajat D J. 2016. Genetic variation of fruit, seed, and seedling characteristics among 11 populations of white jabon in Indonesia. *Forest Science and Technology* **12**(1):9-15.

Sukirti. 2022. Seed source variation in *Terminalia bellirica* Retz, in Himachal Pradesh. M.Sc. Thesis Deptt. of Tree Improvement and Genetic Resources. Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan. 49p.

Suman K, Thakur I K and Kumari A. 2018. Variation in growth characteristics of different clones of *Morus alba*. *Journal of Pharmacognosy and Phytochemistry* **7**(6): 1236-1238.

Sumbali S, Gurav M and Hubbali S. 2012. Effects of pre-sowing treatments on germination and seedling growth of *Terminalia chebula* Retz, - An important medicinal plant. *International Journal of Life Sciences* **1**: 68-73.

Tchokponhoue D A, Dako E G, Danikou S, Nyadanu D, Kahane R, Houéto J, Hotegni N V F, Odindo A O and Sibiya J. 2020. Phenotypic variation, functional traits repeatability and core collection inference in *Synsepalum dulcificum* (Schumach & Thonn.) Daniell reveals the dahomey gap as a centre of diversity. *Scientific reports* **10**:1- 17.

Tewari R, Kumar V and Sharma H K. 2019. Physical and chemical characteristics of different cultivars of Indian gooseberry (*Emblica officinalis*). *Journal of Food Science and Technology* **56**:1641–1648.

Thilaga S, Largia M J V, Parameswari A, Nair RR and Ganesh D. 2013. High frequency somatic embryogenesis from leaf tissue of '*Emblica offcinalis'* Gaertn. —a high valued tree for non-timber forest products. *Australian Journal of Crop Sciences* **7**:1480-1487.

Verma R, Pandey C S, Pandey S K and Sahu K. 2019. Influence of pre-sowing treatment and growing conditions on growth performance of Indian gooseberry seedlings (*Emblica officinalis* Gaertn). *International Journal of Current Microbiology and Applied Sciences* ***8***:1936-1948.

Waiboonya P, Elliott S and Tiansawat P. 2019. Seed Storage Behaviour of Native Forest Tree Species of Northern Thailand. *Environment Asia* **12(**3):104-111.

Wali V K, Bakshi P, Jasrotia A, Bhushan B and Bakshi M. 2015. Aonla. *Directorate of Extension, SKUAST*-Jammu. 30p.

Ward. 1963. Hierarchical grouping to optimise an objective function. *Journal of the American Statistical Association* **58**:236:244.

Yadav S S and Yadav P N. 2010. Studies on maturity indices of Aonla (*Emblica officinalis* G.) fruits. *Progressive Agriculture* **10**(2):384-386.

Zobel B and Talbert J. 1984. *Applied forest tree improvement*. John Wiley & Sons 505p.

APPENDIX-I

MOTHER TREE WISE VALUES FOR TREE MORPHOMETRIC CHARACTERSTICS WITHIN NATURAL POPULATIONS OF *Phyllanthus emblica*

Region	Populations	Mother Trees	Tree height (m)	Tree girth (m)
Bilaspur	**Beri**	BB1T1	6.71	0.28
		BB1T2	8.53	0.41
		BB1T3	6.01	0.35
		BB1T4	7.62	0.64
		BB1T5	6.71	0.46
	Kasol	BB2T1	9.14	0.81
		BB2T2	10.97	0.61
		BB2T3	12.19	0.68
		BB2T4	11.89	0.74
		BB2T5	8.23	0.36
	Panjgain	PB3T1	4.57	0.24
		PB3T2	7.32	0.25
		PB3T3	6.4	0.2
		PB3T4	5.49	0.48
		PB3T5	5.49	0.51
Hamirpur	**Khaggal**	KH1T1	6.71	0.64
		KH1T2	8.23	0.49
		KH1T3	10.67	0.76
		KH1T4	12.19	0.71
		KH1T5	11.58	0.72
	Pahlu	PH3T1	11.58	0.69
		PH3T2	7.62	0.35
		PH3T3	6.01	0.26
		PH3T4	6.71	0.2
		PH3T5	7.01	0.23
	Rangas	RH1T1	7.32	0.38
		RH1T2	4.57	0.46
		RH1T3	8.23	0.58
		RH1T4	9.14	0.46
		RH1T5	10.67	0.81
Kangra	**Ganoh**	GK3T1	6.71	0.59
		GK3T2	10.97	0.62

		GK3T3	10.36	0.54
		GK3T4	5.49	0.21
		GK3T5	5.18	0.31
	Jachh	JK1T1	9.14	0.28
		JK1T2	7.31	0.25
		JK1T3	3.66	0.28
		JK1T4	5.18	0.3
		JK1T5	9.14	0.91
	Kathal	KK2T1	8.23	0.52
		KK2T2	9.14	0.5
		KK2T3	11.89	0.65
		KK2T4	11.58	0.7
		KK2T5	11.89	0.53
Mandi	**Baroti**	BM3T1	7.62	0.2
		BM3T2	5.79	0.36
		BM3T3	7.62	0.3
		BM3T4	6.4	0.18
		BM3T5	6.1	0.3
	Jarol	JM2T1	6.4	0.35
		JM2T2	9.75	0.64
		JM2T3	7.62	0.46
		JM2T4	12.19	1.27
		JM2T5	7.92	0.55
	Slapper	SM1T1	9.14	0.54
		SM1T2	10.67	0.55
		SM1T3	9.14	0.31
		SM1T4	5.49	0.33
		SM1T5	6.4	0.2

APPENDIX-II

MOTHER TREE WISE VALUES FOR FRUIT LENGTH, FRUIT BREADTH, FRUIT WEIGHT AND FRUIT LENGTH/WEIGHT RATIO WITHIN NATURAL POPULATIONS OF *Phyllanthus emblica*

Region	Population	Tree	Fruit length (mm)	Fruit breadth(mm)	Fruit weight (g)	Fruit length/weight ratio
Bilaspur	**Beri**	BB1T1	16.68	19.43	4.70	0.86
		BB1T2	16.92	19.74	4.83	0.86
		BB1T3	16.83	19.55	4.74	0.86
		BB1T4	19.85	24.61	7.58	0.81
		BB1T5	18.39	21.83	6.03	0.84
	Kasol	BB2T1	16.78	19.34	4.58	0.87
		BB2T2	18.22	22.88	6.59	0.80
		BB2T3	18.92	20.94	5.55	0.90
		BB2T4	18.61	21.14	5.60	0.88
		BB2T5	19.70	21.92	6.20	0.90
	Panjgain	PB3T1	20.52	23.08	6.83	0.89
		PB3T2	19.02	23.22	6.87	0.82
		PB3T3	18.07	20.24	5.11	0.89
		PB3T4	19.81	22.44	6.52	0.89
		PB3T5	19.51	22.05	6.23	0.89
Hamirpur	**Khaggal**	KH1T1	19.42	20.76	5.59	0.94
		KH1T2	18.68	22.36	5.41	0.84
		KH1T3	17.16	19.44	4.50	0.88
		KH1T4	20.80	23.42	7.03	0.89
		KH1T5	18.55	21.62	6.00	0.87
	Pahlu	PH3T1	15.46	17.29	4.69	0.89
		PH3T2	20.13	21.75	5.45	0.93
		PH3T3	17.87	20.35	4.83	0.88
		PH3T4	20.97	21.84	6.06	0.96
		PH3T5	19.23	22.31	6.43	0.86
	Rangas	RH1T1	19.47	22.27	6.48	0.87
		RH1T2	23.06	25.29	7.75	0.91
		RH1T3	22.45	24.64	7.35	0.91
		RH1T4	24.32	26.05	7.96	0.94
		RH1T5	22.68	24.87	7.60	0.91
Kangra	**Ganoh**	GK3T1	18.96	21.10	5.60	0.90

Region	**Population**	**Tree**	**Fruit length (mm)**	**Fruit breadth(mm)**	**Fruit weight (g)**	**Fruit length/weight ratio**
		GK3T2	19.80	23.14	6.85	0.86
		GK3T3	20.78	22.28	6.44	0.93
		GK3T4	19.90	20.75	5.50	0.96
		GK3T5	18.56	22.17	6.30	0.84
	Jachh	JK1T1	20.32	21.33	5.95	0.95
		JK1T2	19.22	20.01	5.11	0.96
		JK1T3	19.39	19.99	5.19	0.97
		JK1T4	19.20	20.01	5.24	0.96
		JK1T5	17.83	19.10	4.70	0.93
	Kathal	KK2T1	19.59	22.32	6.30	0.88
		KK2T2	19.80	21.93	6.18	0.90
		KK2T3	18.89	20.94	5.60	0.90
		KK2T4	19.07	21.14	5.73	0.90
		KK2T5	19.49	21.83	6.19	0.89
Mandi	**Baroti**	BM3T1	21.56	23.98	7.11	0.90
		BM3T2	18.34	20.36	5.36	0.90
		BM3T3	21.43	20.62	6.14	1.04
		BM3T4	22.26	20.08	6.39	1.11
		BM3T5	22.49	20.53	6.49	1.10
	Jarol	JM2T1	17.91	21.48	5.90	0.83
		JM2T2	18.28	21.13	5.68	0.87
		JM2T3	19.83	22.80	6.67	0.87
		JM2T4	19.09	21.33	5.80	0.90
		JM2T5	19.08	21.83	6.16	0.87
	Slapper	SM1T1	19.56	21.83	6.17	0.90
		SM1T2	20.00	21.94	6.25	0.91
		SM1T3	21.01	23.61	7.13	0.89
		SM1T4	21.12	23.69	7.04	0.89
		SM1T5	20.18	22.76	6.63	0.89
		$CD_{0.05}$	**0.63**	**0.67**	**0.36**	**0.02**

APPENDIX-III

MOTHER TREE WISE VALUES FOR STONE LENGTH, STONE BREADTH, STONE WEIGHT, PULP WEIGHT AND PULP THICKNESS WITHIN NATURAL POPULATIONS OF *Phyllanthus emblica*

Region	Population	Tree	Stone length(mm)	Stone breadth(mm)	Stone weight (g)	Pulp weight (g)	Pulp thickness (mm)
Bilaspur	**Beri**	BB1T1	9.20	8.20	0.81	3.89	5.62
		BB1T2	9.31	8.40	0.82	4.01	5.67
		BB1T3	9.31	8.36	0.81	3.93	5.59
		BB1T4	12.76	11.92	0.99	6.59	6.34
		BB1T5	10.68	9.69	0.88	5.14	6.07
	Kasol	BB2T1	9.23	8.09	0.81	3.76	5.62
		BB2T2	11.43	10.35	0.90	5.69	6.27
		BB2T3	10.03	9.06	0.84	4.71	5.94
		BB2T4	10.18	9.16	0.85	4.75	5.99
		BB2T5	10.70	9.64	0.88	5.32	6.14
	Panjgain	PB3T1	11.47	10.29	0.88	5.94	6.39
		PB3T2	11.52	10.39	0.90	5.97	6.41
		PB3T3	9.67	8.59	0.83	4.28	5.82
		PB3T4	11.14	10.08	0.89	5.63	6.18
		PB3T5	10.80	9.77	0.89	5.34	6.14
Hamirpur	**Khaggal**	KH1T1	11.23	10.16	0.86	4.72	5.30
		KH1T2	12.82	11.23	1.04	4.37	5.56
		KH1T3	9.35	8.50	0.81	3.69	5.47
		KH1T4	12.59	11.37	0.97	6.05	6.02
		KH1T5	11.21	10.25	0.91	5.09	5.68
	Pahlu	PH3T1	8.62	7.64	0.79	3.89	4.83
		PH3T2	10.56	9.41	0.86	4.59	6.17
		PH3T3	9.81	8.72	0.84	3.98	5.82
		PH3T4	11.28	10.20	0.92	5.14	5.82
		PH3T5	11.73	10.67	0.92	5.50	5.82
	Rangas	RH1T1	10.77	11.38	0.87	5.60	5.45
		RH1T2	13.18	12.04	1.08	6.67	6.63
		RH1T3	12.69	11.49	1.07	6.28	6.57
		RH1T4	13.83	12.55	1.21	6.76	6.75
		RH1T5	12.84	11.73	1.08	6.52	6.57
Kangra	**Ganoh**	GK3T1	10.18	10.81	0.85	4.75	5.14

Region	Population	Tree	Stone length(mm)	Stone breadth(mm)	Stone weight (g)	Pulp weight (g)	Pulp thickness (mm)
		GK3T2	11.75	13.33	0.95	5.90	4.90
		GK3T3	11.00	13.04	1.03	5.41	4.62
		GK3T4	10.16	14.96	1.33	4.17	2.89
		GK3T5	10.87	12.32	1.10	5.20	4.93
	Jachh	JK1T1	10.82	9.70	0.86	5.09	5.82
		JK1T2	9.69	8.60	0.84	4.28	5.70
		JK1T3	9.84	8.92	0.83	4.35	5.53
		JK1T4	9.87	8.95	0.83	4.40	5.53
		JK1T5	9.41	8.40	0.82	3.88	5.35
	Kathal	KK2T1	10.88	9.75	0.86	5.44	6.29
		KK2T2	10.57	9.58	0.86	5.32	6.18
		KK2T3	9.99	9.09	0.84	4.76	5.93
		KK2T4	10.32	9.28	0.85	4.87	5.93
		KK2T5	10.64	9.69	0.86	5.33	6.07
Mandi	**Baroti**	BM3T1	12.27	11.83	1.14	5.97	6.07
		BM3T2	10.47	9.43	0.96	4.41	5.47
		BM3T3	11.34	10.08	0.96	5.17	5.27
		BM3T4	11.01	10.78	0.94	5.45	4.65
		BM3T5	11.00	9.86	0.92	5.57	5.33
	Jarol	JM2T1	10.46	9.42	0.87	5.03	6.03
		JM2T2	10.21	9.25	0.85	4.83	5.94
		JM2T3	11.32	10.41	0.89	5.77	6.20
		JM2T4	10.17	9.08	0.85	4.95	6.13
		JM2T5	10.71	9.65	0.86	5.30	6.09
	Slapper	SM1T1	10.59	9.53	0.86	5.32	6.15
		SM1T2	10.68	9.55	0.86	5.39	6.20
		SM1T3	11.95	10.81	0.96	6.17	6.40
		SM1T4	11.84	10.73	0.94	6.10	6.48
		SM1T5	11.20	9.99	0.88	5.75	6.39
		$CD_{0.05}$	**0.50**	**0.54**	**0.05**	**0.34**	**0.22**

APPENDIX-IV

MOTHER TREE WISE VALUES FOR SEEDLING CHARACTERSTICS WITHIN NATURAL POPULATIONS OF *Phyllanthus emblica*

Region	Population	Tree	Seedling height (cm)	Shoot length (cm)	Collar diameter (mm)	Leaf number	Leaf area (cm^2)	Internodal length (cm)
Bilaspur	**Beri**	BB1T1	12.28	10.17	1.96	9.10	19.26	1.39
		BB1T2	11.48	9.18	2.11	8.67	17.48	1.41
		BB1T3	9.80	7.67	1.81	7.40	14.74	1.06
		BB1T4	11.13	8.93	1.49	8.67	14.25	1.24
		BB1T5	12.52	10.16	1.77	9.70	17.98	1.36
	Kasol	BB2T1	11.22	8.75	1.89	9.00	15.19	1.27
		BB2T2	11.50	9.18	1.83	8.60	18.92	1.27
		BB2T3	11.27	8.85	1.77	8.90	16.77	1.21
		BB2T4	11.07	8.68	1.64	8.83	13.99	1.12
		BB2T5	11.75	9.62	1.92	9.23	15.21	1.20
	Panjgain	PB3T1	10.93	9.00	1.69	9.30	13.92	1.12
		PB3T2	11.40	9.18	1.61	8.20	15.28	1.41
		PB3T3	13.35	10.95	1.69	9.97	16.35	1.41
		PB3T4	11.08	8.70	1.72	8.17	13.59	1.19
		PB3T5	9.82	7.88	1.65	7.87	16.23	0.90
Hamirpur	**Khaggal**	KH1T1	15.27	12.62	2.41	10.63	23.16	2.06
		KH1T2	12.68	10.82	1.97	10.43	19.71	1.94
		KH1T3	14.87	12.18	2.46	11.37	22.56	1.73
		KH1T4	14.78	12.80	2.55	11.73	21.01	1.95
		KH1T5	15.00	12.43	2.44	7.87	23.35	1.85
	Pahlu	PH3T1	12.63	9.72	2.00	10.10	16.18	1.38
		PH3T2	12.90	11.45	1.98	9.53	17.40	1.56
		PH3T3	13.10	10.98	1.99	9.60	15.76	1.41
		PH3T4	13.40	10.92	1.99	11.23	17.09	1.56
		PH3T5	13.88	11.50	2.22	9.90	18.86	1.66
	Rangas	RH1T1	16.13	13.35	2.62	10.17	24.82	2.11
		RH1T2	14.83	12.12	2.27	10.23	21.94	1.77
		RH1T3	16.05	13.37	2.05	11.37	23.91	1.82
		RH1T4	15.57	13.22	2.08	8.30	22.65	2.00
		RH1T5	14.80	11.83	2.28	11.67	20.88	1.64
Kangra	**Ganoh**	GK3T1	10.88	8.80	1.84	8.60	15.55	1.26
		GK3T2	10.70	8.48	1.89	8.60	13.80	1.28

Region	Population	Tree	Seedling height (cm)	Shoot length (cm)	Collar diameter (mm)	Leaf number	Leaf area (cm^2)	Internodal length (cm)
		GK3T3	10.78	8.65	1.81	8.83	15.42	1.19
		GK3T4	10.68	8.68	2.06	8.77	14.09	1.17
		GK3T5	11.55	9.25	2.17	8.97	15.21	1.21
	Jachh	JK1T1	10.03	8.67	1.95	8.53	13.85	1.12
		JK1T2	11.25	9.78	1.89	8.57	13.87	1.14
		JK1T3	9.92	8.41	1.94	8.47	11.99	1.08
		JK1T4	10.45	7.77	2.00	8.47	13.41	1.19
		JK1T5	11.82	9.77	1.71	9.57	15.70	1.30
	Kathal	KK2T1	11.93	9.24	1.99	9.40	15.01	1.38
		KK2T2	11.67	9.55	1.90	9.70	15.38	1.30
		KK2T3	12.12	9.82	2.11	8.43	15.49	1.43
		KK2T4	9.62	7.95	1.62	8.03	11.82	1.05
		KK2T5	10.97	8.88	1.88	8.63	15.76	1.31
Mandi	**Baroti**	BM3T1	10.20	8.08	1.67	8.47	13.53	1.21
		BM3T2	10.90	8.82	1.46	7.93	14.02	1.28
		BM3T3	10.16	8.02	1.68	7.24	13.15	1.18
		BM3T4	11.87	9.87	1.73	8.45	16.49	1.41
		BM3T5	10.63	8.32	1.59	7.47	12.85	1.29
	Jarol	JM2T1	9.63	7.65	1.62	7.17	12.45	1.22
		JM2T2	10.80	8.20	1.59	8.13	14.29	1.38
		JM2T3	12.30	10.32	1.89	8.53	15.72	1.34
		JM2T4	10.87	8.22	1.70	8.50	14.83	1.40
		JM2T5	9.83	8.15	1.59	7.73	13.36	1.12
	Slapper	SM1T1	12.03	9.33	1.78	8.70	16.59	1.53
		SM1T2	11.43	9.07	1.75	8.77	15.23	1.47
		SM1T3	8.98	7.23	1.44	6.77	11.41	1.23
		SM1T4	12.30	10.10	1.90	9.07	17.09	1.59
		SM1T5	12.58	9.87	1.74	8.83	16.38	1.54
		$CD_{0.05}$	**1.32**	**1.23**	**0.21**	**0.87**	**2.02**	**0.18**

APPENDIX-IV

1. Analysis of variance for fruit length

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	986.35	328.78	156.75	<.0001
Population	8	2575.64	321.96	153.49	<.0001
Mother Tree	48	3041.62	63.37	30.21	<.0001
Replication	3	3.21	1.07	0.51	0.6758
Error	2337	4901.96	2.10		

2. Analysis of variance for fruit breadh

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	394.35	131.45	56.85	<.0001
Population	8	2526.95	315.87	136.62	<.0001
Mother Tree	48	3576.69	74.51	32.23	<.0001
Replication	3	36.49	12.16	5.26	0.0013
Error	2337	5403.29	2.31		

3. Analysis of variance for fruit weight

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	122.31	40.77	59.87	<.0001
Population	8	643.59	80.45	118.14	<.0001
Mother Tree	48	927.62	19.33	28.38	<.0001
Replication	3	10.29	3.43	5.04	0.0018
Error	2337	1591.46	0.68		

4. Analysis of variance for stone length

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	467.94	155.98	121.84	<.0001
Population	8	701.73	87.72	68.52	<.0001
Mother Tree	48	1636.18	34.09	26.63	<.0001
Replication	3	14.09	4.70	3.67	0.0118
Error	2337	2991.83	1.28		

5. **Analysis of variance for stone breadth**

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	401.00	133.67	88.39	<.0001
Population	8	2603.85	325.48	215.24	<.0001
Mother Tree	48	1734.38	36.13	23.89	<.0001
Replication	3	16.94	5.65	3.73	0.0108
Error	2337	3533.96	1.51		

6. **Analysis of variance for stone weight**

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	2.21	0.74	57.86	<.0001
Population	8	11.29	1.41	110.90	<.0001
Mother Tree	48	12.43	0.26	20.36	<.0001
Replication	3	0.18	0.06	4.66	0.003
Error	2337	29.73	0.01		

7. **Analysis of variance for fruit length/breadth ratio**

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	1.30	0.43	165.48	<.0001
Population	8	2.87	0.36	137.27	<.0001
Mother Tree	48	3.33	0.07	26.53	<.0001
Replication	3	0.06	0.02	7.21	<.0001
Error	2337	6.10	0.00		

8. **Analysis of variance for pulp weight**

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	105.99	35.33	60.36	<.0001
Population	8	532.76	66.60	113.77	<.0001
Mother Tree	48	836.10	17.42	29.76	<.0001
Replication	3	7.79	2.60	4.44	0.0041
Error	2337	1367.98	0.59		

9. Analysis of variance for pulp thickness

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	143.85	47.95	190.57	<.0001
Population	8	447.63	55.95	222.38	<.0001
Mother Tree	48	324.19	6.75	26.84	<.0001
Replication	3	3.29	1.10	4.36	0.0046
Error	2337	588.03	0.25		

10. Analysis of variance for seedling height

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	3712.74	1237.58	180.79	<.0001
Population	8	479.71	59.96	8.76	<.0001
Mother Tree	48	1219.89	25.41	3.71	<.0001
Replication	2	69.19	34.59	5.05	0.0065
Error	1738	11897.26	6.85		

11. Analysis of variance for shoot length

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	3117.70	1039.23	175.75	<.0001
Population	8	313.64	39.20	6.63	<.0001
Mother Tree	48	1022.53	21.30	3.60	<.0001
Replication	2	18.46	9.23	1.56	0.2102
Error	1738	10277.30	5.91		

12. Analysis of variance for collar diameter

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	76.58	25.53	141.73	<.0001
Population	8	11.45	1.43	7.95	<.0001
Mother Tree	48	37.16	0.77	4.30	<.0001
Replication	2	1.04	0.52	2.87	0.0568
Error	1738	313.03	0.18		

13. Analysis of variance for leaf number

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	1129.39	376.46	128.75	<.0001
Population	8	37.18	4.65	1.59	0.1229
Mother Tree	48	999.73	20.83	7.12	<.0001
Replication	2	42.19	21.10	7.22	0.0008
Error	1738	5081.72	2.92		

14. Analysis of variance for leaf area

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	11497.89	3832.63	240.02	<.0001
Population	8	3377.91	422.24	26.44	<.0001
Mother Tree	48	3640.71	75.85	4.75	<.0001
Replication	2	214.46	107.23	6.72	0.0012
Error	1738	27752.36	15.97		

15. Analysis of variance for internodal length

Source	DF	Sum of Squares	MSS	F Ratio	Prob > F
Region	3	85.80	28.60	230.69	<.0001
Population	8	19.31	2.41	19.47	<.0001
Mother Tree	48	24.98	0.52	4.20	<.0001
Replication	2	0.53	0.26	2.14	0.1185
Error	1738	215.46	0.12		

Dr Yashwant Singh Parmar University of Horticulture and Forestry
Nauni, Solan (HP) 173 230
Department of Tree Improvement and Genetic Resources

Title of Thesis	**:**	**"Seed source variation in *Phyllanthus emblica* Linn. of Himachal Pradesh"**
Name of the Student	**:**	Pooja Sharma
Admission Number	**:**	F-2021-31-M
Major Advisor	**:**	**Dr. Anita Kumari**
Major Field	**:**	Forest Biology and Tree Improvement
Minor Field(s)	**:**	a) Silviculture and Agroforestry b) Forest Products
Degree Awarded	**:**	Master of Science Forestry (Forest Biology and Tree Improvement)
Year of Award of Degree	**:**	2023
Number of pages of Thesis	**:**	61+xii
Number of words in abstract	**:**	241

ABSTRACT

The present investigation entitled **"Seed source variation in *Phyllanthus emblica* Linn. of Himachal Pradesh"** was confined to 12 populations distributed in Hamirpur, Kangra, Bilaspur and Mandi regions of Himachal Pradesh. From each population 5 mother trees were further selected. 60 mother trees were selected for the study. Variations in fruit, stone, pulp and seedling traits were studied by collecting fruits of this species in the month of December 2022. There was large variation in tree phenotypic characters, fruit, stone and pulp traits. Kathal population recorded maximum tree height and Rangas population had maximum tree girth. The maximum fruit length, fruit breadth, fruit weight, stone length, stone breadth, pulp weight, pulp thickness, seedling height, shoot length and leaf area was recorded in Rangas population. While, collar diameter and leaf number were recorded maximum in Khaggal population. Germination percent i.e., desirable trait in tree breeding was recorded maximum for Rangas population in Hamirpur district. PC 1 showed highest fruit, stone and pulp characteristics accounting for 62.82 % followed by PC2 and PC 3. PC 1 showed highest variation for seedling trait accounting for 82.93 %. In cluster analysis, cluster V, VI and VII contains maximum value for genotypes with the desirable characters. The principal component analysis and cluster analysis suggested a population-based tendency of grouping in genotype for scientific study of germplasm. Overall, the populations of Rangas (Hamirpur), Khaggal (Hamirpur) and Kathal (Kangra) were found best suitable as seed sources of *P. emblica.*

Signature of Major Advisor **Signature of Student**

Countersigned

Professor & Head
Department of Tree Improvement & Genetic Resources
Dr. Y.S. Parmar University of Horticulture & Forestry
Nauni, Solan- 173 230 (H.P.)

BRIEF BIO-DATA

Name	**:**	Pooja Sharma
Father's Name	**:**	Mr. Lalit Kumar
Mother'Name	**:**	Mrs. Reena Devi
Date of Birth	**:**	18.04.1999
Sex	**:**	Female
Permanent address	**:**	Vill.-Bagoun, P.O.-Panjgain, Teh.-Sadar, Distt.- Bilaspur, Pin-174012 (HP)

Academic Qualification:

Examination Passed	Month and Year	University/Board	Percentage (%) or OGPA	Division
Matriculation	2014	C.B.S.E	7.4 out of 10	First
10+2	2016	C.B.S.E	78.60%	First
Graduation	2021	Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP)	8.1 out of 10	First

Whether sponsored by some state/Central Govt./Univ./SAARC	**:**	No
Scholarship/ Stipend/ Fellowship, any other financial assistance received during the study period	**:**	University Stipend

Place : **(Pooja Sharma)**
Date: