MORPHO-CHEMICAL CHARACTERIZATION OF *PHYLLANTHUS EMBLICA* L. GROWING IN WILD CONDITIONS IN THE SELECTED REGIONS OF NORTH-EAST INDIA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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MORPHO-CHEMICAL CHARACTERIZATION OF *PHYLLANTHUS EMBLICA* L. GROWING IN WILD CONDITIONS IN THE SELECTED REGIONS OF NORTH-EAST INDIA

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In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl.

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CERTIFICATE

This is to certify that the thesis entitled **"Morpho-chemical characterization of *Phyllanthus emblica* L. growing in wild conditions in the selected regions of North-East India"** submitted by **Mr. K Pung Rozar** for the award of degree of **Doctor of Philosophy** in **Forestry** of Mizoram University, Aizawl, embodies the record of original investigation carried out by her under my supervision. He has duly registered and the thesis presented is worth of being considered for the award of the Ph.D. degree. The work has not been submitted for any degree to any other University.

Date:

Place: Aizawl

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DECLARATION

MIZORAM UNIVERSITY

DECEMBER, 2024

I **K PUNG ROZAR,** hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

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Date:

Place: Aizawl **(K PUNG ROZAR)**

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List of Abbreviations and Symbols

Acronym/symbol	Full form/meaning
'	Minutes
"	Seconds
%	Percentage
<,>	Less And Greater Than
µg	Milligram
^{o}C	Degree Celsius
AA	Ascorbic Acid
AAS	Atomic Absorption Spectroscopy
ANOVA	Analysis Of Variance
AOAC	Association Of Official Analytical Collaboration
Ca	Calcium
CD	Critical Difference
Cm	Centimeter
Cu	Copper
CV	Coefficient Of Variance
Day^{-1}	Per Day
DMC	Dry Matter Content
E	East
ECMWF	The European Centre For Medium-Range Weather Forecasts
et al.	And Others
Fe	Iron
g	Gram
GPS	Global Positioning System
ha	Hectare
HCL	Hydrochloric Acid
K	Potassium
kg	Kilogram
kg plant^{-1}	Kilogram Per Plant
kg tree^{-1}	Kilogram Per Tree
km	Kilometer
km^{2}	Square Kilometer
L-D	Length Diameter
m	Meter
Mg	Magnesium
mg l-1	Milligram Per Litre
mg/100 g	Milligram Per 100 Gram
mg/100 ml	Milligram Per 100 Millilitre

mg/g	Milligram Per Gram
MGL	Meghalaya
mm	Millimetre
MT	Mean Temperature
MZR	Mizoram
N	Normality
NaOH	Sodium Hydroxide
NRS	Non Reducing Sugar
P	Phosphorous
PCA	Principal Component Analysis
PCs	Principal Components
PPV & FRA	Protection Of Plant Varieties And Farmers' Rights Authority
RF	Rainfall
RHS	Royal Horticultural Society
RS	Reducing Sugar
TA	Total Acidity
TH	Tree Height
TS	Total Sugar
TRP	Tripura
TSS	Total Soluble Sugar
UPGMA	Unweighted Pair Group Method With Arithmetic Mean
USDA	United State Department Of Agriculture

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Chapter 1

INTRODUCTION

1.1 Overview

In India, fruits have been cultivated for thousands of years, holding a significant position in the country's economy. The development of the fruit industry is currently essential, especially in developing nations like India, as it can help overcome food challenges. Among them, aonla plays a crucial role in commercial cultivation, with marketing being of significant importance both domestically and internationally.

Aonla, scientifically known as *Emblica officinalis* Gaertn. or *Phyllanthus emblica* L., commonly referred to as the Indian gooseberry, is an indigenous fruit that holds great significance as a valuable native fruit in the Indian subcontinent. It is renowned for its medicinal and healing qualities, making it a highly sought-after fruit among health-conscious individuals in the Indian subcontinent. This fruit is rich in vitamin C, making it an excellent source of this essential nutrient. Notably, aonla has been widely recognized for its therapeutic effects in addressing various health issues. It has been traditionally used to treat conditions such as bleeding, diarrhea, dysentery, anemia, jaundice, indigestion, and cough. The fruit's versatility is evident in its inclusion as a key ingredient in well-known Ayurvedic medicines like Trifala and Chavanprash. Moreover, aonla uses extend beyond its fruits; other parts of the plant, including the leaves, bark, and seeds, are also utilized for various purposes. This comprehensive utilization of different components showcases the plant's holistic value in traditional practices and remedies. With its numerous health benefits and wide-ranging applications, aonla remains a significant and treasured fruit subcontinental over the world (Wali *et al*., 2015).

Table 1.1 Common names of *Phyllanthus emblica* in different languages.

Language	Local Name	Reference	Language	Local Name	Reference
Assamese	Ambuki; amlakhi	Ghosh and Parida, 2015	Oriya	Anala	Jaiswal and Jaiswal (2022)
Bengali	Amla, Dhatri	Pathak, (2003)	Punjabi	Aola, Amla	Luna (2005)
English	Myrobalan and Indian gooseberry	Pandey *et al.* (2008)	Tamil	Nellikkai, Nelli	Luna (2005)
Garo	Ambare	Jain and Garg (2017)	Telugu	Usirikai	Luna (2005)
Gujarati	Ambala, Amli	Acharya *et al.* (2021)	Urdu	Amla, Amlaj	Chopra *et al.* (1992)
Hindi	Amla, Aonla	Pandey *et al.* (2008)	Manipuri	Heikru	Pachuau and Dutta (2020)
Kannada	Nellikayi	Luna (2005)	Mizo	Suhnlu	Pachuau and Dutta (2020)
Khasi	Sohmylleng	Jain and Garg (2017)	Sanskrit	Amalaka, Amrtaphala, Dhatriphala	Pandey *et al.* (2008)
Malayalam	Nelli	Luna (2005)	Tamil	Attakoram, Amirta-palam,	Pandey *et al.* (2008)
Marathi	Anvala, Avalkathi	Jaiswal and Jaiswal (2022)			

The cultivation of this fruit in India spans over an impressive history of more than 3500 years. Throughout ancient times, its utility in 'Ayurveda' was extensively documented by Sushruta, regarded as the father of ancient medicine (1500 BC-1300 BC). Amla fruit is an esteemed medicinal fruit that holds a significant place in the cultural and traditional practices of the Indian subcontinent. This small, round berry is believed to be derived from the very first tree that appeared on Earth, as per ancient legends and scriptures. According to the mythological narrative, the Amla tree originated from the tears shed by Brahma, the Hindu god of creation, during his intense meditation. The mythological significance attached to the Amla berry has contributed to its veneration and recognition as a symbol of purity, longevity, and divine connection. Revered as a sacred fruit, it has been deeply integrated into various cultural and religious customs, as well as traditional medicinal practices that have been passed down through generations (Khan, 2009). The aonla berry, renowned for its wide-ranging and powerful healing properties, is often associated with a semblance of truth in folklore. Referred to as "sarvadosha hara," meaning the eliminator of all diseases, this extraordinary berry occupies a central position in the venerable tradition of Ayurvedic medicine, the medicinal applications of aonla were also documented in Arabic, Egyptian, and Tibetan texts, Siddha, Unani from India, Sri Lankan, and Chinese medicine, attesting to its multifaceted therapeutic potential medicine systems. All components of the plant, including the root, bark, leaves, flowers, fruit, and seed, were utilized in both dried and fresh forms. In Ayurveda, the amla fruit is recognized for its light and dry properties, as well as its cooling characteristics. In India, the fruit is commonly consumed as a pickle (Baliga, 2011; Shanmugasundaram *et al*., 1983; Unander *et al*., 1990).

Due to its resilient characteristics and adaptability to diverse wastelands, coupled with its remarkable productivity of 15-20 tons per hectare, as well as its significant nutritive and therapeutic benefits, aonla has emerged as a pivotal fruit in the 21st century (Pathak *et al*., 2006).

Throughout history, fruit trees in forests have played a crucial role in providing sustenance and protection for humans. Based on the findings of Powell *et al*. (2013), it is estimated that 50% of the global human fruit consumption can be attributed to arboreal sources, predominantly originating from cultivated varieties

1.2 Habit and Habitat

The aonla tree, which is deciduous, can grow up to 15 meters tall. Its bark is grey-brown, rough and flakes irregularly while its blaze exhibits a pink-red hue. The leaves are simple, alternate and closely overlapping on short deciduous branchlets. They are sub - sessile, with minute lateral stipules that are linear in shape. The lamina measures 0.4 -1.5 x 2 – 4 mm and is either oblong or linear – oblong, with a round base and an obtuse and shortly apiculate apex. The leaves are glabrous and membranous, with obscure nerves. The flowers are unisexual, greenish-yellow and 2-3 mm across, densely clustered in leaf axils. Male flowers have 6 oblaceolate sepals each 1.5 mm with obtuse tips. They also have 3 stamens with oblong anthers connate by their connectives and 6 disc glands. Female flowers have 6 oblanceolate sepals with obtuse tips. The ovary is superior measuring 1.5 mm and having 3 cells, each containing 2 ovules. The styles are 3 broadly fimbriae recurved and stigmatiferous. The fruit is a capsule, 1.5-2.5 cm across subglobose and dehiscing into 6 cocci. The disc enlarges to give the appearance of a fleshy yellowish-green indehiscent berry (Vattakaven *et al.,* 2016)

Aonla are originally found in Tropical and Subtropical Asia, primarily flourishing as a tree in the wet tropical biome, dry deciduous or mixed forests at an altitude between 10–1,450 m. Its native range includes Bangladesh, Borneo, Cambodia, China South-Central, China Southeast, East Himalaya, Hainan, India, Jawa, Laos, Lesser Sunda Island, Malaya, Myanmar, Pakistan, Sri Lanka, Sumatera, Taiwan, Thailand, Vietnam, and West Himalaya. Additionally, it has been introduced into Andaman Island, Cuba, Mauritius, Puerto Rico, Trinidad-Tobago, and the Windward Islands (Barwick, 2004; Pathak *et al*., 1989; POWO, 2024; Subhadrabandhu, 2001). In India, aonla naturally thrives in regions extending from the northwest Himalayas, encompassing areas such as Jammu & Kashmir, Himachal Pradesh, and Uttarakhand, to the eastern territories including Assam, Manipur, Tripura, and Meghalaya. The cultivation of amla is prevalent in states such as Uttar Pradesh, Madhya Pradesh, Haryana, Karnataka, and Tamil Nadu. India holds the top position as the largest producer of aonla globally, with Uttar Pradesh, Madhya

Pradesh, Tamil Nadu, and Gujarat being the foremost contributors to the country's Indian gooseberry production (Wali *et al*., 2015). It is naturally distributed across all the northeastern states of India, thriving both in the wild and within agroforestry gardens. Its presence is not only limited to the region's diverse ecosystems but also extends to being cultivated in domestic settings for various uses (Deka *et al*., 2012, Pathak, 2003; Shukla *et al*., 2005).

Aonla, as a subtropical plant, flourishes in regions characterized by a dry climate and an annual rainfall ranging between 350 and 500 mm. Its native environment predominantly lies in Central South India. The cultivation of aonla has garnered significant popularity owing to its robust yield, favorable returns, and resilience to drought conditions. It demonstrates successful growth in moderately alkaline soils, as well as soils with slight acidity to sodicity, exhibiting a soil pH range from 6.5 to 9.5 (Chadha, 2013). Aonla, a naturally resilient plant, demonstrates adaptability across various agroclimatic conditions. Cultivation of this plant extends to hills reaching heights of up to 1800 meters above sea level. While young plants may suffer from winter frosts, mature trees exhibit resilience, enduring both freezing temperatures and scorching highs of 46° C. Due to its inherent toughness, Aonla holds significant promise for cultivation on degraded forest land, marginal areas, sodic soils, and wastelands. These land categories are prevalent across India's rainfed, desert, and drought-affected regions (Maurya *et al*., 2024).

1.3 Plant and Fruits Morphological Characters

The examination of morphological traits in fruits and their parent plants is essential for identifying promising accessions that can significantly boost agricultural productivity and sustainability. Traits such as fruit size, shape, color, and texture serve as important indicators of a plant's genetic potential and its adaptability to diverse environmental conditions. For example, studies on local mango germplasm have revealed considerable variation in fruit morphology, including shapes like obovoid, elliptic, and round, as well as colors ranging from greenish-yellow to green. This variability is crucial for pinpointing superior accessions suitable for breeding programs (Singh & Singh, 2021). Likewise, an assessment of *Cordia myxa f*ruit traits demonstrated significant differences among accessions, with characteristics such as fruit weight and flesh thickness being vital for selecting high-yield varieties (Mirheidari *et al*., 2022a). Research on additional fruit species, such as *Ziziphus mauritiana*, indicates that morphological diversity can impact consumer preferences and market appeal. Identifying morphotypes with desirable traits, like larger fruit size and higher pulp content, can enhance cultivation practices and yield better economic returns for farmers (Bairwa *et al*., 2022). Moreover, evaluating cashew accessions based on agro-morphological traits emphasizes the importance of phenotypic diversity in breeding efforts focused on improving fruit quality and yield (Matos-Filho *et al*., 2023). In raspberry breeding, understanding the inheritance of morphological traits is crucial for achieving desired outcomes, such as increased productivity and resilience to environmental stressors. The substantial variation among different raspberry accessions highlight the potential for selecting superior cultivars that meet market needs (Titirică *et al*., 2023). Incorporating morphological trait analysis into fruit breeding programs not only aids in the selection of valuable accessions but also supports the development of varieties that align with consumer preferences and can adapt to changing environmental conditions. By focusing on these traits, researchers and breeders can enhance genetic diversity and adaptability in fruit crops, thereby promoting sustainable agricultural practices in the face of global challenges

1.4 Genetic Diversity of Aonla

Aonla plants are commonly found in the Vindhyan hills, the northeastern hills region (including Garo, Khasi, and Jaintia hills), and the Northwestern Himalayan region, reaching elevations up to 1350 m above mean sea level. Additionally, areas with significant aonla diversity include Andhra Pradesh (specifically Vizag), Gujarat (Anand, Nadiad), Madhya Pradesh (Panna), Maharashtra (Ajanta, Akola, Bhandara, Buldana, Chandrapur, Jalgaon, Kolhapur, Ramtek, Satara, and Yoetmal), Tamil Nadu (Annamalai, Azhakiapandiapuram, Khrayamttels, Krishnagiri, Nilgiri hills, Panpozhil, Salem, and Siruwani hills), Uttaranchal (Kumaon hills), and Uttar Pradesh (Azamgarh, Bareilly, Pratapgarh, Raebareli, Sultanpur, and Varanasi). In aonla, the seedling population varies in terms of fruit size, ripening time, and yield per plant. Seed germination is not a problem. This is the reason why high genetic diversity for desirable economic traits is observed in the Aonla-growing regions of the country (Shukla and Dhandar, 2003). Indian Gooseberry, is a crucial aspect of the species' survival and adaptation to different environments. This diversity is observed in various forms such as fruit size, shape, color, taste, and tree habit. Studies have been conducted to assess the genetic diversity of aonla using various molecular markers, including RAPD (Random Amplified Polymorphic DNA) markers (Chaurasia *et al*., 2009) and EST-SSR (Expressed Sequence Tag Simple Sequence Repeat) markers (Kapoor *et al*., 2023).

The genetic diversity of aonla is vast due to its wide distribution across different agro-climatic regions in India. This wide distribution has led to the natural selection of specific traits in different regions, resulting in unique characteristics. Studies have shown that aonla exhibits a high level of genetic diversity, which is crucial for its conservation and utilization in breeding programs (Rai *et al*., 1993)

1. 5 Chemical Constituents

The fruits of *Phyllanthus emblica*, are particularly rich in ascorbic acid (vitamin C). The remarkable stability of this vitamin in amla fruits is attributed to the presence of polyphenols and tannins (Mandliya *et al*., 2023; Modi *et al*., 2023; Morton, 1960). Various plant parts including the fruits, bark, roots, and leaves are abundant in bioactive compounds such as tannins, phenolic acids (e.g., gallic acid, ellagic acid, and vanillic acid), and flavonoids (e.g., quercetin, kaempferol, and furosin), along with other compounds like corilagin, geranin, emblicanins, and glycosides (Anila and Vijayalakshmi, 2002; Bhattacharya *et al*., 2002; Bajpai *et al*., 2005; Chaiittianan *et al*., 2014; Kumaran & Karunakaran, 2006; Nisha *et al*., 2004; Scartezzini & Speroni, 2000; Zhang *et al*., 2003). Non-polar components found in the stem and fruit extracts include succinic acid dimethyl ester, dimethyl pentanedioate, and dimethyl adipate, while polar components consist of methyl adipate and 1,3-Dioxolane-4-methanol (Harahap *et al*., 2020). Additionally, the essential oil derived from the fruit contains esters, hydrocarbons, aldehydes, alcohols, and ketones (El Amir *et al*., 2014).

Aonla is highly valued for its potent antioxidant properties (Bajpai *et al*., 2005; Naik *et al*., 2005; Poltanov *et al*., 2009; Rao *et al*., 2005), with its ascorbic acid content contributing to 45%–70% of its total antioxidant activity. This fruit is also a source of diverse beneficial compounds, including phenolics, tannins, alkaloids, carbohydrates, and amino acids. Nutritional analysis of aonla reveals it contains approximately 14.1% carbohydrates, 0.5% protein, 0.1% fat, 0.7% minerals, 0.05% calcium, 3.5% fiber, 0.02 mg/100 g phosphorus, 1.2 mg/100 g iron, 600 mg/100 g vitamin C, and 0.2 mg/100 g nicotinic acid, along with compounds like saponins, alkaloids, and anthraquinones (Sumalatha, 2013).

1.6 Phytochemicals and Bio-chemicals

Phytochemicals are naturally occurring compounds found in plants that contribute to their color, flavor, and disease resistance. These bioactive substances are not classified as essential nutrients like vitamins and minerals, but they play significant roles in promoting human health and preventing chronic diseases. Phytochemicals can be broadly categorized into several groups, including flavonoids, carotenoids, phenolic acids, and glucosinolates, each with unique health benefits. The health benefits associated with phytochemicals are vast. They have been linked to anti-inflammatory effects, modulation of immune function, and protection against oxidative stress. Studies indicate that regular consumption of fruits and vegetables rich in phytochemicals can lower the incidence of diseases such as diabetes, obesity, and certain types of cancer (Kumar *et al*., 2023; Raghu *et al*., 2023).

Biomolecules are organic molecules that are essential to the structure and function of living organisms. They can be categorized into four primary classes: carbohydrates, proteins, lipids, and nucleic acids. Each class plays a unique role in biological processes, contributing to the overall functioning of cells and organisms. Carbohydrates, for instance, serve as energy sources and structural components; they can be simple sugars like glucose or complex polysaccharides like starch and cellulose, which are vital for energy storage and providing structural integrity to cell walls (Baptista *et al*., 2021; Rovira *et al*., 2021)

1.7 Pharmacological Properties of Aonla

Aonla has garnered attention in the field of pharmacology due to its diverse therapeutic properties. According to various studies, it exhibits significant anti-aging effects (Pal *et al.,* 2017; Wu *et al*., 2022), and possesses anti-cancerous properties, as documented by Mahata *et al*. (2013) and Wiart (2013). The fruit has also been shown to help in managing diabetes, with multiple studies highlighting its anti-diabetic effects (Kumar *et al*., 2012b; Nain *et al*., 2012; Kalekar *et al*., 2013; Fatima *et al*., 2017; Srinivasan *et al*., 2018). Additionally, aonla demonstrates anti-bacterial and anti-microbial activity (Saeed & Tariq, 2007; Srikumar *et al*., 2007; Dinesh *et al*., 2017) and anti-mutagenic effects (Sumitra *et al*., 2009). Its anti-pyretic, analgesic, and anti-inflammatory properties have been supported by research (Perianayagam *et al.,* 2004; Mythilypriya *et al*., 2007; Muthuraman *et al*., 2011; Asmilia *et al*., 2020). Furthermore, the plant exhibits strong anti-oxidant properties, as indicated by several studies (Bafna & Balaraman, 2005; Dhanalakshmi *et al*., 2007; Golechha *et al*., 2012; Rose *et al*., 2018; Majeed *et al*., 2020). It is also noted for its anti-ulcerous and wound healing capabilities (Sai *et al*., 2002; Bafna & Balaraman, 2005; Mehrotra *et al*., 2011; Chatterjee *et al*., 2012; Chularojmontri *et al*., 2013). Cardio-protective and chemo-protective properties have been documented (Krishnaveni and Mirunalini, 2012; Baliga *et al.,* 2013), along with hepatoprotective effects (Lee *et al*., 2006; Sultana *et al.,* 2008 Baliga *et al*., 2019). The plant also has immuno-modulatory effects (Sai *et al*., 2002; Suja *et al*., 2009; Zeng *et al*., 2017) and is recognized for its memory enhancing and neuro-protective benefits (Vasudevan & Parle, 2007; Xie *et al*., 2012; Mathew & Subramanian, 2014; Shalini & Sharma, 2015; Justin Thenmozhi *et al*., 2016; Bharathi *et al.,* 2018; Rajalakshmi *et al.,* 2019). This wide range of pharmacological properties underscores the potential of aonla as a versatile therapeutic agent in various health applications.

1. 8 Traditional Uses

Aonla fruit, also known as a rejuvenating agent or *Rasayana* (Udupa, 1985), has been traditionally employed for treating conditions such as diarrhea, jaundice, and inflammation. It is one of the core ingredients in the herbal blend known as "Triphala," which consists of equal parts of *Phyllanthus emblica*, *Terminalia chebula*, and *T. bellerica*. This mixture is recognized for its benefits in managing chronic dysentery, biliousness (Chopra *et al.*, 1958), hemorrhoids, and liver enlargement (Shastri, 1952). Consuming aonla is believed to revitalize various organ systems, enhance overall strength and wellness, and support immune function. Additionally, aonla fruit extract (FPE) is noted for its uses as an ophthalmic treatment, carminative, and digestive aid (El-Desouky *et al.*, 2008).

The fruits of aonla are traditionally valued for their medicinal properties across a range of treatments. When pickled or preserved in sugar, and consumed dry or fresh, the fruit acts as a mild laxative to alleviate constipation. In decoction form, either from the leaves or seeds, or as a compound with other medicinal herbs, it serves as a cooling and laxative agent, commonly used to reduce fever and the bark's antimicrobial properties aid in treating gonorrhea, and fruit paste serves to alleviate headaches and nausea (Baliga and Dsouza, 2011; Kumar *et al.*, 2012b; Patel & Goyal, 2011). The juice from aonla, when mixed with bitter gourd juice, is taken daily to manage diabetes and related eye complications. The decoction of fruit and other parts like bark, root, and leaves, provides anti-diarrheal benefits, addressing both acute and chronic forms of diarrhea, For dental pain and inflammation, ground roots and leaves are used as a topical painkiller and anti-inflammatory. Aonla is also employed for enhancing hair growth, treating aphthous ulcers in the mouth, and as an anti-rheumatic agent for conditions like rheumatism (Kumar *et al.*, 2012b; Singh *et al.*, 2011).

1.9 Aonla Production in India

India's varied agro-climatic zones support the abundant cultivation of a wide array of fruits and vegetables essential for human health across its regions. As the world's second-largest producer of fruits and vegetables, following China, India plays a major role in the global horticulture sector. According to the National Horticulture Database (2nd Advance Estimates) released by the National Horticulture Board, India produced 112.62 million metric tonnes of fruits and 204.96 million metric tonnes of vegetables in the 2023-24 season. The total area dedicated to fruit cultivation covered 7.04 million hectares, while vegetables were grown over an area of 11.11 million hectares. In the 2021-22 period, India's production of aonla (or gooseberry) reached an estimated 1,206.17 thousand tonnes, as reported by the National Horticulture Board. Madhya Pradesh led the nation with a production of 403.77 thousand tonnes, contributing 33.48% to the total, closely followed by Uttar Pradesh at 402.79 thousand tonnes (33.39%). Tamil Nadu was a distant third, producing 173.93 thousand tonnes, and making up 14.42% of the share. Other notable contributors included Gujarat with 64.90 thousand tonnes (5.38%) and Chhattisgarh with 45.78 thousand tonnes (3.80%). Smaller but noteworthy contributions came from Assam (1.68%), Haryana (1.37%), and Bihar (1.30%), while several states, such as Kerala and Mizoram, produced lower quantities. The central and northern states dominates in aonla production, with Madhya Pradesh and Uttar Pradesh alone accounting for nearly two-third of India's total output.

1.10 Aonla Production in North-East Region

The north-east regions of India possess a rich diversity of minor fruits, which hold significant importance for the rural communities residing there. These minor fruits serve as a crucial lifeline, not only by offering essential nutritional supplements but also by generating additional income for the impoverished population. The region's indigenous fruits, in particular, stand out as a treasure trove of minerals, vitamins, and fibers, bestowing numerous health benefits upon the rural populace. Such natural wealth plays an integral role in improving the overall well-being of the people in these areas. Moreover, beyond their nutritional value, these minor fruits hold deep-rooted cultural significance, as emphasized by Arora (1998). Minor fruits like aonla play a significant and vital role in the overall fruit production landscape. Many of these fruits are found in their natural, wild state, lending a unique and authentic flavor to the local produce. However, certain fruit varieties have shown great potential for commercial cultivation, presenting an opportunity for farmers to tap into their economic value and wider distribution.

The production of aonla in the Northeastern states of India, as per the 2021–22 data from the National Horticulture Board (NHB), showcases a modest contribution to the national total. Among these states, Assam stands out as the largest producer, with 20.21 thousand tonnes, accounting for 1.68% of the national share. Nagaland follows with a production of 2.48 thousand tonnes, contributing 0.21%. Mizoram and Manipur produced 1.23 and 0.85 thousand tonnes, respectively, with corresponding shares of 0.10% and 0.07%. The other northeast states comes under the "Others" category which reported minimal production at 0.08 thousand tonnes, representing 0.01% of the share. Despite the relatively low contribution of the region to the national total, the figures highlight significance in aonla cultivation within the Northeast. The data also underscores the untapped potential for expanding aonla production in the region, given its favorable agro-climatic conditions, which could be further leveraged through strategic investments and improved horticultural practices.

1.11 Scope of Study

The present study seeks to address critical gaps in the understanding, cultivation, and utilization of aonla, with a focus on the north-eastern region of India. Despite its nutritional, medicinal, and economic potential, aonla cultivation has been limited by the poor returns from older, inferior trees. Currently, systematic efforts to improve aonla are still in their infancy. The proposed research aims to systematically collect and characterize aonla accessions, providing valuable insights into breeding programs and crop improvement. This process will aid in identifying high-yielding accessions of aonla, which can be cultivated by local farmers in their jhum fields, homestead plantations, and orchards. As aonla is both fire-resistant and light-demanding, it holds promise for sustainable use in such challenging landscapes (Troup, 1921).

A significant aspect of the research involves the morpho-chemical characterization of wild aonla accessions. The north-eastern region of India, located within the Indo-Burma biodiversity hotspot, is home to diverse ecotypes of aonla that thrive in wild or semi-wild conditions. However, a lack of comprehensive data on the physico-chemical characteristics of these wild accessions hinders their optimal utilization. By examining the genetic diversity of aonla, the study will compare variations in fruit and plant structure, leaf shape, tree height, fruit colour, and other morphological traits across different accessions. Additionally, the research will assess the biochemical composition of the fruits, providing insights into their nutritional and functional properties. These findings will be crucial for understanding the potential of aonla growing in North East, India as a valuable food and medicinal resource.

The outcomes of this study have far-reaching implications for conservation, breeding, and commercialization efforts. Identifying accessions with significant genetic diversity, high fitness, and strong commercial potential will enable the development of *ex-situ* conservation strategies that capture broad adaptability. These strategies are essential for diversifying the genetic composition of seed orchards and ensuring the long-term sustainability of aonla populations. Furthermore, the genetic structure revealed through this research will help pinpoint populations with the highest diversity and adaptability, serving as a resource for breeding and propagation programs aimed at enhancing rural economies.

This research is particularly relevant given the fruit's role in supporting the livelihoods of local communities in north-eastern India. The region is known for its diverse minor fruit varieties that contribute significantly to local diets and economies. By improving the understanding of genetic variations in wild-growing aonla populations, the study can facilitate the introduction of improved strains with better commercial potential. Such efforts could unlock broader economic applications for aonla, particularly in remote areas where its wild and semi-wild growth currently limits its utilization.

From an economic standpoint, this research has the potential to aid rural communities in North East India by identifying high-yield, nutritionally superior, and commercially viable accessions of aonla. Such accessions could be cultivated more widely, providing income opportunities for local farmers and potentially contributing to regional economies through the commercialization of Indian gooseberry products. The identification of accessions with higher concentrations of bioactive compounds such as tannins, polyphenols, and antioxidants could also have applications in the pharmaceutical, nutraceutical, and cosmetic industries. Furthermore, the study aligns with national goals of promoting indigenous and underutilized fruit crops as part of a broader strategy to enhance food security, health, and economic growth. By fostering sustainable practices and supporting local economies, the study not only strengthens agricultural biodiversity but also encourages the cultivation and preservation of indigenous plant varieties, ensuring that communities benefit from the rich biological resources of the region.

1.12 Aim and Objectives

1. To study morphometric variations of *Phyllanthus emblica* L. trees growing in the wild conditions of NE India
2. To study the physical and bio-chemical characteristics of the fruits of *Phyllanthus emblica* growing in different localities of NE India

Chapter 2

Review of Literature

This chapter aims to provide an in-depth assessment of the research conducted on aonla and its various aspects and is presented in various subheadings as outlined below:

2.1. Morphological characteristics of *Phyllanthus* spp.

2.1.1. Tree morphology

Rao and Subramanyum (2009) reported the cultivar NA-10 with the greatest height (4.2 m), number of branches (12.6), plant spread (39.9 m^3), and the highest number of fruits (861.6). Singh *et al*. (2016) in a study on the morphological features of different accessions reported that the fruit stem end cavity was smooth, slightly depressed, or depressed. These variations were observed in the morphology. Kumar *et al*. (2016) evaluated and concluded that the growth habit of aonla was tall pendulous, erect spreading, semi-spreading, and tall erect. The height of the plants ranged from 3.64 to 5.69 m across all kinds. The color of the trunk varied between shades of grey and light green.

Qualitative morphological study of the stem shape and stem surface of five *Phyllanthus* spp by Chandra *et al*. (2018) revealed that the stem shape was round for *P. amarus* and *P. tenellus* and angular for *P. fraternus*, *P. myrtifolius* and *P. urinaria*. Furthermore, the stem surface was glabrous for *P. tenellus* and *P. fraternus* while *P. urinaria* and *P. amarus* has hispidulous shape and *P. myrtifolius* had scabridulous shape. The tree morphology of the examined genotypes by Sing *et al*. (2021) reported that the shape of the tree shape was spreading (CHES-1, Chakaiya, Krishna, NA-6, NA-7, NA-10, and BSR-1); drooping (NA-20); and upright (G-1, S-1, and S-2).

Kumar *et al*. (2021) reported that the plant shape of various aonla cultivars was spreading and upright. Furthermore, also added the plant height ranges from 4.90 to 6.70 m, the plant spread in the east-west direction range from 4.47 to 7.15 m, the plant spread in the north-south direction range from 4.44 to 7.53 m, the stem girth ranges from 46.45 to 95.37 cm, the plant volume that the plant shape of various aonla cultivars ranged from 86.8 to 283.9 cm^3, and the plant canopy area range from 15.59 to 42.35 m^2. Tree growth patterns were found as spreading (CHES 1, Chakaiya, Krishna, NA 6, NA 7, NA 10, and BSR 1), drooping (NA 20), and upright (G 1, Seedling 1, and Seedling 2) by Singh *et al*. (2022).

2.1.2. Leaf morphology

Kumar *et al*. (2016) reported the shape of the leaves ranged from oval oblong to rectangular and elliptical. The leaf apex also exhibited variations, with some leaves having an obtuse apex and others having an acute apex. The dimensions of the leaves, in terms of length and width, varied from 1.28 cm × 0.24 cm to 48 cm × 0.33 cm, respectively. Comparison on the morphological traits of three different cultivars revealed that the leaves of desi cv. was medium in size and dark green in color, the leaves of Banarasi cv. was medium size and green in color and the leaves of Sheesha cv. was large and light green (Rabbani *et al*., 2019).

Study on the leaf morphology of five *Phyllanthus* species by Okanume *et al*. (2019) reported that all the species studied had simple leaves with an alternating leaf arrangement and a smooth edge. *P. muellerianus*, *P. niruri*, and *P. reticulates* showed elliptical leaf shape whereas *P. nivosus* has an ovate leaf shape and *P. discoideus* had an oblanceolate shape. The leaf base was cuneate for *P. discoideus* and *P. reticulates* and rounded for *P. nivosus*, *P. muellerianus* and *P. niruri*. Glaborous leaf surfaces were observed, while the tips of the leaves varied in shape, ranging from rounded, acute and obtuse.

Ajibua *et al*. (2023) evaluated on the leaf morphological characters of *Phyllanthus muellerianus* and *fraternus* revealed that the leaf shape was elliptical and with entire margin. The leaf color was pale deep green for *P. muellerianus* and light green for *P. fraternus* and the leaf type was simple and bipinnate for *P. muellerianus* and *P. fraternus* respectively. Alternate leaf arrangement was observed by 5 *Phyllanthus* spp studied by Chandra *et al*. (2018). The study also revealed that the leaf shape was oblong for *P. amarus* and *P. urinaria*, elliptic for *P. fraternus* and *P.*

tenellus and oblanceolate for *P. myrtifolius*. Leaf apex varied from rounded, acute, obtuse and apiculate while the leaf base was round (*P. amarus*), acute (*P. fraternus*), cordate (*P. myrtifolius*) and obtuse (*P. tenellus* and *P. urinaria*).

2.1.3. Fruit morphology

An investigation into the physical characteristics of Kanchan fruits found that the shape of the fruit varied from round to oblate, with a sphericity of 92-99%. Also, it was revealed that the maximum and minimum surface area of fruit was 4024 and 2905 mm^3 respectively. The aonla fruit was determined to have a bulk density of 669.01 kg/m^3 and a true density of 1090.68 kg/m^3 (Brimapureeswaran and Anadakumar, 2015). Shaik *et al*. (2016) reported that the shape of the fruit of cultivar Chakaiya and NA-7 was categorized as spheroid to oblate due to its sphericity exceeding 90%. Ingale *et al*. (2016) studied four cultivars of aonla and they observed that the shape of the fruits ranged from prolate to round. Kumar *et al*. (2016) in their study reported that the cultivar NA-7 had the highest fruit-setting rate at 51.95% and Francis had the lowest fruit-setting and fruit retention rate at 36.56% and 11.43% respectively. The fruits were categorized into small, medium, and giant based on their size variations.

Singh *et al*. (2016) reported fruits of different genotypes of aonla collected from Nagaland exhibited variations in their fruit shape (round flattened, round spherical, and round). Additionally, the study also claimed variations in fruit color, ranging from light green to pale yellowish green, yellowish green, and dark green. The genotypes tested showed variation in the styler end, which were sunken, smooth, deeply sunken, slightly depressed, or depressed. The stone shape observed in various forms across all genotypes includes round triangular at the apex, flattened triangular, flattened round, spherical round, and spherical round triangular at the apex. Kaim and Bisht (2017) reported that the cultivars Kanchan, Amrit, Neelam, and NA-10 had stones that were white-brown, whereas Chakaiya and Banarasi had brown stones. Chandra *et al*. (2018) reported that the fruit morphology of *P. amarus*, *P. tenellus*, *P. fraternus* and *P. myrtifolius* was greenish round while the fruit of *P. urinaria* was yellowish round with wavy surface.

Significant variation in fruit size was observed in all three varieties of Amla fruit. The Desi and Sheesha varieties had modest fruit size, while the Banarasi types had enormous fruit size. The fruit exhibited a range of colors, including green, light green, and solid green in the Desi, Sheesha, and Banarasi varieties, respectively (Rabbani *et al*., 2019). Kumar *et al*. (2021a) studied the morphology of four underutilised fruits of Uttar Pradesh and reported that the aonla fruit shape ranged from oval to round, the fruit color was light green with a yellowish hue, and the pulp color varied from whitish to greenish in appearance.

Kumar *et al*. (2021b) evaluated the fruit shape of nine promising cultivars of aonla from Haryana. They reported that the fruit shape was seen to be flattened circular, triangular, oval and round, and the fruit apex was reported to be flat, papillate, and depressed. Singh *et al*. (2022) observed that the fruit of Chakaiya, Krishna, NA-6, NA-10, G-1, and Seedling 1 displayed a light green color while CHES-1, NA-7, NA-20, and Seedling 2 had yellow-green color. On the other hand, the fruit of cultivar BSR 1 had a red tinge against a light green background. The total number of segments in all the germplasm was determined to be six.

Study on the wild amla from the Himalayan region by Sharma and Gupta (2023) reported that the fruit of amla was light greenish yellow color and spherical in shape. However, in a study by Nimse and More (2018) claimed that the aonla fruit was light green to yellowish in color. Bulo *et al*. (2024) evaluated 30 genotypes from four districts of Arunachal Pradesh and reported that the fruit shape was spherical (21 genotypes), flattened (2 genotypes), triangular (5 genotypes) and oval shape (2 genotypes). The study also reported that majority of genotypes were light green color, while some displayed shades of medium green and medium yellow-green.

2.2. Physical characteristics of *Phyllanthus emblica* fruits

Significant variation in the length, average weight and diameter of the fruit was reported by seven different aonla cultivars: Banarasi, Krishna, Chakaiya, Kanchan, NA-7, NA-9, and NA-10 (Godara *et al*., 2004). Physical examination of fruits of seven cultivars namely Krishna, Kanchan, Narendra Aonla-6, Narendra Aonla-7, Narendra Aonla-10, Francis and Chakaiya by Jaiswal *et al*. (2007) reported that the fruit weight was greatest in cv. Krishna followed by Narendra Aorla -10 and Narendra Aonla-6. However, the differences were at par. Minimum fruit weight was observed in cv. Kanchan. The fruits of cv. Narendra Aonla-6 exhibited minimum seed and fibre content, whereas greatest was detected in cv. Kanchan.

Hazarika *et al*. (2009) studied on physical characteristics of various accessions and reported significant variation among the accessions. The weight fruit varied from 3.24 and 10.18 g, pulp weight ranged from 2.83 to 9.41 g, while the seed weight varied from 0.37 and 1.66 g and the pulp to seed ratio ranged from 3.21 to 14.00. The mean fruit length, weight, diameter, and stone weight were measured as 33.60 g, 3.40 cm, 3.99 cm, and 2.08 g, respectively. The mean volume, weight of pulp, and ratio of pulp to stone of the fruits were determined to be 31.30 ml, 29.70 g, and 14.28, respectively. The mean specific gravity was 1.07. The mean moisture content was measured at 78.88 percent (Sahu, 2013).

Singh *et al*. (2016) carried out a study on the elite genotypes of wild aonla in the northeastern region of India, where it was observed that all the genotypes showed a wide range of variability in the fruit length, fruit weight, fruit girth, stone weight and specific gravity. However, Chandra *et al*. (2009) observed a somewhat similar range of variations in the physical attributes of fruits in aonla genotypes from the Garo hills of Meghalaya. Shaik *et al*. (2016) reported the moisture content of fruit of the cultivar NA-7 Chakaiya and as 78.5% and 80.5% respectively. Also, reported the average values for size, sphericity, aspect ratio, surface area, volume, density, and pulp to seed ratio of the Chakaiya and NA-7 cultivars as 36.33 mm and 32.95 mm, 95.8% and 94.7%, 90.84% and 88.23%, 4249.9 mm^2 and 3601.8 mm^2, 28.95 cm3 and 22.56 cm3, 1.06 g/cc and 1.07 g/cc and 21.14 and 15.77 respectively. Similarly, in a study by Goyal *et al*. (2007) the moisture contents of cultivars NA-7 and Chakaiya were 69.46% 74.6% and respectively.

The moisture content of several cultivar fruits, measured on a fresh weight basis, ranged from 84.89% to 87.50% (Tewari *et al*., 2019). Another pharmocognostic study by Dhale (2012) revealed that the moisture content and total ash content of the leaf, stem and fruits of *P. emblica* were 5.95%, 7.8% and 9.35%

and 4.5%, 5.0% and 2.8% respectively. The analysis conducted by Nimse and More (2018) revealed that the sample contained a moisture content of 85.6%, an ash percentage of 0.9%, a fat content of 0.5%, and a fiber content of 3.7%, indicating a composition that reflects its inherent nutritional and physical properties. These values suggest a high water retention capacity, minimal fat levels, and moderate fiber content, which could influence its potential applications in food processing or other industries.

Ingale *et al*. (2016) concluded that the average volume and sphericity of four cultivars of aonla fruits ranged from 31.565 to 42.809 cm^3 and 0.954 to 0.995 respectively. Also reported that the rolling resistance ranged from 12.51 to 21.990. The observed fruit size ranged from 3.10 to 4.47 cm. Another study on various cultivars of amla fruit reported a moisture content ranging from 81.26 to 84.65% by Parveen and Khatkar (2015). Kaim and Bisht (2017) studied the physical characteristics of six cultivars of aola (Amrit, Neelam, Chakaiya, Kanchan, NA-10 and Banarasi. The results revealed a substantial variation among the cultivars where Banarasi recorded maximum fruit weight (36.23 g), stone weight (2.65 g), stone length and width (1.66 am and 1.49 cm respectively) and pulp weight (33.58 g), highest pulp to stone ratio was observed by the cultivar NH-10 and cultivar Kanchan exhibited the maximum specific gravity (1.10 g/c^3).

Singh *et al*. (2017) evaluated the physical properties of six cultivars of aonla and reported that kanchan exhibited the highest fruit weight (37.90 g), fruit breadth (5.24 cm) pulp weight (32.66 g). The stone's weight was determined to be the lowest at 3.30 g in Kanchan, and the highest at 4.11 g in Krishna. In a study by Kulkarni *et al*. (2017) revealed that the aonla fruits have a diameter of 38.80 mm (vertical) and 33.28 mm (horizontal). The weight of the fruit, pulp, and seed were 31.80 g, 28.21 g, and 2.48 g, respectively. The fruits had a specific volume of 29.50 ml and a specific gravity of 1.07.

Significant variation in the physical characteristics among different varieties of aonla was observed by Chiranjeevi *et al*. (2018). The Krishna variety had the highest measurements for fruit length (3.82 cm), fruit diameter (4.22 cm), fruit weight (49.33 g), and pulp weight (41.1 g). The NA-10 variety had the highest pulp content at 84.75%, while the Krishna variety had the highest pulp to stone ratio at 5.65. The Kanchan cultivar exhibited the highest recorded values for stone weight (7.7 g), seeds per fruit (6.6), and seed length (0.54 cm).

Nimse and More (2018) carried out a study to examine the physical characteristics of aonla fruit, including length, diameter, whole fruit weight, pulp weight, percentage of pulp, and percentage of seed. The measurements obtained were 3.434 cm for fruit length, 3.567 cm for fruit diameter, 28.391g for fruit weight, 26.231 g for pulp weight, 92.3% for pulp %, and 7.60% for percentage of seed. Assessment on various genotypes of aonla from Mizoram revealed that the fruit weight, fruit length, fruit volume, specific gravity, pulp weight, pulp-stone ratio, pulp percentage, stone length, stone weight, and moisture content ranges from 5.42 to 9.04 g, 18.98 to 24.08 mm, 4.58 to 8.79 cc, 1.029 to 1.167 g/cc, 7.26 to 3.92 g, 1.63 to 6.98, 60.27 to 84.81%, 9.27 -12.80 mm, 0.58 to 2.94 g, and 78.70 to 87.57% respectively (Hazarika and Laltluangkimi, 2019).

Naithani *et al*. (2020) in a study on the physical properties of aonla fruits in in the Garhwal Himalaya Region reported that the fruit weight, fruit diameter, fruit volume, pulp thickness and pulp weight ranged from 8.86–3.39 g, 2.34–1.78 cm, 9.14–2.70 ml, 0.88–0.34 and 8.70–2.19 g respectively. Furthermore, also concluded that the physical feature that exhibited the most variability was the weight of the fruit. Bairwa *et al*. (2020) conducted a study on the physical characteristics of different cultivars of aonla and revealed that the maximum measurements: fruit length (4.32 cm), fruit width (4.62 cm), fruit weight (42.53 g), specific gravity (1.27), pulp percentage (95.11%), stone percentage (13.65%), and pulp to stone ratio (1:11.68) were recorded in the cultivars NA-7, NA-7, Chakiaya, Francis, NA-6, and Banarasi, respectively.

Study on the physical characteristics of wild amla of the Himalayan region reported that the fruit weight measured 14.94 g, while the fruit length and fruit diameter measured 2.23 and 2.96 cm respectively (Sharma and Gupta, 2023). Tase and Jamir (2024) assessed on the fruit length and breadth of wild amla of Kohima and reported that the value was 1.35 cm and 0.68 cm respectively. Furthermore, the study also revealed that among the studied wild fruits, the maximum and lowest moisture content were reported in *Phyllanthus emblica* (85.33%) and *Passiflora edulis* (75.67%) respectively. In contrast, *Passiflora edulis* had the highest dry matter content and *Phyllanthus emblica* the lowest.

2.3. Biochemical characteristics of *Phyllanthus emblica*

Maholiya *et al*. (2015) examined four cultivars: Kanchan, Krishna, Chakaiya, and NA 7. Their investigation reveals that the Kanchan cultivar has the highest acidity level at 2.13%, while the Chakaiya variety has the lowest acidity level at 1.79%. In their study, Bakshi *et al*. (2015) analyzed six distinct cultivars of aonla (Banarasi, Chakaiya, Neelam, Francis, and Desi) in the rainfed environments of the lower Shivalik foothills of the Himalayas. They found that Banarasi had the highest vitamin C content (584.00 mg/100 g), while Desi had the lowest (480.20 mg/100 g).

Sabir *et al*. (2017) observed the total polyphenol concentrations of the aqueous extract of *P. emblica* ranged from 72.91 to 115.2 mg gallic acid g^{-1} extract and also the ascorbic acid content of *P. emblica* fruit ranges from 217.7 to 400 mg/100 g. According to statistics from the National Institute of Nutrition (Longvah *et al*., 2017) aonla fruit has the highest vitamin C concentration compared to apple (3.57 mg), banana (8.6 mg), guava (222 mg), and orange (42.7 mg). Tewari *et al*. (2019) conducted a study on the physical and chemical properties of Indian gooseberry across six different cultivars (NA-7, NA-9, NA-10, Balwant, and Hathijhool). Highest ascorbic acid content was recorded by NA-7 (559.61 mg/100 g), while Hathijhool the lowest (528.10 mg/100 g).

Gocher *et al*. (2020) conducted a study to assess the overall vitamin C content in *P. Emblica* from the Garhwal Himalayas and observed that the fruits of Banarsi had the highest vitamin C content at 607.05 mg/100 g, while the fruits of wild had the lowest at 248.85 mg/100 gm. Comparative biochemical study on 37 species of fruits (both underutilized and consumed fruits) of Sri Lanka by Abeysuriya *et al*. (2020) reported that the total vitamin C content varied from 8.1 to 529.6 mg/100 g. Further it was also claimed that among the underutilized fruits the TVC content in *P.*

emblica was more than 10 times greater than that in *P. guajava*. The total phenolic content ranged from 12.9 to 2701.7 mg GAE/100 g of fresh weight, of which *P. emblica* had the highest, while *C. lantanus* had the lowest TPC.

In their extensive investigation, Singh *et al*. (2021) examined eleven distinct aonla genotypes and documented an array of ascorbic acid levels that ranged from 309 to 566 mg/100 g in the pulp. According to prior research, the total phenol content of water and ethanol extracts from the fruit of *P. emblica* was 336 and 318 µg GAE mg^{-1}, respectively (Luqman *et al*., 2012). According to Naik *et al*. (2005), the total phenolic content of the aqueous extract from 30 fruits of *P. emblica* was 33%, which is similar to gallic acid. Screening of the total phenolic and total flavonoid content of the dried fruits of *P. emblica* by Jhaumeer *et al*. (2018) observed that the ethyl acetate extract recorded the highest total phenol and flavonoid content measuring 640.55 mg GAE g^{-1} and 215.45 mg QE g^{-1} respectively. Another study by Liu *et al*. (2008) reported among the four solvent fractions, the ethyl acetate extraction of *P. emblica* fruits exhibited the highest phenolic content measuring 439.9 mg g^{-1}.

In a study by Fitriansyah *et al*. (2018) observed that the ethyl acetate extract of stem bark of *P. emblica* had the highest total phenol content (12.818 g GAE/100 g) while the lowest was observed in n-hexane extract of stem bark (0.110 g GAE/100 g). The ethanol extract of *P. emblica* leaves had the highest total flavonoid content (3.594 g QE/100 g), while the n-hexane extract of leaves had the highest total carotenoid content (0.759 g BE/100 g). Yadav *et al*. (2021) reported the total phenolic contents of the leaves in the ethanol and aqueous extract to be 86.42 mg GAE g^{-1} and 31.58 mg GAE g^{-1} respectively.

According to the results of Halim *et al*. (2022), the total flavonoid and total phenolic content of the extract ethanol of *P. emblica* fruit were 5.82 mg QE g^{-1} extract and 274.59 mg GAE g^{-1} extract respectively.

Phytochemical study of *P. emblica* extracts reported that ethyl acetate extract among all the extracts recorded the highest total flavonoid and total phenolic content measuring 48.04 mg QE g^{-1} and 172.26 mg GAE g^{-1} (Saptoka *et al*., 2022). The nutritional composition of aonla fruit, as reported by Nimse and More (2018), includes 2.187% protein, 7.113% carbohydrates, 7.32% total sugars, and 1.42% reducing sugars, alongside a titratable acidity of 2.34%, an ascorbic acid content of 552.6 mg/100 g, and a pH value of 2.98, highlighting the fruit's rich nutritional profile, particularly its high vitamin C content, making it a valuable dietary component for health-conscious individuals.

A study on biochemical properties in different parts (fruits, stems and leaves) of *P. emblica* (Orabi *et al*., 2023), revealed that the total phenolic contents were higher in fruits (29 mg GAE g^{-1} dry extract) and leaves (29 mg GAE g^{-1} dry extract). The flavonoids contents were higher in the fruits (24 mg QE g^{-1} of dry extract). The stem branches had the highest tannin level (4.2 mg g^{-1} in terms of dry weight). Phytochemicals study in the fruit extracts of *P. emblica* obtained from several districts of Himachal Pradesh revealed that the fruits obtained from the Mandi area had a total phenolic content of 239.74 mg g^{-1} gallic acid equivalents (GAE), while the Kangra district had a greater total flavonoid content of 356 mg g^{-1} rutin equivalents (Saini *et al*., 2024).

In the study conducted by Chaphalkar *et al*. (2017), it was observed that aonla fruits contain a flavonoid concentration of 3.89 mg g^{-1}, which is equivalent to quercetin. Fitriyansyah *et al*. (2018) conducted a study and observed that the total flavonoid concentration in the extract of *Phyllanthus emblica* ranged from 2.9 mg g^{-1} QE to 3.8 mg g^{-1} QE. The fruit juice of *P. emblica* has the greatest concentration of vitamin C, measuring 478.56 mg/100 ml. This concentration surpasses that found in oranges, tangerines, and lemons, as reported by Jain and Khurdiya in 2004. Study on 52 underutilized fruit species of Malaysia claimed that *Sandoricum macropodum* and *Phyllanthus emblica* had the highest total phenolic content measuring 3185.05 and 2664.97 mg/ 100 g respectively (Ikram *et al*., 2009).

Investigated on different wild fruits of Thailand by Kubulo *et al*. (2011) revealed that *P. emblica* recorded the highest vitamin C content measuring 2.2 mg g^{-1}. However, the phenolic content was higher in *Diospyros decandra* (215 mg GAE g^{-1}) followed by *Agele marmelos* (81.46 mg GAE g^{-1}) and *P. emblica* (65 mg GAE g^{-1}).

The results of the study conducted by Suriyavathana and Subha (2011) revealed that *P. emblica* has higher levels of the total carbohydrate, starch, total protein and the Ca compared to *P. acidus* and *Citrus limon*.

Pandey *et al*. (2014) evaluated on the biochemical constituents of the different germplasm accessions and reported that the TSS ranged from 10.17 to 17.40 ^{o}B, the acidity from 2.07% to 2.97%, the vitamin 'C' content ranged from 347.67 to 632.33 mg/100 g pulp, the tannin content ranged from 2.80% to 7.08%, the reducing sugars ranged from 2.43% to 4.35%, the total sugar ranged from 4.98% to 8.85%, the TSS acid ratio ranged from 3.96 to 8.29%, and the sugar acid ratio ranged from 1.88 to 4.21%. Assessment on various genotypes of aonla from Mizoram revealed that the TSS, acidity, ascorbic acid, total sugars, reducing sugar, non-reducing sugars, sugar: acid ratio and TSS: acid ratio ranged from 9.48 -14.93 °B, 1.35- 2.69%, 418.27 - 894.15 mg/100 g, 5.59 -13.08%, 1.29 - 9.37%, 1.29 - 6.16%, 2.71 -10.93 and 3.89 - 11.87 respectively (Hazarika and Laltluangkimi, 2019).

In a study by Nigam *et al*. (2021) revealed that the total ash content of the plant leaves was measured to be 3.1%, indicating a low presence of inorganic components. The water-soluble ash and acid insoluble ash were determined to be 1.7 and 1.3%, respectively. Additionally, the water-soluble extractive value was discovered to be 28.8%, which is relatively low compared to the alcohol soluble extractive value of 59.2%. Study on the chemical characteristics of wild amla of the Himalayan region reported that the fruit were acidic with pH of 2.93, TSS measuring 9.77 °Brix, titratable acidity measuring 3.07%, while reducing sugars and total sugars measuring 5.11and 7.27%, respectively (Sharma and Gupta, 2023).

Hazarika *et al*. (2009) in a study with different accessions of aonla reported that the total soluble solids, titrable acidity, ascorbic acid content and reducing sugars ranged from 12.0% to 19.0%, 2.29% to 4.61%, 400 mg/100 g to 850 mg/100 g and 3.76% to 10.98% respectively. In a study by Singh et al. (2006) found that the total sugar content of the fruits of Agra bold variety has the greatest percentage of total sugar at 7.70, followed by Banarasi and Francis.

Kumari *et al*. (2024) studied the biochemical characterization of eight genotypes and wild genotypes of aonla. The observations revealed that the fruits of variety NA-10 had the highest estimated vitamin C content (627.11 mg/100 g) and wild fruits had the lowest (372.57 mg/100g), the TSS ranged from 5.4 to15.330 Brix. The percent acidity ranged 0.66% to 5.87%, the total phenolic content ranged from 3.65 to 8.12 mg/g GAE and the total flavonoid content ranged from 3.25 to 6.38 mg/g QE. The wild fruits were found to have the highest tannin concentration, measuring 4.46 mg/g TAE.

Bulo *et al*. (2024) reported significant variations in the biochemical properties studied namely TSS (07 to 12.3 °Brix), acidity (0.70 to 3.20%), crude fiber (8.60 to 23.4%), pectin (3.05 to 8.75%), vitamin C (172 to 541 mg/ 100 g), total phenol (48.9 to 88.1 mg g^{-1}), and crude protein (2.06 to 8.03 mg 100 g^{-1}). Motalab *et al*. (2022) studied on the physico-chemical characteristics of indigenous fruits of Bangladesh and revealed that the amla fruits represent about 9.17% total soluble solids, 0.99% reducing sugar, 1.61% total sugar, 475.0 mg/100 g ascorbic acid, 0.19% protein, 0.75% ash content, 2.19% crude fiber and 19.43% carbohydrates.

2.4. Yield of *Phyllanthus emblica*

A study by Godara *et al*. (2004) reported the Chakaiya cv. produced the maximum fruit yield output of 258 kg $tree^{-1}$, followed by Kanchan with 217 kg $tree^{-1}$ when compared among seven different cultivars of aonla. Rao and Subramanyum (2009) reported in their study that the cultivar Kanchan produced the maximum yield of 76.1 kg $tree^{-1}$. Kumar *et al*. (2011) carried out an investigation on yield of eight cultivars of aonla from Karnataka and reported that cultivar BSR-1 produced the highest yield with 17.56 kg $plant^{-1}$ and NA-6 recorded the least with kg $plant^{-1}$. Similarly, Bhavani Sanker *et al*. (1999) also reported cultivar BSR-1 as a highly productive aonla variety suitable for various agro-climatic areas in Tamil Nadu.

Ghosh *et al*. (2013) investigated on the performance of aonla cultivars in the laterite soil of West Bengal, and reported that Neelum variety had the highest average yield of 56.0 kg $plant^{-1}$, followed by Kanchan with a yield of 27.7 kg $plant^{-1}$. The Anand-1 and BSR-1 varieties had the lowest yield, ranging from 0.2 to 1.0 kg $plant^{-1}$.

Aulakh *et al*. (2013) reported the fruit yield of six cultivars of aonla produced fruit yield that ranged from 0.22 kg tree^{-1} (Krishna cv.) to 85.33 kg tree^{-1} (Balwant cv.). In a study by Iqbal *et al*. (2015) reported the fruit yield aonla ranged from 63.76 kg plant^{-1} to 72.77 kg plant^{-1}. Bakshi *et al*. (2015) carried out a study on six cultivars of lower Shivalik foothills of Himalayas and reported that the cultivar Neelam outperformed all other cultivars in terms of yield qualities with 72.77 kg plant^{-1} and the lowest yield was reported in Desi with 44.13 kg plant^{-1}.

In a study by Malshe *et al*. (2016) significant variation in the fruit yield was observed among six cultivars in both the harvest. The fruit yield ranged from 2.16 kg/tree (Chakayya) and 12.09 kg tree^{-1} (Kanchan) at May harvest and 2.22 kg tree^{-1} (NA-6) and 6.14 kg tree^{-1} (Kanchan). Singh *et al*. (2021) in their study observed among the various genotypes examined produced fruit yield that vary from 27.0 to 97.2 kg tree^{-1}.

2.5. Mineral content of *Phyllanthus emblica*

Studies on *P. emblica* indicated that the Na, K, and Zn levels in the fruits are 4.2, 282, and 1.8 mg/100 g of fresh weight, respectively (Barthakur and Arnold, 1991). In a comparative study of heavy metals in *P. emblica* of Muzaffarnagar district reported the nutrient level was in the order Cu > Cr > Zn >Mn while there was no trace of Ni and Pb (Kumar and Vivah, 2013). Study on the nutritional composition of five varieties of aonla by Parveen and Khatkar (2015) conclude that the content of Fe ranged from 1.77 – 3.10 mg/100g, Zn ranged from 45.66- 65.56 ppm, K ranged from 43.67-63.90 mg/100g, Ca ranged from 17.84- 28.40 mg/100g and Na ranged from 53.71-71.51 ppm.

Kumari and Khatkar (2018) studied on the mineral profile of the fruit of 5 cultivars and reported that the content of Fe, Zn, Na, K and Ca ranged from 1.83 to 3.19 mg/100 g, 39.52 to 64.25 ppm, 50.49 to 69.46 ppm, 42.69 to 63.68 mg/100g and 18.61 to 29.54 mg/100 g respectively. The mineral composition of the fruit of aonla in a study by Nimse and More (2018), showed that the calcium level was 27.6 mg/100 g, phosphorus was 28.2 mg/100 g, iron was 16.6 mg/100 g, copper was 1.8 mg/100 g, zinc was 0.28 mg/100 g, and manganese was 1.1 mg/100 g.

Abeysuriya *et al*. (2020) reported the total Fe content of *P. emblica* measured was 0.7 mg/ 100 g (fresh weight) which was lesser comparing to *A. occidenlate*, *D. ovoideum*, *P. granatum* and *P. guajava*. Another study by Yang et al. (2021) reported that among the 20 mineral elements found in 18 different species of *Phyllanthus emblica*, potassium, magnesium, calcium, sulfur, and phosphorus were the most abundant, while nickel and chromium were the least abundant. Assessment on the nutrient profiling of amla from Bangladesh in a study by Motalab *et al*. (2022) revealed that the amla fruits contained 0.02, 0.87, 0.62, 0.09, 0.04 and 2.16 mg/ 100 g of Cu, Fe, Mn, Zn, Se and Co respectively. Furthermore, the macronutrient profile represents 1.21, 156.10, 26.40, 76.40 and 25.16 mg/ 100 g of Na, K, Ca, Mg and P respectively.

A study on nutrient contents in different parts of *P. emblica* (fruits, stems and leaves) claimed that the highest concentration of K, Na and Fe was higher in the fruits (13,510 mg kg^{-1}), stem branches (807 mg kg^{-1}) and leaves (1039 mg kg^{-1}) respectively (Orabi *et al*., 2023). Nutrient profiling of 30 genotypes of wild aonla of Arunachal Pradesh by Bulo *et al*. (2024) reported that the highest P content was reported by G_{29} (58.4v mg/100 g) while the lowest was observed in G_{17} (31.4 mg/100 g). The highest potassium content was observed in G_{19} (23.1 mg/100 g) and the lowest in G_{11} measuring 8.2 mg/ 100 g.

2.6. Selection of Superior Fruit Accessions

In the study conducted by Mirheidari *et al*. (2022) selected superior Indian jujube (*Ziziphus mauritiana* Lamk.) genotypes based on fruit-related parameters. A total of 119 genotypes were selected from Sistan-va-Baluchestan province in southern Iran. The average fruit weight was 24.17 g, ranging from 15.68 to 33.62 g. Genotypes varied in fruit skin ground color from pale green to orange. Certain factors, especially fruit size, correlated significantly. PCA divided the features into 12 main components, accounting for 75.07% of the variance. Two primary genotype groupings showed significant variety. The high fruit weight, flavor, skin color, and quality of twenty-one genotypes made them promising.

Genetic diversity assessment in 46 asparagus accessions was studied by Chen *et al.* (2020) through the utilization of morphological and inter-simple sequence repeat (ISSR) markers. Variation coefficients for 20 morphological traits ranged from 12.45 to 62.22%. It was observed that nine variables clarified 83.37% of the overall variation according to factor analysis. The 46 accessions were split into two clusters at a spacing of 135.7 Euclidean units. The Genetic coefficient of similarity (GSC) calculated from ISSR data ranged from 0.60 to 0.97, showing a considerable genetic pool. Furthermore, the 46 asparagus accessions could be grouped into three distinct clusters at a GSC of 0.74. The Mantel test indicated no significant association between the two marker systems. Morphological clustering was less distinct than ISSR data clustering, but specific groupings were identified between the two dendrograms. As a result, the genetic background of asparagus germplasm was revealed and hybrid parent determination was achieved, which will help optimize resource use and provide genetic improvement data.

Gangappa *et al*. (2022) investigated 33 morpho-biochemical parameters in 28 guava germplasm lines to determine genetic variability, variety, and structure. The evaluated traits in guava germplasm showed high genetic diversity. The coefficient of variation values ranged from 23.5 to 72.36% for qualitative traits and from 1.39 to 58.62% for quantitative features. Among the germplasm lines, Thai, Lucknow 49, Punjab Pink, *Psidium friedrichsthalianum*, and Shweta exhibited the highest fruit weight (359.32 g), ascorbic acid content (197.27 mg/100 g fruit), total phenolic content (186.93 mg GAE/100 g), titratable acidity (0.69%), and antioxidant capacity (44.49 µ mol Trolox/g), respectively. The coefficient of variation values ranged from 23.5 to 72.36% for qualitative traits and from 1.39 to 58.62% for quantitative features. Among the germplasm lines, Thai, Lucknow 49, Punjab Pink, *P. friedrichsthalianum*, and Shweta exhibited the highest fruit weight (359.32 g), ascorbic acid content (197.27 mg/100 g fruit), total phenolic content (186.93 mg GAE/100 g), titratable acidity (0.69%), and antioxidant capacity (44.49 µ mol Trolox g^{-1}), respectively.

Hssaini *et al*. (2020) screened 135 fig (*Ficus carica* L.) cultivars for morphoagronomic and biochemical suitability. The study evaluated free radical scavenging utilizing DPPH, ABTS, and β-Carotene bleaching tests. Canonical Correlation Analysis (CCA) revealed a significant relation between biological components and fig morpho-agronomy. Except for the ostiole drop, lenticel colour, and seed sizes, all variables differed significantly. The average fruit weight for all genotypes was 34.41 g, with a globose form. Principal component analysis identified fruit geometrical traits, colour, and peel as key characteristics. Total sugars (10.08-15.10 g/100 g dw), total anthocyanins (0.41-47.95 mg cy-3-rutinoside/100 g dw), and flavonoids (103.7-14.6 mg CE/100 g dw) also significantly influenced fig assessment. The Euclidean distance-based unweighted pair group cluster analysis identified five separate groups, with the local genotype 'Ounq Hmam PS14′ being categorized as an independent branch due to its characteristic profile. The findings confirmed the efficiency of morpho-agronomic and biochemical investigations in fig assessment and showed substantial phenotypic variety in the analyzed fig germplasm, suggesting strong genetic linkages.

Krishna *et al*. (2020) examined 10 mulberry genotypes from three species (*Morus alba*, *M. rubra,* and *M. laevigata*) for morphological, phytochemical, and antioxidant properties. CUPRAC, FRAP, and DPPH assays evaluated antioxidant capacity. Ascorbic acid ranged from 6.8 to 27.1 mg 100 g^{-1}, total polyphenols from 0.51 to 1.58 mg g^{-1}, flavonoids from 0.37 to 1.26 mg g^{-1}, and O-dihydric phenol from 0.14 to 0.33 mg g^{-1} fresh weight. The CUPRAC and FRAP experiments showed average antioxidant activity of 3.02-6.92 and 2.79-5.70 µM TE g^{-1}, respectively. The genotype Delhi Local has the highest DPPH free-radical scavenging activity, followed by Thar Lohit. The study found that the dark red-fruited mulberry 'Delhi Local' with increased antioxidant potential may be commercially viable.

Gharibi *et al*. (2023) examined the morphological and biochemical traits of 20 *Morus alba*, *M. rubra*, and *M. nigra* genotypes in Golestan Province, northern Iran. M12 had the longest leaf (15.51 cm), petiole (5.37 cm), vitamin C (4.34 mg/100 g), and phenol (31.89 mg g^{-1}) among the genotypes studied. M10 had the longest fruit (5.52 cm), pedicle (17 mm), soluble solids (18.26%), and sucrose (31.64 mg g^{-1}), whereas M17 had the highest glucose (288.82 mg g^{-1}) and fructose (121.97 mg/g).

The M20 genotype had the largest fruit fresh and dry weights (0.3-67.80 g), fruit diameter (1.99 cm), leaf width (11.94 cm), and flavonoid content (24.67 mg g^{-1}). Additionally, M1 and M2 genotypes showed stronger anthocyanin (1.13 μ mol g^{-1}) and antioxidant activity (66.71%) than other genotypes. Fruit length and diameter, pedicle length, leaf and petiole length, and fresh and dry weights correlated positively. The strongest favourable link was between anthocyanin, vitamin C, and phenol. The study found that morphological and biochemical variables explained 99% of variance in four and three primary components. Cluster analysis assigned genotypes to three main groupings. Fruit weight, petiole length, leaf width, antioxidant activity, fructose, and flavonoid concentration were most heritable and genetically advanced.

Singh *et al*. (2024) compared 80 bael genotype seedlings to two commercial cultivars (NB-5 and NB9) from important bael-growing districts in Jammu, Samba, and Kathua, India. Morpho-pomological and biochemical characteristics varied significantly among genotypes. Bael had morpho-pomological and biochemical diversity from 6.17 to 133.65%. Tree spread (N–S) was 1.00–6.30 m, and trunk girth was 29.50–63.40 cm. Fruit length ranged from 4.60 to 12.05 cm and width from 4.64 to 11.72 cm. Additionally, fruit weight ranged from 56.33 to 917.65 g and pulp percentage from 58.64 to 81.38%. Soluble solids ranged from 25.90 to 36.77 °Brix, while ascorbic acid was 14.38 to 25.45 mg/100 g. Fruit length was positively connected with fruit width, weight, pulp%, seed length, diameter, and number of seeds per fruit, and negatively correlated with fruit surface and total number of fruits $plant^{-1}$. The principal component analysis showed that 13 components explained 76.66% of the variability. Euclidean distance-based Ward cluster analysis divided genotypes into two groups.

Ravi *et al*. (2021) examined 120 South Indian drumstick tree genotypes for good yield per tree. They found significant heterogeneity in shape, yield, and quality parameters, emphasizing the need for additional study. Coefficients of variation (CV), genotypic coefficient of variation (GCV), environmental coefficient of variation (ECV), phenotypic coefficient of variation (PCV), and heritability were analyzed for diversity. Fruit length (30.56–127.57 cm), weight (72.22–163.27 g), breadth (3–8 cm), number of fruits tree^{-1} (320–1000), and seeds fruit^{-1} (11–29) varied across genotypes. Positive correlations were found between fruit yield, number of fruits tree^{-1}, fruit length, and single fruit weight. PCV estimates were slightly higher than GCV estimates for all traits, demonstrating genetics and environment impact variation. All attributes were above 90% heritable.

Ud Din *et al*. (2020) examined the genetic diversity of Pakistani jamun accessions. The pulp percentage of the samples ranged from 49 to 92%. The accession TUK-03 had the highest pulp percentage, whereas SKUK-02 had the lowest. The total fruit weight (pulp + seed) varied from 2.67 g (SKD-01) to 12.63 g (SFM-08). Biochemical analysis indicated heterogeneity in total soluble solids (TSS) ranging from 10.8 to 20.3% and titratable acidity (TA) from 0.64 to 1.69% across distinct accessions. The accession SFG-07 demonstrated the highest phenolic content (318.6 mg GAE/100 g), whilst MWD-01 showed the lowest (23.00 mg GAE/100 g). A principal component analysis (PCA) biplot demonstrated the most phenotypic variability in SFM-08, SFS-02, TUK-03, and KDC-04. Furthermore, a dendrogram obtained from agglomerative hierarchical clustering (AHC) classified the accessions into three separate clusters.

Seventeen tree tomato (*Solanum betaceum* Cav.) genotypes from the north eastern Himalayas of India were tested for morpho-biochemical diversity using a Randomized Block Design with three replications. Genotypes were divided into five groups, with cluster I having the most (6). The maximum inter-cluster distance (372237) occurred between clusters II and V, while cluster III had the most intra-cluster diversity (28651.72). STT-110 had the highest average fruit weight (81 g) and other fruit yield attributes. Conversely, STT-40 had the most iron (1.86 mg/100 g), copper (0.47 mg/100 g), and manganese (1.38 mg/100 g). Anthocyanin (77.26%, 77.19%, 99%, and 158.85%), flavonoid (56.91%, 56.90%, 100%, and 117.22%), total phenol (52.76%, 52.72%, 99%, and 108.54%), manganese (50.87%, 49.26%, 93%, and 98.28%), and ascorbic acid (41.73%, 41.71%, 99%, and 85.89%) had high PCV, GCV, heritability, and genetic advance. Polar and equatorial fruit diameters were also significantly associated with average fruit weight, according to correlation coefficient analysis. A substantial intrinsic relationship between the assessed variables was shown by greater genotypic correlation coefficients than phenotypic ones (Prasad *et al*., 2024).

Ahmed *et al*. (2021) examined the morphological diversity of fruit traits in mulberry genotypes from the Mulberry Germplasm Bank of Bangladesh Sericulture Research and Training Institute. The research includes the characterisation of 50 mulberry genotypes based on their fruit properties. Taste, seed colour, and fruit colour were assessed. The research discovered nine distinct fruit hues, including reddish-black, black-berry, cream, black, white-cream, pink, pinkish, orange, and radish. Fruit taste varied from sour sweet to sweet, light sweet, light-sour sweet, and deep sweet. Seeds were light yellow to blackish brown. Fruit length ranged from 0.73 to 5.58, width from 0.52 to 1.9, and weight from 0.07 to 4.11 across genotypes. The study identified promising genotypes such BSRM-56 (black-berry, sweet taste), BSRM-1 (cream colour, sweet taste), and BSRM-34 (white cream, sweet taste) for their high fruit production capability, suggesting potential for commercial utilization.

In Iran's Taleghan region, Kuhkheil *et al*. (2020) studied wild sea buckthorn populations' phytochemical and morpho-physiological traits over two years. The study found significant differences ($P \leq 0.01$ or $P \leq 0.05$) in primary morpho-physiological features and phytochemical qualities of leaves and fruits across two years. Total phenol, carotenoid, flavonoid, and vitamin C levels differed widely in fruit. Factor analysis applying PCA indicated that the first three principal components accounted for roughly 70% and 76% of the total variance in phytochemical and morpho-physiological variables, respectively. Fruit glucose, TSS, vitamin C, and leaf lycopene dominated PC1 phytochemical characteristics.

Mondal *et al*. (2023) evaluated West Bengal's natural population for better rose apple germplasm. They evaluated rose apple plants in different places depending on their taste and subsequently selected top 10 genotypes' physical and biochemical fruit attributes. Elite varieties were examined for average weight, length, diameter, pulp weight, thickness, and edible portion percentage. In addition, total soluble solids (TSS), titratable acidity, total sugar, reducing sugar, and ascorbic acid were measured. On evaluation, type-9 fruits had larger size, higher pulp weight and thickness, and a higher percentage of edible portion, while type-5 had desirable fruit quality attributes like elevated TSS levels, TSS acidity ratio, ascorbic acid content, total sugar content, and lower acidity. The study found Baruipur type-5 and type-9 types best.

Jaisankar *et al*. (2016) used morpho-biochemical and DNA marker technologies to characterize Jamun from the Andaman and Nicobar Islands, India using 10 ISSR and 15 RAPD DNA fingerprinting primers. Among these 5 ISSR and 7 RAPD primers produced 38 and 52 amplicons, respectively. Polymorphism was detected in 24 ISSR and 31 RAPD amplicons, representing 63.15% and 59.61%, respectively. The maximum polymorphism was found in ISSR primer IS12 (78%) and RAPD primer OPF1 (75%). ISSR analysis gave more accurate polymorphism data than RAPD primers. The average polymorphism of 22 Jamun accessions using 12 primers was 61.11%. This extensive Jamun accessions characterization aids conservation and fruit quality and yield knowledge.

Mawalagedera *et al*. (2014) examined a total of 475 *Phyllanthus emblica* drupes collected from 66 trees in different districts of Sri Lanka (Anuradhapura, Kandy, and Kurunegala) to assess their morphological characteristics. They measured seven morphometric parameters for each drupe, including height, width, and weight of the drupes, mesocarp thickness, as well as the width, height, and weight of the stones. Additionally, they analyzed the epicarp color of 61 drupes quantitatively. To study bitterness as an organoleptic property relative to drupe size, they employed a taste panel of independent human subjects. The study observed a weaker correlation between stone traits and other drupe characteristics, suggesting potential separate genetic regulation for drupe and stone traits. Cluster analysis based on drupe size traits categorized the *Phyllanthus emblica* germplasm into four distinct clusters. Moreover, they found that while the number of cells in the mesocarp was similar between smaller and larger fruits, the cell size was larger in larger fruits ($p<0.05$). Additionally, significant differences in quantitative color metrics were observed between small and large drupe groups.

Chapter 3

MATERIALS AND METHODS

The present investigation was carried out to study the morphological characters, physical and chemical parameters of *Phyllanthus emblica* L. accessions from selected regions of North East India during 2018 - 2022. The materials and methods followed during the research are described below:

3.1 Geographical Location of Experimental Site

The research was conducted in the states(Table 3.1 and Fig. 3.1). The study sites ranged from 42 to 1447 m. amsl in elevation and latitude from 22°30’15’’ to 25°54’59.56’’ N, longitude 90°1’25.14’’ t of Mizoram, Meghalaya and Tripura of the north eastern region of India o 93°21’54.38”. The geographical details of the selected accessions have been given in Table 3.1. The coordinate’s locations of each accession from the three states are shown in the map (Figure 3.1)

3.1.1 Meghalaya

Located in the north-eastern region of India, Meghalaya spans an area of 22,429 km^2, making up about 0.68% of the country's total land area. The state lies between latitudes 25°02’ and 26°07’ N and longitudes 89°49’and 92°50’E. It is bordered by Assam to the north and east, and shares its southern and western boundaries with Bangladesh. Meghalaya is divided into three distinct regions: Garo Hills, Khasi Hills, and Jaintia Hills. Known for its high rainfall, the state experiences an average annual rainfall ranging from 4,000 mm to 11,500 mm. Mawsynram, the wettest place on Earth, is situated here. The western part of Meghalaya is warmer, with temperatures averaging between 12 °C and 33 °C, while the central highlands are cooler, with temperatures ranging from 2 °C to 24 °C (Forest Survey of India, 2021; Ministry of Environment, Forest and Climate Change, 2017).

Meghalaya is rich in forests, and as a predominantly tribal state, the livelihood of its rural population is deeply intertwined with the forests, both economically and culturally. Shifting cultivation is still practiced in the region.

According to India State of Forest Report 2021 (ISFR, 2021) Meghalaya's forest cover is 17,046 km^2, representing 76% of the state's area. Compared to the previous assessment in 2019 the forest cover has decreased by 73 km^2.

3.1.2 Mizoram

Located in the north-eastern region of India, Mizoram spans an area of 21,081 km^2, accounting for 0.64% of the country's total geographical area. Positioned between latitudes 21°58' N to 24°35' N and longitudes 92°15' E to 93°29' E, Mizoram is bordered by Tripura to the west, Assam and Manipur to the north, and shares international borders with Myanmar to the east and Bangladesh to the south and west. The state's landscape is characterized by rugged hills and interspersed valleys. Mizoram experiences a climate that ranges from moist tropical to moist sub-tropical, with annual rainfall varying between 2,100 mm and 3,500 mm. Temperatures during winter range from 11 °C to 24 °C, while summer temperatures range from 18 °C to 29 °C. The monsoon season, from May to September, brings heavy rainfall (Directorate of Economics and Statistics, Mizoram, 2018; Forest Survey of India, 2021).

The state is rich in biodiversity, with a wide variety of flora and fauna, including many rare and endemic species. Mizoram boasts the highest percentage of forest cover in the country relative to its geographical area. According to the Champion & Seth Classification of Forest Types (1968), Mizoram's forests are categorized into four main type groups, further divided into six forest types.

According to the ISFR (2021), Mizoram's forest cover is 84.53%, which is approximately 17,820 km^2 of the state's total geographical area. This marks a reduction of about 186 km^2 compared to the ISFR 2019 report.

3.1.3 Tripura

Tripura, a state in the north-eastern region of India, spans an area of 10,491 km^2, which accounts for just 0.32% of the country's total geographical area. Positioned between 22°7' N to 24°2' N latitude and 91°0' E to 92°0' E longitude, Tripura is bordered by Bangladesh to the north, south, and west, and shares its eastern boundaries with Assam and Mizoram. The state experiences a humid climate, with annual rainfall ranging between 1922 mm and 2855 mm, and temperatures varying from 7 °C to 36 °C. Humidity levels remain consistently high year-round. During the summer, relative humidity ranges from 50% to 74%, while in the rainy season, it exceeds 85% (Forest Survey of India, 2021; Government of Tripura, 2024).

The forests of the state are categorized into two primary groups, which are further subdivided into five distinct types, mainly comprising tropical evergreen, semi-evergreen, and moist deciduous forests. A large part of these forests is densely populated with bamboo brakes, a vital economic asset for the region. The state's forested area spans 7,725.6 km², covering 73.69% of its total land. Since 2019, the state has lost 4 km² of forest area, according to the ISFR.

3.2 Experimental Details

An extensive survey was conducted during the year 2019 – 2020 in the states of Mizoram, Meghalaya and Tripura, NER, India. Promising wild aonla trees for selections were identified from the forest areas and adjoining villages of these regions. Efforts were made to identity only regular and prolific bearing trees with good fruit size, excellent fruit quality and tolerance to biotic (pest and diseases) and abiotic (frost and drought) stresses. A total 60 accessions (20 per state) having desirable fruit characters with good bearing performance were marked *in-situ*. The method of random sampling from a population and biased sampling after gathering information about a particular accession was followed (Sinha, 1981). While selecting the accessions a minimum of 100 m distance between the two accessions was taken into consideration while selecting them. However, in cases where there was noticeable variation in morphological traits in two accessions, the distance criterion was compromised to some extent to ensure a diverse sample. The accessions selected for studies were marked and tagged with a number on the tree as well as the coordinates of the locations were recorded. The accession number consisted of letter "MZR" for Mizoram, "MGL" for Meghalaya and "TRP" for Tripura.

The primary survey was done in the month of July and August of 2019 and the fruits were collected in three phases, early harvest in October and November, mid harvest in December 2019 and January 2020, and late harvest till March of 2020. The morphological characters of the aonla trees and leaves were studied during the survey, while the fruits were harvested from their respective locations before 2020, but the fruits harvested during the lockdown (corona) were collected by the locals from the selected aonla tree and parcel to the department of forestry MZU. The fruits collected were studied and analyse in 2020 and 2021.

Leaves that were fully mature and not showing signs of active growth, positioned in the middle of tertiary branches, were selected for observation. The fruits were harvested at an optimum maturity stage. The fruits' ripeness was determined by their visual attributes, including their colour, size, and firmness. Completely ripe fruits exhibited a lighter and more lustrous colour compared to their unripe counterparts. The fruits were collected randomly from the bottom branch to the top branches. The fruit samples were collected in a cotton bag. The healthy fruits from each accession were collected and transported immediately to the laboratory of the Forestry Department, Mizoram University, Aizawl, and kept in a deep freezer (-80 °C) for further physico-chemical characterisation.

Table 3.1 Details of the accession locations/regions

Accession	Region	District	State	Latitude	Longitude	Elevation (m)	Mean Temp (°C)	Rainfall (cm)
MGL1	Garobhada	West Garo Hills	Meghalaya	N25°35'10.06''	E90°1'25.14''	71	20.46	1019.939
MGL2	Cherangre	East Garo Hills	Meghalaya	N25°29'37.25''	E 90°35'21.54''	294	18.72	895.625
MGL3	Garobhada	West Garo Hills	Meghalaya	N25°35'56.52''	E90°2'19.70''	80	20.46	1019.939
MGL4	Moolasngi	East Jaintia Hills	Meghalaya	N25°21'51.22''	E092°32'09.17''	978	16.26	387.1736
MGL5	Moolasngi	East Jaintia Hills	Meghalaya	N25°21'55.48''	E092°32'05.55''	988	16.26	387.1736
MGL6	Kyrwen	West Jaintia Hills	Meghalaya	N25°32'38.03''	E092°27'45.85''	1094	16.36	267.3964
MGL7	Kyrwen	West Jaintia Hills	Meghalaya	N25°32'40.96''	E092°27'45.57''	1078	16.36	267.3964
MGL8	Nongpoh	Nongpoh	Meghalaya	N25°54'59.56''	E091°52'17.68''	669	16.81	329.5789
MGL9	Nongpoh	Nongpoh	Meghalaya	N25°54'58.73''	E091°54'49.21''	710	16.81	210.1888
MGL10	Shangkalong	South West Khasi Hills	Meghalaya	N25°15'06.32''	E091°15'45.51''	564	16.90	2317.117
MGL11	Shangkalong	South West Khasi Hills	Meghalaya	N25°15'21.99''	E091°15'38.89''	560	16.90	2317.117
MGL12	Riangdo	West Khasi Hills	Meghalaya	N25°40'15.47''	E091°03'45.15''	988	16.25	735.0939
MGL13	Riangdo	West Khasi Hills	Meghalaya	N25°40'14.90''	E091°03'30.46''	988	16.25	735.0939
MGL14	Tura	West Garo Hills	Meghalaya	N25°31'51.43''	E90°14'17.68''	546	19.52	976.7492
MGL15	Tura	West Garo Hills	Meghalaya	N25°31'53.29''	E90°14'19.36''	542	19.52	976.7492
MGL16	Umroi	Nongpoh	Meghalaya	N25°39'16.68''	E091°57'32.98''	1087	15.35	329.7025
MGL17	Umroi	Nongpoh	Meghalaya	N25°38'45.89''	E091°56'30.72''	1068	14.75	329.7025
MGL18	Dbetkolgre	East Garo Hills	Meghalaya	N25°30'29.59''	E90°37'31.25''	269	18.72	895.625

Table 3.1 Contd.

MGL19	Williamnagar	East Garo Hills	Meghalaya	N25°30’29.64	E90°37’31.25’’	269	18.72	895.625
MGL20	Dbetkolgre	East Garo Hills	Meghalaya	N25°30’30.57’’	E90°37’31.63’’	270	18.72	895.625

Accession	Region	District	State	Latitude	Longitude	Elevation(m)	Mean Temp (°C)	Rainfall (cm)
MZR1	Malkawn	Champhai	Mizoram	N 23°23’26.63”	E93°21’53.90”	1438	14.19	281.6561
MZR2	Champhai	Champhai	Mizoram	N 23°23’19.21”	E93°21’06.45”	1427	14.19	281.6561
MZR3	Sialhawk	Chanphai	Mizoram	N 23°17’00.76”	E 93°05’39.45”	1353	14.97	300.5037
MZR4	Kolasib	Kolasib	Mizoram	N24°13’28.40”	E092°40’48.22”	619	18.77	435.1162
MZR5	Kolasib	Kolasib	Mizoram	N 24°13’14.74’’	E 092°41’40.38’’	421	18.77	435.1162
MZR6	Lengte	Aizawl	Mizoram	N23°47’40.1’’	E092°36’12.4’’	309	17.66	317.6531
MZR7	Lunglei	Lunglei	Mizoram	N 22°50’53.2’’	E 092°47’45.5’’	1168	16.98	417.1614
MZR8	Lunglei	Lunglei	Mizoram	N 22°49’50.8’’	E 092°48’12.0’’	1046	16.98	417.1614
MZR9	Lawngtlai	Lawngtlai	Mizoram	N 22°30’15’’	E92°53’43’’	712	16.80	420.3482
MZR10	Mamit	Mamit	Mizoram	N23°56’32.3’’	E092°29’19.3’’	1052	18.62	392.8105
MZR11	Mamit	Mamit	Mizoram	N23°56’42.31’’	E92°29’13.38’’	730	18.62	392.8105
MZR12	MZU Campus	Aizawl	Mizoram	N23°44’14.88’’	E092°39’42.91’’	779	17.08	318.9324
MZR13	Sairang	Aizawl	Mizoram	N23°48’26.19’’	E92°39’24.27’’	189	17.42	318.9324
MZR14	Serchip	Aizawl	Mizoram	N 23°18’45.7’’	E092°49’36.9’’	1145	16.31	295.9028
MZR15	Serchip	Aizawl	Mizoram	N 23°18’39.5’’	E 092°49’34.2’’	1139	16.31	295.9028
MZR16	Mualching	Serchip	Mizoram	N 23°11’39”	E 93°04’45”	1133	14.46	300.5037
MZR17	Mualching	Serchip	Mizoram	N23°10’21.50”	E093°03’42.68”	1035	14.46	300.5037
MZR18	Tisopi	Siaha	Mizoram	N 22°33’24.0’’	E 092°59’30.1’’	958	15.77	420.3482
MZR19	Tisopi	Siaha	Mizoram	N 22°33’19.60’’	E 092°59’40.73’’	1051	15.77	420.3482

Table 3.1 Contd.

Accession	Region	District	State	Latitude	Longitude	Elevation(m)	Mean Temp (°C)	Rainfall (cm)
MZR20	Tisopi	Siaha	Mizoram	N 22°33’17.52’’	E 092°59’42.96’’	1066	15.77	420.3482
TRP1	Chichingcherra	Dhalai	Tripura	N23°58’49.43”	E092°03’12.51”	109	20.11	433.5899
TRP2	Champaknagar	West Tripura	Tripura	N23°48’26.69’’	E091°30’51.44”	80	20.60	462.1127
TRP3	Champaknagar	West Tripura	Tripura	N23°48’28.47”	E091°30’59.01”	83	20.60	462.1127
TRP4	Champaknagar	West Tripura	Tripura	N23°48’19.83”	E091°31’10.16”	92	20.60	462.1127
TRP5	Jarulcherra	Dhalai	Tripura	N23°58’41.72”	E092°02’11.78”	98	20.23	433.5899
TRP6	Jarulcherra	Dhalai	Tripura	N23°58’30.65”	E092°02’27.75”	100	20.23	433.5899
TRP9	Kanchanpur	North Tripura	Tripura	N24°02’23.56’’	E092°11’59.68’’	64	19.62	395.8738
TRP10	Kanchanpur	North Tripura	Tripura	N24°01’52.73’’	E092°11’50.28’’	62	19.62	395.8738
TRP11	Kanchanpur	North Tripura	Tripura	N24°03’24.97’’	E092°12’03.52’’	57	19.84	395.8738
TRP12	Lalcherra	Dhalai	Tripura	N23°56’21.59”	E092°01’28.73”	96	20.14	433.5899
TRP13	Lalcherra	Dhalai	Tripura	N23°56’26.59”	E092°01’13.84”	81	20.14	433.5899
TRP14	Longtarai	Dhalai	Tripura	N23°59’3.59’’	E91°56’50.72’’	99	20.23	433.5899
TRP15	Pecharthal	North Tripura	Tripura	N24°10’32.43’’	E092°05’59.07’’	48	20.20	476.5576
TRP16	Sonaimuri	North Tripura	Tripura	N24°11’30.32”	E092°02’32.57”	56	20.12	476.5576
TRP17	Sonaimuri	North Tripura	Tripura	N24°11’35.18’’	E092°02’08.05’’	56	20.12	476.5576
TRP18	Sepahijala	Sepahijala	Tripura	N23°39’36.80”	E091°17’21.63”	42	20.66	379.586
TRP19	Tepania	Gomati	Tripura	N23°33’31.92”	E091°26.56.93”	54	20.96	413.4992
TRP20	Tepania	Gomati	Tripura	N23°33’32.27”	E091°26’56.26”	50	20.96	413.4992

* Mean Temp (°C) – average from two years (2019 and 2020); Rainfall (cm) – Sum of rainfall from two years (2019 and 2020).

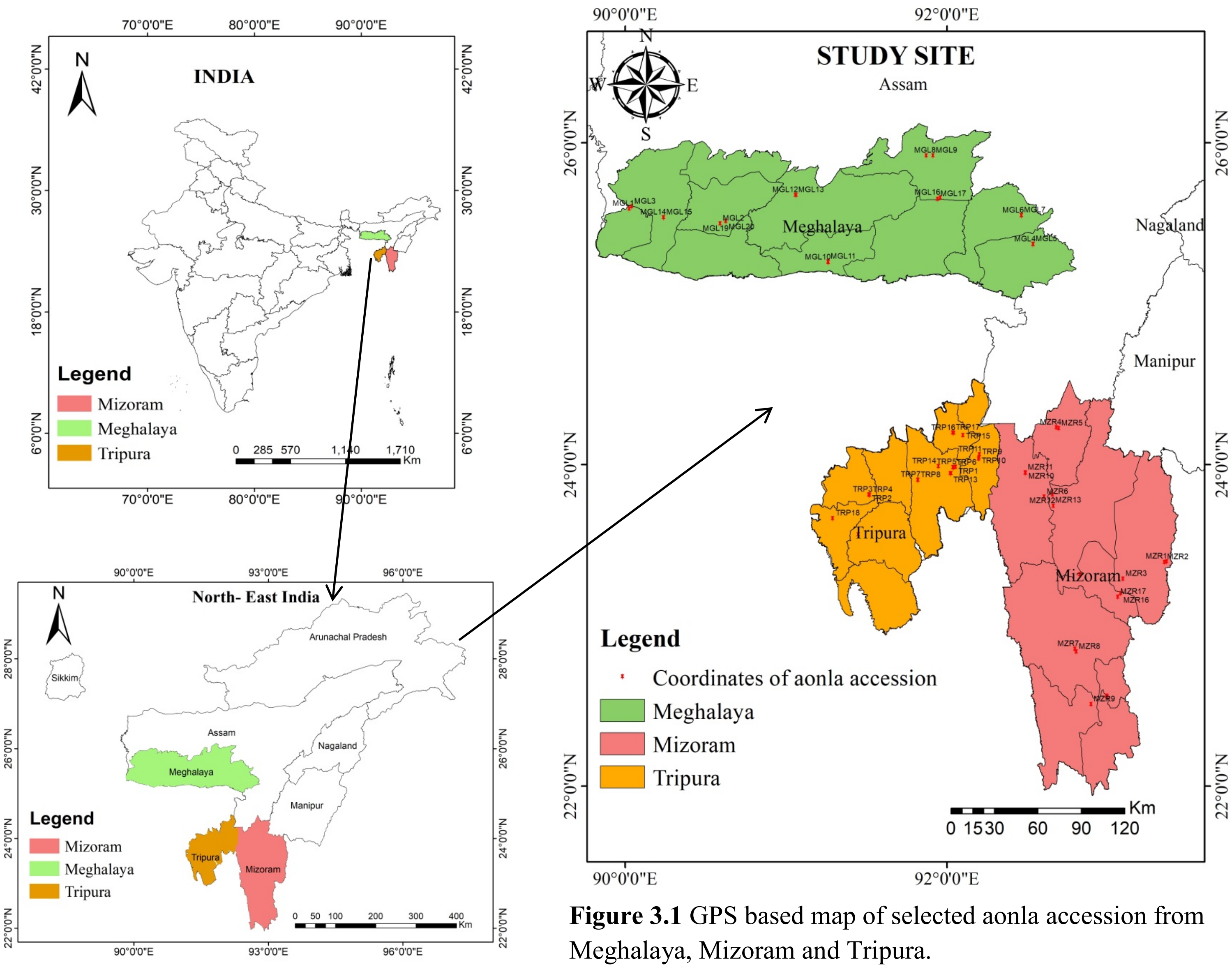


Figure 3.1 GPS based map of selected aonla accession from Meghalaya, Mizoram and Tripura.

3.3 Meteorological Data

This study used temperature and rainfall data from the ERA5-Land dataset, which is accessible through the Copernicus Climate Change Service (C3S) platform (https://cds.climate.copernicus.eu/datasets/reanalysis-era5-land?tab=overview). ERA5-Land, a high-resolution global reanalysis dataset developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), provides robust data to support various land-monitoring applications by tracking detailed shifts in water and energy cycles across land regions.

The ERA5-Land dataset is characterized by a high spatial resolution (9 km) and hourly temporal granularity, offering enhanced accuracy in hydrological and energy cycle descriptions compared to earlier datasets. This level of precision is especially useful for estimating parameters like river discharge, making the data highly suitable for studies on climate variability and its impacts on regional agriculture.

Data collection focused on specific geographic locations associated with aonla accessions in Meghalaya, Mizoram, and Tripura. The timeframe for data gathering spanned from 2019 to 2020 (Table 3.1), capturing a comprehensive climate profile of these areas for the study period. The advanced spatial and temporal resolution of the ERA5-Land data enabled precise analysis of temperature and rainfall trends, which are critical factors for assessing climate resilience in aonla accessions.

In this study, ERA5-Land provided a reliable data foundation to examine mean temperature and rainfall fluctuations in selected regions, facilitating an analysis of climate impacts on the adaptability of different aonla accessions across North-east India.

3.4 Observations of Morphological Characters of Aonla Tree and Fruit

3.4.1 Tree Characters

3.4.1.1 Tree Height (m)

The height of the trees was measured by Ravi multimeter. The tree was measured from the distance of 20 m, where the tip and bottom of the tree was measured. Both numbers were added or subtracted depending upon the place of observation to get the total height of the tree.

3.4.1.2 Trunk Girth (m)

The girth of the aonla trunk was measured at breast height in cm.

3.4.1.3 Tree Shape

The shape of the tree was recorded in its natural state by visual observations by following PPV & FRA (2014). The shape was observed as erect, spreading, semi spreading or drooping.

3.4.1.4 Foliage

The foliage of the aonla accessions was observed visually and categorized as sparse or dense from its natural state by following PPV & FRA (2014).

3.4.1.5 Leaflet shape

The leaflet shape was recorded by visually observing from 20 fully matured random leaflets and they are categorized as elliptical, oblong, oval-oblong or oval by following PPV & FRA (2014).

3.4.1.6 Leaflet Size

20 fully matured leaflets were taken and the leaflet size was measured with the help of measuring scale by following PPV & FRA (2014).

3.4.1.7 Leaflet Apex

20 fully matured leaflets were observed visually and categorized as obtuse or acute by following PPV & FRA (2014).

3.4.1.8 Leaflet Surface

20 fully matured leaflets observed visually and categorized as glabrous, moderately glabrous and non- glabrous by following PPV & FRA (2014).

3.4.1.9 Fruit Yield/Tree

Fruit yield per tree at the time of maturity was calculated and expressed in kg/tree as per branch magnitude method (Kumar *et al.,* 1985)

3.4.2. Fruits Characters

3.4.2.1 Fruit shape

20 matured fruits per tree were taken and they were observed visually as oval, round, flattened round/oblong or triangular (slightly conical at apex) by following PPV & FRA (2014).

3.4.2.2 Fruit surface

Fruit surface was observed visually and categorised as smooth or rough from 20 matured fruits per tree by following PPV & FRA (2014).

3.4.2.3 Fruit Colour

Immediately after harvest, the outer skin colour of the fruit was observed with the help of the RHS colour chart from 20 matured fruits per tree by following PPV & FRA (2014).

3.3.2.4 Fruit Stalk

The fruit stalk was observed visually and categorised as thick or thin from 20 mature fruits per tree by following PPV & FRA (2014).

3.4.2.5 Stone Shape

20 stones per tree were extracted from matured aonla fruits then they are observed visually and categorised as triangular, round, oval round or oval by following PPV & FRA (2014).

3.4.2.6 Harvest Maturity

Depending upon the time of maturity of the fruits the plants was categorised as early, mid or late bearer. The fruits collected before the month of September were categorised as early, between November and December as mid and beyond January were categorized as late bearers.

3.4.3 Physical Parameters of Aonla Fruit

3.4.3.1 Fruit Length

Twenty mature fruits per tree were measured for each replication (total three replications, 20 x 3 = 60 fruits per tree), from the stalk end to the apex, using a Vernier calliper. The measurements were recorded in centimetres.

3.4.3.2 Fruit Diameter

Twenty mature fruits per tree were measured for each replication (total three replications, 20 x 3 = 60 fruits per tree) with the help of Vernier Calliper at maximum thickness. The measurements were recorded in centimetres.

3.4.3.3 L-D ratio

L-D ratio was worked out by dividing length of the fruit by its diameter.

3.4.3.4 Fruit Weight

Twenty mature fruits per tree were randomly measured for each replication (total three replications, 20*3 = 60 fruits per tree) and average weight was recorded in electronic Metler Toledo (ME204) weighing machine.

3.4.3.5 Pulp Percentage

Randomly selected twenty matured fruits per tree were measured for each replication (total three replications, 20*3 = 60 fruits per tree) and pulp was separated from the stone. The pulp of each fruit was weight separately and pulp per cent was worked out

3.4.3.6 Pulp: Stone Ratio

Pulp to stone ratio was worked out by dividing the weight of fresh pulp to weight of stone.

3.4.3.7 Dry Matter Content of the Pulp

10 g of fruit pulp from twenty matured fruit per tree for each replications (total three replications, 20 x 3 = 60 fruits per tree) was dried in oven at 70 °C until a constant weight achieved and observations was expressed in percentage.

3.4.3.8 Moisture Content

Moisture content was determined by drying a weighed sample in a hot air oven until it reaches a stable weight, and the weight loss is used to calculate the percentage of moisture. First, a Petri dish is dried at 100 °C for one hour, and then covered, cooled, and weighed (W_0). Next, 20 g of the sample is evenly spread onto the Petri dish, and the total weight was measured (W_1). The cover was removed, and the sample (W_2) was dried in a hot air oven at atmospheric pressure, maintaining a temperature of 70 °C. Drying continues until a constant weight was obtained. Once dried, the lid was replaced, the dish was cooled in a desiccator, and the weight of the dish with the dried sample is recorded. The moisture content % was calculated by the formula given below:

$$\text{Moisture (Fresh weight basis) \%} = \frac{W_2 - W_0}{W_1 - W_0} \times 100$$

3.5 Bio - Chemical Parameters of Aonla Fruits

3.5.1 Total Soluble Solid (TSS)

TSS was measured with hand refractometer and values were corrected to 20 °C. The measurement was taken in (°Brix). A drop of the solution was carefully placed on the prism of the refractometer. The percentage of TSS was then determined through a direct reading from the instrument.

3.5.2 Titratable Acidity

The titratable acidity was determined following the method outlined by AOAC (2000). A 10 g portion of the sample was crushed and thoroughly homogenized using a mortar and pestle, with the addition of a small amount of distilled water. The mixture was then transferred into a 100 ml volumetric flask, and the volume was brought up to the mark with more distilled water. After filtration, a 10 ml aliquot of the solution was titrated with 0.1 N NaOH, using a 1% phenolphthalein solution as an indicator, until a pink colour appeared, indicating the endpoint. The titratable acidity was calculated as a percentage, expressed as anhydrous citric acid, using the formula given below.

$$\text{Titratable acidity (\%)} = \frac{0.1 \times titrate\ value \times Volume\ make\ up \times 0.064}{Aliquot\ taken \times wt.of\ sample.} \times 100$$

3.5.3 TSS: Acidity

TSS: acidity was worked out by dividing the TSS value with titratable acidity.

3.5.4 Ascorbic Acid

The ascorbic acid content of aonla was measured using a titration technique based on the method described by Ranganna (2004). This involved using a 2, 6-dichlorophenol indophenol dye solution. In this process, ascorbic acid in sodium bicarbonate solution reduces the dye to a colourless form.

Initially, the dye solution was standardized against pure ascorbic acid to establish the dye factor. The aonla sample was diluted with 3% meta-phosphoric acid, and this acid extract was titrated with the dye solution until a persistent pink colour appeared for 15 seconds. The dye factor was calculated using the formula:

Dye factor = 0.5 / Volume of titrant

The concentration of ascorbic acid (in mg/100 g) was then determined using the following equation:

$$\text{Ascorbic acid (mg/100g)} = \frac{Dye\ factor\ value \times Titrate\ value \times Volume\ made\ up}{aliquot\ of\ sample\ used \times weight\ of\ sample} \times 100$$

3.5.5 Total Sugar

The total sugar content was determined using the Lane and Eynon titration method. A 5 g sample was crushed and mixed with 10 mL of distilled water, followed by the addition of 2-3 drops of concentrated HCl. The mixture was heated until it turned brown, and then cooled. Afterward, NaOH pellets were added until red litmus paper turned blue, indicating neutralization. The volume was adjusted to 50 mL with distilled water. In a separate conical flask, 2 ml of Fehling's Solution A and B were mixed with 10 ml of distilled water. The prepared sample extract was placed in a burette, and the Fehling's solution was heated to boiling. The extract was added drop wise, along with 2-3 drops of methylene blue indicator, until the endpoint was reached, indicated by a colour change to red. The total sugar was calculated by the equation given below

Total sugar (%) = 20/Reading(ml)

3.5.6 Reducing Sugar

The total sugar content was determined using the Lane and Eynon titration method. To determine total sugar, 5 g of the sample was crushed and mixed with distilled water, and the volume was made up to 50 ml. In a conical flask, 2 ml each of Fehling's Solution A and B were added, along with a small amount of water. The prepared extract was then placed in a burette for titration. The conical flask was heated, and once boiling began, 2-3 drops of the extract were added, followed by 2-3 drops of methylene blue indicator. The titration continued with the extract being added until the endpoint was reached, indicated by the formation of a brick-red precipitate.

Reducing Sugar (%) = 20/Reading(ml)

3.5.7 Non-Reducing Sugar

Non reducing sugar was worked out by subtracting reducing sugar from total sugar. The equations are given below.

Non reducing sugar = Total sugar – reducing sugar.

3.5.8 Phenol

The total phenol content of the fruit extracts was measured using the Folin–Ciocalteu method. A 0.5 g sample was combined with 5 mL of 80% methanol and centrifuged at 10,000 rpm for 10 minutes. The clear supernatant was evaporated to dryness on a hot plate, and the residue was dissolved in 5 mL of water and diluted 20-fold. From this solution, 0.2 mL was pipetted into a test tube and diluted to 3 mL with water. After adding 0.5 mL of Folin-Ciocalteu reagent and allowing it to react for 3 minutes, 2 mL of 20% sodium carbonate was added and thoroughly mixed. The test tubes were then heated in boiling water for 1 minute, cooled to room temperature, and the absorbance was measured at 650 nm. Total phenol content was determined using a standard curve with gallic acid and expressed as gallic acid equivalents in mg per 100 g of fruit extract.

3.5.9 Protein

The protein content of the samples was analyzed using Lowry's (1951) method. To prepare Fohlin-Ciocalteu's phenol reagent, a buffer solution of 0.82 g sodium dihydrogen phosphate dehydrates and 0.792 g sodium hydrogen phosphate dehydrates was added. 100 mL distilled water) and solution A (2g sodium carbonate anhydrous in 100 ml 0f 0.1 N NaOH solution B (0.5% copper sulphate in 100ml of 1% potassium sodium tartrate solution and solution C (1 ml solution B in 50 ml solution A) were utilized. The reading was taken in a UV Spectrophotometer at 660 nm against a blank. Value was measured in the percentage and calculated using the standard protein curve.

$$\text{Protein content \%} = \frac{\text{Y (Concentration)x volume x 100}}{\text{Wt.of sample x 1000 x aliquot taken}}$$

3.6 Minerals (P, K, Ca, Mg, Fe)

The mineral estimation was conducted by dry ash method and Atomic absorption spectroscopy (AAS) is employed to determine mineral concentrations in aonla samples. The method involves the absorption of light, at an element-specific wavelength, by the free atoms of that element. A sample weighing 1.0g is placed into a "high form" porcelain crucible. It is introduced into a furnace, where the temperature is steadily increased to 500 °C. Once the temperature is reached, the sample undergoes ashing for 3 hours. The sample is then moistened with a small amount of distilled water, followed by the addition of 5-10 ml of 6 N HCl, and heated on a hot plate until it is nearly dry. To dissolve the resulting ash, 10 mL of 1 N HCl is added to the crucible. The dissolved ash is carefully transferred into a 100 mL volumetric flask. The sample is rinsed with distilled water, diluted to the required volume with distilled water, and shaken thoroughly and the aliquot was collected in an ICP test tube.

The calibration blank is aspirated to establish a blank level. Next, the calibration blank and standard solutions are aspirated to construct a calibration curve, using at least three standard solutions in addition to the blank to cover the linear range. Each point on the calibration curve is based, if possible, on replicate analyses. Distilled water is aspirated after each standard and sample. A quality control standard is analyzed to verify the calibration, followed by a calibration blank to check for memory effects. The unknown samples are then aspirated. A quality control standard is aspirated for every 10^{th} sample to monitor drift. Samples with concentrations higher than the highest standard are diluted and re-analyzed. The concentration of metal is calculated in mg/l or ppm, with the metal concentration in mg/100 g determined using the formula:

$$\text{The Sample (Mineral) mg/100 g} = \frac{Conc.of\ sample\ in\ ppm\ or\ mg/l\ x\ volume\ made}{weight\ of\ sample}$$

3.7 Selection of promising aonla accessions

To select the most promising accessions, several key parameters such as yield, fruit weight, pulp-to-stone ratio, TSS, ascorbic acid content, protein, total sugar, and phenols were used as selection criteria. The Weighted-Ranged method, along with modified characteristic estimates, was used to identify the best aonla accessions, following approaches by Güleryüz *et al*., (1998), Serdar (1999), and Ecevit *et al*., (2008). Table 3.2 presents the relative scores and characteristic class scores. Each characteristic score was multiplied by its relative score, and the total WR scores were calculated for each Aonla accession.

Table 3.2 Characters, relative scores, classes, and scores of the characteristics for the 'Weighted-Ranged' method of Aonla accessions.

Characteristics	**Relative scores**	**Classes**	**Scores of characteristics**
Fruit size	30	Average Fruit weight (g)	
		2.14 - 4.67	1
		4.68 - 7.19	4
		7.20 - 9.72	7
		2.14 - 4.67	10
Yield	30	Total fruit weight per tree (kg)	
		31.25 - 64.32	1
		64.33 - 97.40	4
		97.41 - 130.47	7
		130.48 - 163.54	10
Pulp stone ratio	20	Pulp weight/stone weight	
		7.50 - 10.13	1
		10.14 - 12.75	4
		12.76 - 15.38	7

		15.39 -18	10
TSS	12	Refractometric Value(°Brix)	
		7.50 - 10.13	1
		10.14 - 12.75	4
		12.76 - 15.38	7
		15.39 -18	10
Vitamin C	8	Ascorbic acid (mg 100g-1)	
		180.0 - 483.13	1
		483.14 - 786.25	4
		786.26 - 1089.38	7
		1089.39 - 1392.5	10
Total sugar	8	Total sugar (%)	
		3.90 - 6.19	1
		6.2 - 8.48	4
		8.49 - 10.77	7
		10.78 - 13.06	10
Protein	8	Protein (%)	
		2.19 - 3.20	1
		3.21 - 4.21	4
		4.22 - 5.22	7
		5.23 - 6.24	10
Phenol	8	Phenol mg/100g	
		687.70 -1316.13	1
		1316.14 - 1944.55	4
		1944.56 -2572.98	7
		2572.99 -3201.4	10

3.9 **Statistical Analysis**

The data were subjected to ANOVA analysis by following a completely randomized design. Significance and non-significance differences between different treatments were determined by calculating the respective *F* value and comparing with the appropriate value of *F* at 5% probability level (Panse and Sukhatme 1985) and the critical difference was calculated using SPSS software, version 25.0 (SPSS Inc.).

The Pearson's correlation coefficient (r) was calculated for quantitative and qualitative traits using R software. The significance of these correlations was evaluated at a 5% significance level by referring to a correlation table. Boxplot analysis based on accessions from three states was compared and analyse in SPSS software (Version 25.0).

Principal component analysis (PCA) was conducted using the R program software. To identify the principal components (PCs) that accounted for the most variation in each trait, the eigenvectors of the PCs were analyzed for each characteristic. The PC with the highest absolute value was chosen to best represent the characteristic being examined. Additionally, tree clustering analysis was employed to assess the similarity among accessions. A PCA bi-plot analysis was also conducted on the data matrices to assess the overall nutritional variability across the different accessions by using R program.

The 60 accessions were grouped and analyzed using squared Euclidean distance, and a tree diagram was created using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) in the software Past (version 4.03).

Chapter 4

Result and Discussion

An experiment titled "Morpho-Chemical Characterization of *Phyllanthus emblica* L. in Wild Conditions across Selected Regions of North East India" was conducted from 2018 to 2022 at Mizoram University, Aizawl, Mizoram.

Key findings from the study are presented and discussed in the following section.

4.1 Morphological Characteristics of Aonla Accessions

4.1.1 Morphological Characters of Aonla Trees and Leaves

4.1.1.1 Tree Height

The height of aonla trees selected for the study from different locations is given in Table 4.1. The tree height among the different aonla accessions collected from North East India exhibits significant variation. The tallest tree, MGL9, reaches an impressive 13.4 m, while the shortest, MGL6, stands at just 4.5 m as presented in Table 4.1. Most accessions fall within the 7-11 m range, with several hovering around 9-10 m. However, there are outliers—accessions like MGL20, MZR6, MZR16, TRP3, TRP9, and TRP13—reaching heights of 12-13 m. Conversely, the shortest accessions (MGL6, MGL7, MGL10, and MGL11) measure between 4.5 and 6.5 m. This wide range underscores the high genetic diversity among aonla accessions in the North East India region. The boxplots of the tree height are shown in Figure 4.1 which further illustrates how the variations from the three states are described among the aonla accessions studied.

Others studies on aonla tree height shows shorter height for instance, among the aonla cultivars varieties studied under zero irrigation semi-arid conditions the height ranged between 3.78 (Chakaiya) to 5.67 m (Anand-2) (Singh *et al.,* 2015). Singh *et al.* (2022) in his study recorded the tree height of different *Phyllanthus emblica* germplasm between 4.83 m to 6.62 m. Kumar *et al*. (2016) also recorded a minimum tree height in Chakaiya (3.83 m) and the highest plant height in Anand 2 cultivars with 5.63 m. In comparisons with the aonla plants cultivar studied, the height of the aonla plants from northeast were comparatively taller with maximum height up to 13.4 m.

4.1.1.2 Tree Girth

The girth of a tree plays a pivotal role in determining its fruit production, with larger trees typically yielding more fruit due to their greater photosynthetic potential, stronger structural framework, and enhanced ability to compete for resources. However, fruit production is also influenced by factors like tree density in the surrounding area and the availability of nutrients. Recognizing these complex interactions is vital for effective forest management and conservation strategies focused on maximizing fruit yield across different tree species. The girth of the trees across the studied accessions varied between 20 and 132 cm as presented in Table 4.1, with an average girth of 60.8 cm observed among 60 accessions. The boxplots in Figure 4.1 display the tree girth data, highlighting the differences in the aonla accessions across the three states. This visual representation emphasizes the variation observed in the accessions examined. The largest girth, 132 cm, was recorded in the TRP13 accession from Tripura, while the smallest, 20 cm, came from the MGL19 accession in Meghalaya. Similarly, Singh *et al.* (2021) reported stem girth ranging from 46.4 to 95.33 cm in various aonla tree cultivars grown under semi-arid conditions in Haryana.

4.1.1.3 Tree Shape

The various tree shape of the aonla accessions studied is shown in Table 4.1, and the frequency Table is provided in Table 4.2. The tree shape varies from erect to spreading, with some accessions exhibiting a semi-spreading or drooping habit which may influence light capture and resource allocation. The categories include spreading (27) representing 45%, semi spreading 37.7% (22), erect 11.7% (7) and drooping 6.5% (4) of the total accessions studied. The most common shape observed is spreading, indicating a preference for a wider canopy structure in many accessions.

Various Studies also showed variation in aonla tree shapes. Singh *et al.* (2022) recorded spreading (CHES 1, Chakaiya, Krishna, NA 6, NA 7, NA 10 and

BSR 1), drooping (NA 20) and upright (G 1, Seedling 1 and Seedling 2) tree habits) under semi-arid ecosystem of Haryana (India). A considerable variation in tree shape of aonla cultivars was observed by Kumar *et al.* (2016) in Francis (Drooping), Chakaiya (Upright Spreading), NA 7 and Goma Aishwarya (tall semi-spreading) and Aanad 2 (Tall upright). Spreading shape and semi spreading shape of aonla trees was also found from the most notable accession selected from Faizabad, Pratapgarh, Allahabad, Mirzapur and Varanasi district of U.P. (Rai *et al.,* 1993). Likewise in a study by Singh *et al.* (2015), it was demonstrated that the aonla varieties exhibited significant differences in tree habit. Specifically, the Banarasi, Krishna, and Chakaiya varieties were observed to have an upright spreading habit, while Anand 1 and Anand 2 were characterized by a tall upright growth. The NA 7 variety displayed a tall spreading habit, Francis showed a tall drooping habit, and Kanchan exhibited a tall semi-spreading habit under the rainfed conditions of western India.

4.1.1.4 Foliage Density

The foliage density of the aonla accessions studied are shown in Table 4.1 and the frequency Table is provided in Table 4.2. Foliage density is either sparse or dense affecting photosynthetic capacity and potentially the overall health and productivity of the tree. Sparse foliage with 69.4% (35) is more common, but dense foliage with 41.7% (25) is also well represented, particularly in spreading and drooping tree shapes.

Singh *et al*. (2015) observed sparse foliage in the Banarasi, Chakaiya, Krishna, Kanchan, Anand 1, and Anand 2 varieties, while observing dense foliage in the Francis, NA 7, and NA 10 varieties under zero irrigation semi-arid conditions. In another study the accessions of Chakaiya, Krishna, NA 6, G 1, BSR 1, Seedling 1, and Seedling 2 were noted for their sparse foliage density, while CHES 1, NA 7, NA 10, and NA 20 exhibited dense foliage under semi-arid condition of Haryana (Singh *et al*., 2022). The complexity of foliage density in plants is shaped by the interaction of genetic, environmental, and developmental factors. Different foliage densities are exhibited by accessions possessing various alleles for growth habit, stress tolerance, and resource allocation, particularly when these plants are grown under diverse environmental conditions and planting densities (Chapman, 1987; Gao *et al*., 2022; Koczorski *et al.,* 2021; Niinemets, 2014; Younis *et al*., 2021).

4.1.1.5 Leaf Shape and Size

The leaf shape and size of the aonla accessions studied are shown in Table 4.1 and the frequency Table is provided in Table 4.2. The aonla accessions collected from North East India exhibit a variety of leaf shapes and sizes. The most common leaf shapes are, oblong - found in 41 accessions representing about 68.3%, oval - found in 19 accessions accounting for 31.7%, of the total accessions studied. Similar variations in leaf shapes were also recorded by other researchers (Singh *et al.,* 2015; Kumar *et al.,* 2016), in which three types of shapes i.e. oval – oblong, oblong and elliptical in various aonla cultivars from different agro climatic regions. The leaf sizes vary from 0.9 cm to 1.6 cm in length, with most accessions having leaves ranging between 1.1 - 1.5 cm long. The boxplots of the leaf size are shown in Figure 4.1 which highlights the differences in the aonla accessions across the three states. The most common leaf length is 1.2-1.4 cm. Our results are in close proximity with Singh *et al.* (2015) who recorded the leaf length between 1.24 and 1.47 cm. Kumar *et al.* (2016) also reported the leaf length of aonla cultivars in between 1.28 to 1.48 cm.

4.1.1.6 Leaf Apex

The leaf apex of the aonla accessions studied is displayed in Table 4.1. and the frequency Table is provided in Table 4.2. The Leaf apex is either acute or obtuse, 38 accessions have acute leaf apex, whereas the rest of the 22 accessions showed obtuse leaf apex, and the leaf surface is mostly glabrous (57), with a few accessions having moderately glabrous (3) leaves. Girth measurements range from 20 cm (MGL19) to 196 cm (MZR19), with most accessions having a girth between the ranges of 40-80 cm. An obtuse leaf apex in the aonla varieties of Francis, NA 7, Goma Aishwarya, Anand 2 and an acute leaf apex in Chakaiya and Kanchan varieties was reported (Kumar *et al,.* 2016; Singh *et al.,* 2015).

The variation in leaf shape and morphology maybe heavily influence by genes. Differences in the expression or regulation of genes involved in leaf development can result in varying leaf shapes between accessions. Changes in leaf morphology can be induced by environmental conditions such as light, temperature, and water availability, due to phenotypic plasticity. Higher altitudes have also been found to influence leaf shape, with plants at these elevations often exhibiting smaller, thicker leaves compared to those at lower altitudes. The complex interplay between genetic and environmental factors determines leaf shape. Although leaf morphology can be significantly influenced by accession, environmental conditions can override or modify genetic effects, leading to phenotypic variation (Hovenden *et al.,* 2004; Wang *et al.,* 2019; Ye *et al.,* 2020; Li *et al.,* 2021; Wang *et al.,* 2021; Li *et al.,* 2023;)

4.1.1.7 Leaf Surface

The leaf surface of the aonla accessions studied is presented in Table 4.1 and the frequency Table is provided in Table 4.2. Leaf surface characteristics—such as wax coatings, trichomes, texture, and other morphological features—can vary significantly across different accessions within the same plant species. These variations are crucial for advancing plant breeding efforts, identifying stress responses, and enhancing the accuracy of leaf optical models (Peters and Noble, 2023). The leaf surface of the aonla accessions studied were dominantly glabrous (57 accession) while only 3 accessions had moderately glabrous leaf. A glabrous leaf surface was recorded in *Phyllanthus* species in Jos, Nigeria (Okanume *et al.,* 2019).

Table 4.1 Morphological character of aonla trees and leaves.

Accession	TH (m)	GR (cm)	TS	FL	LS	LSZ (cm)	LA	LSF
MGL1	9	41	E	Sp	Ot	1.2	Ac	G
MGL2	9.5	61	SS	Sp	Ot	1.4	Ac	MG
MGL3	10.3	86	D	Dn	Ov	1.5	Ac	G
MGL6	4.5	24	S	Dn	Ov	1.2	Ac	G
MGL7	5.2	22	S	Dn	Ot	1.2	Ac	G
MGL4	9	75	E	Sp	Ov	1.4	Ac	G
MGL5	7	70	S	Sp	Ot	1.1	Ac	G
MGL8	7.8	46	SS	Sp	Ot	1.2	Ot	G
MGL9	13.4	47.6	S	Dn	Ot	1.4	Ac	G
MGL10	5.5	33.4	E	Sp	Ov	1.2	Ac	G
MGL11	6.5	50	S	Sp	Ot	1.1	Ac	G

Accession	TH (m)	GR (cm)	TS	FL	LS	LSZ (cm)	LA	LSF
MGL12	7.5	75	SS	Sp	Ot	1.5	Ac	G
MGL13	7	48.4	S	Sp	Ot	1.4	Ot	G
MGL14	10.9	62.3	SS	Sp	Ot	1.4	Ot	G
MGL15	10.7	43	SS	Sp	Ov	1.4	Ot	G
MGL16	6.5	43.4	SS	Sp	Ov	1.4	Ot	G
MGL17	7	53.5	S	Sp	Ot	1.3	Ot	G
MGL18	8.2	28	E	Sp	Ot	1.2	Ac	G
MGL19	7.3	20	E	Sp	Ot	0.9	Ac	G
MGL20	12.3	50	S	Dn	Ot	1.2	Ac	G
MZR1	9.7	30.7	SS	Dn	Ot	1.3	Ot	G
MZR2	9.2	54.9	S	Sp	Ov	1.4	Ac	G
MZR3	9.4	38.3	SS	Sp	Ot	1.2	Ac	G
MZR4	9	79	SS	Sp	Ot	1.2	Ot	G
MZR5	9	76	D	Dn	Ot	1.2	Ot	G
MZR7	10.6	84	S	Sp	Ov	1.4	Ac	G
MZR8	9.4	32	SS	Dn	Ot	1.3	Ot	G
MZR6	11.3	88	S	Dn	Ov	1.6	Ac	G
MZR9	8.5	68	SS	Dn	Ov	1.1	Ac	G
MZR10	8.3	65	SS	Sp	Ot	1.5	Ot	G
MZR11	8.9	53.4	S	Dn	Ot	1.2	Ac	G
MZR12	10.5	45	S	Dn	Ov	1.5	Ot	G
MZR13	9	74	SS	Dn	Ot	1.3	Ac	G
MZR14	10.5	97	S	Sp	Ov	1.3	Ac	MG
MZR15	8.6	70	S	Sp	Ov	1.2	Ot	G
MZR16	12.3	46.8	S	Dn	Ot	1.2	Ac	G
MZR17	10.5	40.5	E	Sp	Ot	1.3	Ac	G
MZR18	8.4	90	D	Dn	Ov	1.3	Ot	G
MZR19	11	124	SS	Sp	Ot	1.3	Ac	G
MZR20	9.8	118	SS	Sp	Ot	1.2	Ot	G
TRP1	9	51.4	S	Dn	Ot	1.4	Ac	G
TRP2	7.5	55	SS	Sp	Ov	1.1	Ot	G
TRP3	12	78.5	S	Dn	Ot	1.2	Ac	G
TRP4	8.3	42.5	S	Dn	Ot	1.4	Ot	G
TRP5	10.3	50.3	SS	Sp	Ov	1.2	Ac	G
TRP6	9	84.5	S	Dn	Ot	1.2	Ac	G
TRP7	8.3	60.3	S	Sp	Ot	1.2	Ac	G
TRP8	11.6	46.3	SS	Sp	Ot	1.3	Ac	G
TRP9	12.5	101.5	S	Dn	Ov	1.3	Ot	G
TRP10	8.6	28.6	SS	Sp	Ot	1.3	Ot	G

Accession	TH (m)	GR (cm)	TS	FL	LS	LSZ (cm)	LA	LSF
TRP11	10	98.2	S	Dn	Ot	1.3	Ac	G
TRP12	9	65	SS	Sp	Ot	1.3	Ot	MG
TRP13	13	132	D	Dn	Ot	1.4	Ac	G
TRP14	11.8	45	SS	Sp	Ot	1	Ot	G
TRP15	9	58.5	SS	Sp	Ot	1.2	Ac	G
TRP16	9.2	63	S	Dn	Ov	1.5	Ac	G
TRP17	11	93	S	Dn	Ot	1.2	Ac	G
TRP18	10.2	40	SS	Sp	Ov	1.3	Ac	G
TRP19	8.1	46.4	E	Sp	Ot	1.2	Ot	G
TRP20	11.2	54	SS	Dn	Ot	12	Ac	G

*TH – Tree Height; GR – Girth; TS- Tree Shape; FL – Foliage; LS – Leaf Shape; LSZ – Leaf Size; LA – Leaf Apex; LSF – Leaf Surface; Semi-Spreading - SS; Spreading - S; Erect - E; Drooping - D; Sparse – Sp; Dense –Dn; Oblong -Ob; Oval -Ov; Obtuse – Ot; Acute – Ac; Glabrous - G; Moderately Glabrous – MG.

Table 4.2 Distribution and frequency of qualitative traits among different aonla accessions.

Characters		Frequency	Percentage (%)
Tree Shape Semi spreading Spreading	Drooping	4	6.7
	Erect	7	11.7
	Semi Spreading	24	40.0
	Spreading	25	41.7
Foliage parse	Dense	25	41.7
	Sparse	35	58.3
Leaflet Shape	Oval	19	31.6
	Oblong	41	68.3
Leaflet Apex	Acute	38	63.3
	Obtuse	22	36.7
Leaf Surface	Glabrous	57	95.0
	Moderately Glabrous	3	5.0

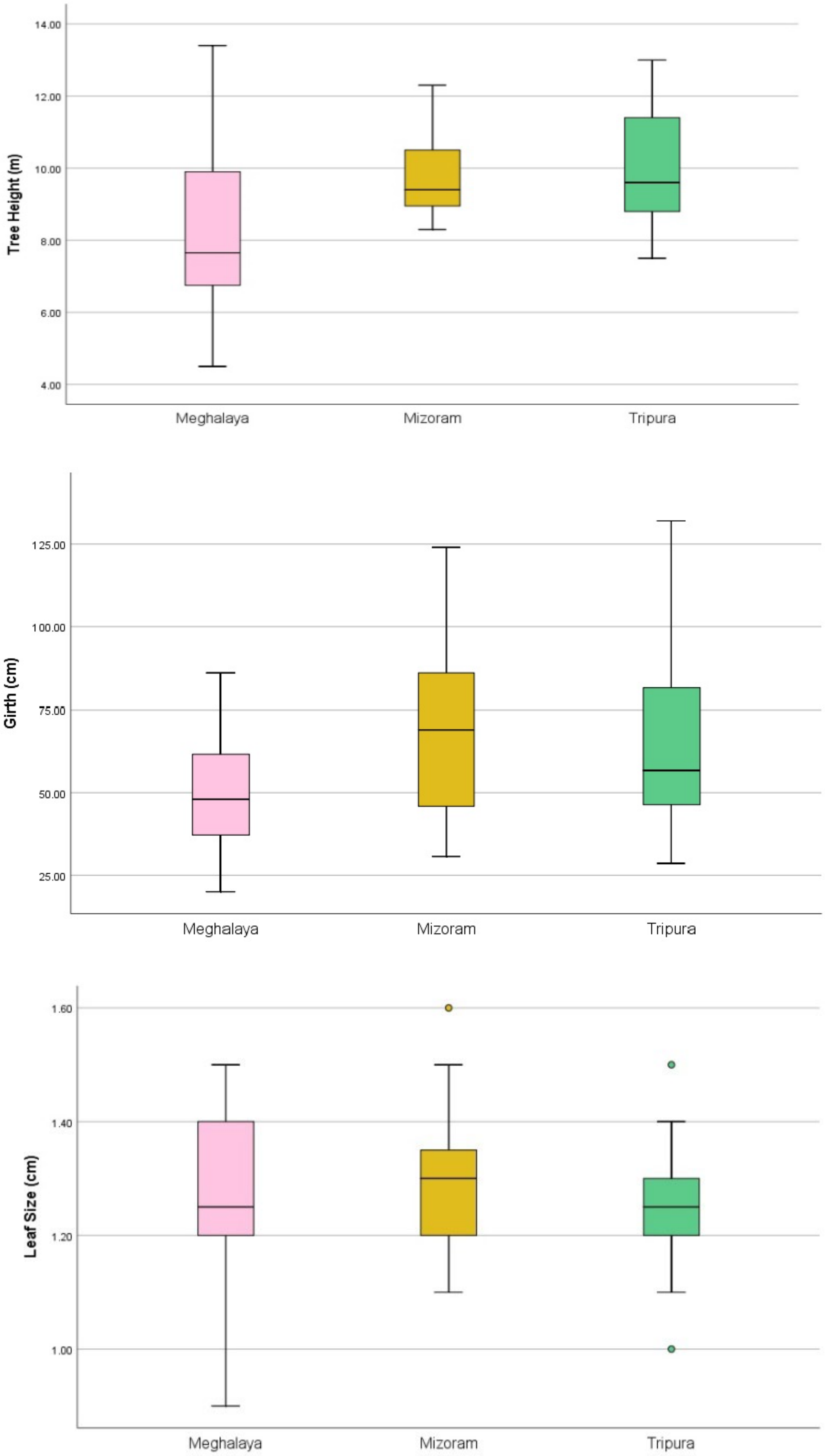


Figure 4.1 Boxplot of aonla's tree height, girth and leaf size from Meghalaya, Mizoram and Tripura

4.1.2 Morphology Characterization of aonla Fruits

The valuation of a fruit's internal features is deemed very important, while the external characteristics of fresh produce are considered the core of consumer acceptance and marketability. Various physical and mechanical characteristics of fruits, such as shape, size, smoothness, shiny surface, and firmness, are regarded as important qualitative attributes for attracting consumers (Tewari *et al.,* 2019). The primary morphological attributes of aonla fruit examined in this research, including fruit shape, fruit color, fruit surface, fruit stalk, and stone shape, are detailed in Table 2. The fruit morphological traits of 60 wild aonla accessions were analyzed, and the results are summarized in Table 4.3 and 4.4.

4.1.2.1 Fruit Shape

The observations on the fruits shape are presented in Table 4.3 and 4.4. The accessions exhibited variations in fruit shape, categorized primarily as round, flattened round, and triangular. The majority of the accessions had either a round with 38.33% (23) and flattened round with 53.33% (32) fruit shape. Specifically, accessions MGL1, MGL3, MGL6, MGL10, MGL11, MGL12, MGL19, MZR2, MZR3, MZR5, MZR9, MZR14, MZR15, MZR16, MZR18, TRP2, TRP5, TRP12, TRP16, TRP17, TRP19 and TRP20 exhibited a round fruit shape. Accessions MGL2, MGL4, MGL7, MGL8, MGL9, MGL13, MGL15, MGL16, MGL17, MGL20, MZR1, MZR4, MZR6, MZR7, MZR8, MZR10, MZR11, MZR13, MZR19, MZR20, TRP1, TRP4, TRP6, TRP7, TRP8, TRP10, TRP11, TRP13, TRP14, TRP15, TRP18, and TRP20 exhibited a flattened round shape. A smaller number of accessions, specifically MGL14, MGL18, MZR12, TRP3, and TRP9, exhibited a triangular fruit shape representing 8.33%. The more processing preference is given to fruits with a flattened round shape and medium large size (Jaiswal *et al.,* 2007).

Our readings are in close proximity with others studies on aonla and its cultivars where the fruit shape of aonla varieties was reported as round to oblate shapes by Kumar and Khatkar (2015). Various cultivars of aonla were noted to have triangular, flattened round, and flattened oval shapes by Singh *et al.* (2015). The shapes of fruits from different accessions of wild aonla from the north-eastern region of India were described as round flattened, round spherical, and round by Singh *et al.* (2016). In the study by Kaim and Bisht (2018), the fruit shapes of Kanchan were small and flattened oblong, Chaikaiya had small to medium sizes, Banarasi had a large triangular shape, and Amrit, Neelam, and NA-10 cultivars were small to medium and flattened round, respectively, in Uttarakhand, western Himalaya. Aonla fruit shapes from different germplasm were recorded by Singh *et al.* (2022) as round (NA 20), flattened round (CHES 1, Chakaiya, NA 6, NA 10, G 1, and BSR 1), oval (NA 7, Seedling 1, and Seedling 2), and triangular (Krishna) under semi-arid conditions in Haryana. A predominant spherical fruit shape was observed while Flattened shapes, triangular fruit shapes, Oval shapes were found but in lesser number (Bulo *et al.,* 2024)

4.1.2.2 Fruit Colour

The details regarding the colour of the fruits are outlined in Table 4.2 and 4.4. The fruit colour of the accessions is predominantly in the yellow-green range, with various shades such as 144C, 153C, 145B, 145D, 151D, 145A, 145C, 150D, 151A, and 153B. Only one accession, MZR12, has an orange-red (35B) fruit colour.

Similar variations in fruits were also recorded by other researchers (Kumar and Khatkar, 2015), in which the fruit colour of NA-7, Banarasi, Kanchan, and Chakaiya was observed to be yellowish green, while the Desi variety was observed to be green in colour. Fruit colour was recorded as whitish green for Banarasi and Kanchan; light green for Krishna, Francis, and Chakaiya; yellowish green for NA 7, NA 10, and Anand 2; and greenish yellow for Anand 1 (Singh *et al.,* 2015). Fruit colour of light green, pale yellowish green, yellowish green and dark green was observed in a study by Singh *et al.* (2016). Light green fruit colour was noted for cultivar Kanchan and Amrit, light green for Chakaiya, whitish green for Banarasi, yellowish green for Neelam, and yellowish green for NA-10 (Kaim and Bisht, 2018). Light green fruit colour was observed in Chakaiya, Krishna, NA 6, NA 10, G 1, and Seedling 1; yellow green in CHES 1, NA 7, NA 20, and Seedling 2, while the fruit of cultivar BSR 1 had a red tinge on a light green colour background (Singh *et al.,* 2022). In several accessions, Light green fruit color was recorded by Bulo *et al.*

(2024), with medium green and medium yellow-green shades being displayed by others. Aonla germplasm from Pakistan showed fruit colour varied from green to light green fruit and solid green in Desi type (Rabbani *et al.,* 2019). Stable characteristics are represented by these attributes and could be useful for the identification of specific accessions.

4.1.2.3 Fruit Surface

The details of the fruit surface observations are provided in Table 4.2 and 4.4. The variation in fruit surface texture within a plant species is primarily influenced by genetic factors, ripening stage, and environmental conditions, resulting in both smooth and rough fruit surfaces being naturally allowed to occur due to differences in plant cell structure and turgor pressure (Barrett *et al*., 2010; Wang *et al*., 2015; Food Crumbles, 2018). The fruit surface was categorized as smooth, rough, and moderately rough. The majority of the accessions had a smooth fruit surface with 45 accessions out of the 60 accessions. Rough surfaces were observed in 13 accessions MGL2, MGL9, MGL13, MGL20, MZR4, MZR8, MZR13, MZR14, MZR20, TRP7, TRP11, TRP15 and TRP20. Moderately rough surfaces were less common and observed in MZR9 and MZR15. The cultivar of Kanchan, Chakaiya, Banarasi, Neelam and Amrit exhibited smooth fruit surfaces and a rough fruit surface was observed in NA-10 (Kaim and Bisht, 2018)

4.1.2.4 Fruit Stalk

The findings regarding the fruits stalk are given in Table 4.2 and 4.4. The fruit stalk is crucial for fruit development and quality due to its role in nutrient and water transport, structural support, fruit abscission, postharvest handling, and genetic and breeding studies. It supplies essential resources, supports the fruit physically, aids in natural detachment when mature, affects shelf life and susceptibility to disease, and exhibits heritable traits valuable for breeding program. The fruit stalk thickness also varies, with 26 (43.3%) accessions having a thick stalk and 34 (56.7%) accessions having a thin stalk.

The findings are in agreement with those recorded by Kumar *et al.* (2016), who observed short and thick fruit stalks in NA 7 and Goma Aishwarya, and short and thin fruit stalks in Francis, Chakaiya, and Anand 2. While, Kaim and Bisht (2018) recorded only short and thick fruit stalks in various cultivars of aonla.

4.1.2.5 Stone Shape

The details of the stone shape characteristics are outlined in Table 4.2 and 4.4. The stone shapes among the accessions displayed a diverse array, including oval, round, triangular, and oval-round forms. The most common stone shape is round found in 23 accessions followed by oval (16 accessions), oval round (11 accessions) and triangular (10 accessions).

The results reported by Singh *et al.* (2016) are consistent with these findings, where the stone shape was observed as round triangular at the apex, flattened triangular, flattened round, spherical round, and spherical round triangular at the apex in all the accessions collected from north-east India. Variation in stone shape was also observed across various cultivars of aonla. An oval shape was noted in Francis, an oval-round shape in NA 7 and Goma Aishwarya, and a round shape in Chakaiya and Anand 2 (Kumar *et al.,* 2016). Additionally, the results reported by Singh *et al.* (2012) in bael and Singh *et al.* (2014) in *Morinda tomentosa* under rainfed conditions of western India are also consistent with these findings.

4.1.2.5 Harvest Maturity

The details of the fruit's harvest maturity are presented in Table 4.2 and 4.4. The accessions exhibit a range of harvest maturities, with 39 accessions classified as late, 18 as moderate, and 3 as early. The late-maturing accessions are the most common, while the early-maturing accessions are the least frequent.

In studies conducted by Bakshi *et al.* (2015) on aonla cultivars, Banarasi was recorded as the earliest to mature (27 November), followed by Desi (29 November), Kanchan (1 December), Chakaiya (2 December), and Francis (3 December). The fruits of Neelam matured last on 15 December. Similarly Shukla *et al.* (2009) also recorded the maturity of aonla was from 11–15 November in Krishna cultivars to 2–5

December in Kanchan cultivars. The time of fruit maturity was observed during the last week of October in Francis and NA 7, the first week of November in Goma Aishwarya, the second week of November in Chakaiya, and the last week of November in Anand 2 (Kumar *et al.,* 2016).

Table 4.3 Morphology characterization of different accessions of *Phyllanthus emblica* fruit

Accession	Fruit Shape	Fruit colour	Fruit Surface	Fruit Stalk	Stone Shape	Harvest Maturity
MGL1	R	Yellow green 144C	Smooth	Thick	OR	L
MGL2	FR	Yellow green 153C	Rough	Thick	OR	M
MGL3	R	Yellow green 145B	Smooth	Thin	T	L
MGL6	R	Yellow green 151D	Smooth	Thick	R	E
MGL7	FR	Yellow green 145D	Smooth	Thick	R	L
MGL4	FR	Yellow green 145A	Smooth	Thick	O	E
MGL5	R	Yellow green 145A	Smooth	Thin	O	M
MGL8	FR	Yellow green 150D	Smooth	Thin	R	M
MGL9	FR	Yellow green 150D	Rough	Thin	R	L
MGL10	R	Yellow green 153C	Smooth	Thin	R	E
MGL11	R	Yellow green 153C	Smooth	Thin	T	M
MGL12	R	Yellow green 153B	Smooth	Thick	O	L
MGL13	FR	Yellow green 151A	Rough	Thick	OR	L
MGL14	T	Yellow green 153B	Smooth	Thin	FR	L
MGL15	FR	Yellow green 145C	Smooth	Thin	R	L
MGL16	FR	Yellow green 145C	Smooth	Thin	R	L
MGL17	FR	Yellow green 145C	Smooth	Thick	R	L
MGL18	T	Yellow green 145C	Smooth	Thin	O	L
MGL19	R	Yellow green 144C	Smooth	Thin	T	L
MGL20	FR	Yellow green 145A	Rough	Thick	OR	L
MZR1	FR	Yellow green145B	Smooth	Thin	O	M
MZR2	R	Yellow green 144C	Smooth	Thin	T	L
MZR3	R	Yellow green 145B	Smooth	Thick	T	L
MZR4	FR	Yellow green 145C	Rough	Thick	OR	M
MZR5	R	Yellow green145A	Smooth	Thin	O	L
MZR7	FR	Yellow green 151A	Smooth	Thin	OR	L
MZR8	FR	Yellow green 153C	Rough	Thin	R	L
MZR6	FR	Yellow green 153B	Smooth	Thin	R	M
MZR9	R	Yellow green 151A	Moderately rough	Thin	R	M

Accession	Fruit Shape	Fruit colour	Fruit Surface	Fruit Stalk	Stone Shape	Harvest Maturity
MZR10	FR	Yellow green 145B	Smooth	Thick	R	M
MZR11	FR	Yellow green 145B	Smooth	Thin	R	L)
MZR12	T	Orange Red 35B	Smooth	Thin	OR	L
MZR13	FR	Yellow green 145C	Rough	Thick	O	M
MZR14	R	Yellow green 151A	Rough	Thick	OR	M
MZR15	R	Yellow green 153C	Moderately rough	Thick	O	M
MZR16	R	Yellow Green 145C	Smooth	Thin	O	L
MZR17	FR	Yellow green 145C	Smooth	Thick	T	L
MZR18	R	Yellow green 151A	Smooth	Thin	R	M
MZR19	FR	Yellow green 151A	Smooth	Thick	OR	M
MZR20	FR	Yellow green 145A	Rough	Thin	R	M
TRP1	FR	Yellow green 151D	Smooth	Thick	T	L
TRP2	R	Yellow green 153C	Smooth	Thin	O	L
TRP3	T	Yellow green 145D	Smooth	Thick	T	L
TRP4	FR	Yellow green 145C	Smooth	Thin	R	L
TRP5	R	Yellow green 151A	Smooth	Thin	O	L
TRP6	FR	Yellow green 151A	Smooth	Thick	T	L
TRP7	FR	Yellow green 144C	Rough	Thick	OR	M
TRP8	FR	Yellow green 151A	Smooth	Thick	O	L
TRP9	T	Yellow green 145D	Smooth	Thick	T	L
TRP10	FR	Yellow green 145C	Smooth	Thin	O	M
TRP11	FR	Yellow green 145D	Rough	Thin	R	L
TRP12	R	Yellow green 144C	Smooth	Thin	O	M
TRP13	FR	Yellow green 145D	Smooth	Thick	R	L
TRP14	FR	Yellow green 144C	Smooth	Thin	R	L
TRP15	FR	Yellow green 145C	Rough	Thin	OR	L
TRP16	R	Yellow green 144C	Smooth	Thin	R	L
TRP17	R	Yellow green 153C	Smooth	Thick	R	L
TRP18	FR	Yellow green 151A	Smooth	Thin	R	L
TRP19	R	Yellow green 145D	Smooth	Thin	O	L
TRP20	R	Yellow green 145C	Rough	Thick	O	L

*R- Round, FR- Flattened Round, T- Triangular, O- Oval, OR- Oval Round, E-Early, M- Moderate and L – Late.

Table 4.4 Frequency Table of aonla fruit characters.

Parameters	Characters	Frequency	Frequency percentage (%)
Fruit Shape	Flattened round	32	53.33
	Round	23	38.33
	Triangular	5	8.33
Fruit Colour	Orange Red 35B	1	1.67
	Yellow green 144C	7	11.67
	Yellow green 145A	4	6.67
	Yellow green 145B	4	6.67
	Yellow green 145C	12	20.00
	Yellow green 145D	6	10.00
	Yellow green 150D	2	3.33
	Yellow green 151A	10	16.67
	Yellow green 151D	2	3.33
	Yellow green 153B	3	5.00
	Yellow green 153C	7	11.67
	Yellow green145A	1	1.67
	Yellow green145B	1	1.67
Fruit Surface	Moderate	2	3.33
	Rough	13	21.67
	Smooth	45	75.00
Fruit Stalk	Thick	26	43.33
	Thin	34	56.67
Stone Shape	Flattened round	1	1.67
	Oval	16	26.67
	Oval round	11	18.33
	Round	22	36.67
	Triangular	10	16.67
Harvest Maturity	Early	3	5.0
	Moderate	18	30.0
	Late	39	65.0

4.1.3 Fruits' Physical Parameters

Fruit morphometric traits, such as diameter and length, are measured to assess genetic variability within plant populations, which aids genetic improvement programs by allowing desirable traits to be identified and selected. Evolutionary adaptations to avoid predation through Batesian mimicry may be indicated by similarities in fruit size and shape, with studies on phenotypic similarity between fruits and structures like galls providing insights into mimicry and its effects on predation. Additionally, fruit dimensions are considered key quality indicators that influence commercial value and suitability for processing in various culinary or industrial applications. By analyzing these traits across different plant provenances or environmental conditions, understanding of the physiological mechanisms underlying fruit development and growth can be enhanced (Hernández *et al.,* 2020; López-Colin *et al.,* 2018; Niang *et al.,* 2015).

The Table 4.5 to 4.8 offers a fascinating glimpse into the remarkable diversity of physical attributes found among different accessions of the Indian gooseberry. This treasure trove of information reveals the remarkable range of possibilities within this species, showcasing the incredible natural variation that exists.

4.1.3.1 Fruit Length and Diameter

The fruit length and diameter of the fruits from the different aonla accessions examined are presented in Table 4.5, 4.6, 4.7 and 4.8. The fruits length as well as diameter from the three states i.e. Meghalaya, Mizoram and Tripura showed significant variations among the accessions studied. The fruits span a captivating spectrum, from the diminutive 12.771 mm length of MGL8 to the impressive 24.722 mm of MGL6. Among state wise, the maximum average fruit length was recorded from Meghalaya with 19.26 mm and the shortest from Mizoram with 17.11 mm. Similarly, the diameters range from the petite 14.666 mm of MZR9 to the stately 28.036 mm of MGL6. The averages of fruit diameter obtain from Meghalaya had the maximum diameter at 21.07 mm and the lowest from Mizoram at 19.18 mm. This diversity in size is mirrored in the length-to-diameter (L/D) ratios, which fluctuate from the elongated 1.202 of MGL19 to the more rounded 0.780 of MZR5. The boxplot in figure 4.2 shows that Meghalaya has the widest distribution of fruit lengths, and its data contains one lower outlier. Mizoram has a slightly narrower range than the other two regions and contains one upper outlier. Tripura falls in between in terms of distribution spread, with no visible outliers. Whereas figure 4.3 revealed, that Meghalaya show moderate variation in fruit sizes with a median in the middle range. Mizoram has a slightly smaller median diameter and a more consistent size range, while Tripura leads with the largest median fruit diameter and the most uniform sizes among the three regions. Such a wide array of shapes and sizes opens up intriguing possibilities for breeders and growers to select for specific market preferences or processing needs.

The present finding is in conformity with the result of Singh *et al.* (2016) in aonla accessions collected from north-east India, where the length of the fruit ranges between 1.26 cm. to 2.53 cm. the diameter ranges between 1.27 to 2.57 cm. It also resonates closely with the results of Hazarika and Laltluangkimi (2019) in aonla fruit length (18.98 - 24.08 mm) and fruit diameter (19.46 -20.02 mm).Pandey *et al.* (2008) likewise studied the variation of different aonla accessions of the fruit length and diameter and they observed that the fruit length ranged between 2.53 and 3.83 cm; fruit diameter between 2.57 and 4.63 cm. Other studies on aonla cultivars from different part of the country also showed variations in fruits length and diameter, which are similar to the present findings (Chiranjeevi *et al.,* 2018; Kaim and Bisht, 2018; Maurya *et al.,* 2024; Pandey *et al.,* 2016)

4.1.3.2 Fruit Weight

The fruit length and diameter of the fruits from the different aonla accessions examined are presented in Table 4.5, 4.6, 4.7 and 4.8. The fruit weights are equally diverse, with the lightest at 2.139 g (MGL11) and the heaviest at 12.238 g (MGL17). The average weight of aonla fruits recorded from Meghalaya was 6.44 g, 5.72 g from Tripura and 4.83 g from Mizoram. Meghalaya, fruit weights show moderate variation around a mid-range median. The boxplot in figure 4.5 shows that, in Meghalaya, a moderate range of fruit weights is observed, with a median value around the middle of the scale. In Mizoram, fruit weights are slightly lower and show less variability, indicating consistency. Tripura displays the highest median fruit weight with a relatively narrow range, suggesting heavier and more uniform weights.

The present finding is in conformity with the report of Singh *et al.* (2016) who recorded fruit weight ranging between 1.39-10.59 g in aonla accessions from north east India. Other researchers also recorded similar fruit weight from the north east India regions (Bulo *et al.,* 2024; Chandra *et al.,* 1998; Hazarika *et al.,* 2009; Hazarika and Laltluangkimi, 2019; Singh and Singh, 2016). The fruit weight of the wild aonla as compared to the aonla cultivars showed wide gap as the size of the cultivars were recorded as heavy as 56.98 g in NA-25 varieties (Maurya *et al.,* 2024) 49.97 g in Banarasi variety (Kumar and Khatkar, 2015), 41.46 g in Neelam cultivars (Bakshi *et al.,* 2015) 34.33 g in Amrit (Aulakh *et al.,* 2013) and 33.90 g in Banarasi (Singh *et al.,* 2015).

4.1.3.3 Moisture Content and Dry Matter Content

The fruit length and diameter of the fruits from the different aonla accessions examined are shown in Table 4.5, 4.6, 4.7 and 4.8. A significant difference from the three states was recorded in the moisture content of the aonla accessions, the content ranges from 76.93% which was collected from Tripura (TRP6) to 85.91% collected from Meghalaya (MGL). The averages of the moisture content observed from Meghalaya was 81.17% expressing the maximum ranged among the states, Mizoram at 80.71% which shows the lowest moisture and Tripura at 80.87%. Interestingly, the dry matter content also exhibits significant variation, ranging from 14.09% (MGL1) to 23.07% (TRP6). Meghalaya maintains a moderate moisture level with noticeable, though not extreme, fluctuations. Mizoram follows with a slightly lower and steadier moisture profile, while Tripura stands out with the highest, most consistent moisture levels across the three the three states as shown in figure 4.6 boxplot. Similar trends were obtained for dry matter content (Figure 4.7)

This result's shows that some accessions may be better suited for certain culinary or processing applications than others. The fruit of aonla, a non-climacteric type, is characterized by a double sigmoid growth curve. After being set, the fruit undergoes dormancy for 100-120 days. Rapid growth occurs from 120-125 to 180-190 DAFB with the onset of the rainy season, followed by a slower growth period from 190-200 days as maturation progresses. The main accumulation of dry matter in Indian gooseberry fruit is observed during the final phase of maturity, stabilizing during the last three weeks before harvest (Pareek and Kitinoja, 2011; Singh *et al.,* 2015).

Similar findings were also reported by Hazarika and Laltluangkimi, (2019) of moisture content ranging between 78.70% and 87.57% among the 30 aonla accessions collected from different regions of the Mizoram, North-Eastern region of India. Hazarika *et al*. (2009) also observed the moisture content in between 78.51 - 84.29% from Assam. Moisture percentage values of aonla fruit population ranged from 71.38% to 83.42% (Naithani *et al.,* 2020). Moisture content in the range of 84.89 to 87.50% was reported by Tewari *et al*. (2019) in different cultivar aonla fruits.

4.1.3.4 Stone Weight

The fruit length and diameter of the fruits from the different aonla accessions studied are presented in Table 4.5, 4.6, 4.7 and 4.8. Stone weight in fruits is crucial for evaluating agronomic traits, yield potential, quality characteristics, and market preferences. The stone-to-pulp ratio impacts yield, with a lower ratio indicating better fruit quality and marketability. Genetic variation among cultivars, as seen in Cornelian cherries, affects stone weight and thus fruit quality. Stone weight influences fruit attributes like taste and texture, affecting consumer satisfaction and processing outcomes, such as juice extraction and flavour. Market preferences lean towards fruits with smaller stones for more edible flesh, driving breeding programs. Understanding stone weight also aids in selecting sustainable and economically viable cultivars, enhancing productivity and profitability (Asghar *et al.,* 2022; Ivanova *et al.,* 2022; Jaćimović *et al.,* 2020; Kaack, 2017).

Among the accessions studied, the lowest average stone weight was recorded in MZR15 (0.33 g) followed by MZR20 (0.36 g), MGL10 (0.37 g) and MGL8 (0.37 g), whereas maximum average stone weight was recorded in MZR16 (1.54 g) followed by MGL17 (1.20 g), TRP7 (0.96 g), MGL17 (1.20 g), MGL6 and MZR3 (0.94 g). State wise the highest average stone weight was recorded from Mizoram (0.67 g) followed closely by Meghalaya (0.66 g) and the lowest was obtain from Tripura (0.63 g). The boxplot in figure 4.8 provides insights into the variability and central tendencies of stone in Meghalaya, Mizoram and Tripura.

The results obtained are consistent with the data of other studies on the formation of the average stone weight in various aonla accessions. Thus, the weight of the stones ranged from 0.28 - 1.50 g in the conditions of North-Eastern India

(Singh *et al.,* 2016). As a result of exploring six aonla cultivars in in Uttarakhand, Western Himalaya, it was identified that all the varieties under study had large stones except for Kanchan cultivars (Kaim and Bisht, 2018). The average weight of aonla varieties ranged from 1.97 g (NA 7) to 2.08 g (Francis) in a study by Singh *et al.* (2015).

4.1.3.5 Pulp Weight

The fruit length and diameter of the fruits from the different aonla accessions examined are presented in Table 4.5, 4.6, 4.7 and 4.8. The pulp weight was observed lowest in MZR2 (1.66 g) followed by MGL11 (1.74 g), subsequently by MZR15 (2.17 g), MZR20 (2.31 g) and MGL8 (2.61 g). While the highest pulp weight was observed in MGL20 (11.14 g), followed by MGL17 (11.04 g), MGL6 (10.73 g), MGL15 (8.38 g) and MGL16 (8.02 g). Among the states the average pulp weight from Meghalaya was recorded the highest at 5.79 g, Tripura at 5.09 g and Mizoram at 4.16 g. From figure 4.9, the boxplot shows that Meghalaya has the highest pulp weight variability and median, Mizoram has moderate variability with a mid-range median, while Tripura shows the least variability and the lowest median pulp weight.

The present findings closely align with those of Naithani *et al.* (2020), who reported pulp weights ranging from 8.70 to 2.19 grams among aonla populations in the Garhwal Himalaya. Similarly, Gocher *et al.* (2020) found that the desi variety had the lowest pulp weight at 3.90 grams, while the NA-7 cultivars had the highest at 21.88 grams. Kaim and Bisht (2018) observed the maximum pulp weight in the Banarasi cultivar at 33.58 grams and the minimum in the Kanchan cultivar at 9.05 grams. Additionally, Pandey *et al.* (2016) reported that the fruit pulp weight among ten diverse promising accessions of Indian gooseberry, along with two commercial varieties, ranged from 22.91 to 33.92 g.

4.1.3.6 Pulp Percentage

The fruit length and diameter of the fruits from the different aonla accessions studied are displayed in Table 4.5, 4.6, 4.7 and 4.8. The true treasure, however, lies in the pulp characteristics which not only enhances its value as a fruit but also indicates its potential for nutrient density. The pulp percentage spans an impressive 72.63% (MZR2) to 92.91% (MGL20). Among the states Meghalaya showed high averages of pulp% (92.1%), Tripura (88.6%) and the lowest in Mizoram (85.44%). The boxplot in figure 4.10 provides a comparison of the data distribution across the three states. This considerable pulp yield shows that *P. emblica* can provide a substantial amount of edible product, making it advantageous for both commercial cultivation and nutritional applications.

Similar pulp content percentage was also recorded in aonla cultivars by Bairwa *et al.* (2020) where the maximum pulp percentage was recorded in Francis varieties (98.31%) whereas, minimum pulp percentage was observed in the variety of Laxmi-52 (77.17%). Others studies also recorded similar variations in pulp percentage from different aonla accessions and cultivars (Kaim and Bisht, 2018; Kumar *et al.,* 2013; Kumar *et al.,* 2014; Maholiya *et al.,* 2015; Pandey *et al.,* 2014; Pandey *et al.,* 2016; Singh *et al.,* 2016b).

4.1.3.7 Pulp Stone Ratio

The fruit length and diameter of the fruits from the different aonla accessions examined are presented in Table 4.5, 4.6, 4.7 and 4.8. The pulp-to-stone ratio reaches a remarkable 13.01 (MGL20) followed by MGL6 (11.49), MGL18 (11.46), MGL16 (11.42) and TRP20 (11.22). The ratio also reaches as low as 2.74 (MZR2) followed by MZR16 (3.53), MZR17 (4.21), MGL11 (4.39), MZR9 (4.6) AND TRP9 (5.16). The average of pulp stone ratio recorded from Meghalaya showed the highest ratio (13.1) followed by averages from Tripura (8.38) and the lowest average ratio was obtained from Mizoram (6.69). The boxplot in figure 4.11 shows that Meghalaya has the highest variability in pulp-to-stone ratio, with a broader range and highest maximum value, while Tripura is the most consistent with minimal outliers. Mizoram falls in between, with a balanced distribution and slightly more variability than Tripura.These figures highlight the potential for selecting accessions with exceptional edible portions, catering to the growing demand for high-yield, low-waste fruit options.

Similar variations between aonla accession had been reported by Kumar *et al*. (2013) where he reported pulp stone ratio between 2.77 and 8.24. Another study by Naithani *et al.* (2020) to aligns with the present study, where the pulp:stone ratio varied from 1.93 to 9.82 among the aonla populations from Garhwal regions.

Numerous researchers (Chandravanshi *et al.,* 2022; Gocher *et al.,* 2020; Kaim and Bisht, 2018; Maurya *et al.,* 2024; Patel *et al.,* 2009; Singh *et al.,* 2015) also reported significant variations in pulp stone ratio of aonla accessions and cultivars.

4.1.3.8 Yield

The fruit length and diameter of the fruits from the different aonla accessions examined are presented in Table 4.5, 4.6, 4.7 and 4.8. The yield of fruits is significant not only for enhancing agricultural productivity and economic stability but also for improving public health through better nutrition. Increasing fruit production can address dietary deficiencies and support sustainable agricultural practices, ultimately benefiting both farmers and consumers. The yield of the aonla fruits from different accessions collected from the study showed an average of 63.62 kg/tree, the maximum yield was recorded from MZR18 (163.54 kg/tree) and the minimum yield was obtained in MGL20 accession (31.25 kg/tree). State wise, the Mizoram showed the highest yield averaging 75.22 kg/tree, whereas Tripura (58.31 kg/tree) and Meghalaya (57.33 kg/tree) showed more or less similar average yields. The fruit yield is also shown in boxplots in Figure 4.12, which also show how the aonla accessions differ in the three states. This graphic illustrates the diversity found in the accessions analyzed.

The results of our study present a notable contrast to previously reported values in the literature. Specifically, Maurya *et al*. (2024) reported yields ranging from a maximum of 80.35 kg plant^{-1} to a minimum of 6.15 kg plant^{-1}. The wide yield range observed in our study highlights the potential for variability in plant yields under different conditions and highlights the importance of context-specific practices and interventions.

Table 4.5 Physical parameters of aonla fruits accessions from Meghalaya.

Accession	Fruit Length (mm)	Fruit Diameter (mm)	L/D Ratio	Dry Matter content (%)	Fruit weight (g)	Stone weight (g)	Pulp weight (g)	Pulp%	Pulp stone ratio	Moisture (%)	Yield (kg/tree)
MGL1	20.1	22.2	0.9	14.1	6.1	0.7	5.4	89.0	8.1	85.9	39.8
MGL2	20.9	19.9	0.9	21.9	6.7	0.8	5.9	88.2	7.5	78.1	51.0
MGL3	18.2	19.2	1.0	19.5	4.8	0.8	4.0	83.9	6.0	80.5	33.5
MGL4	16.2	16.8	1.0	16.6	3.5	0.5	3.1	86.9	6.7	83.4	44.8
MGL5	16.7	17.9	0.9	16.7	3.4	0.5	2.9	85.9	6.1	83.3	94.1
MGL6	24.7	28.0	0.9	17.2	11.7	0.9	10.7	92.0	11.5	82.8	77.9
MGL7	18.1	20.0	0.9	20.2	6.6	0.6	6.0	91.5	10.7	79.8	80.5
MGL8	12.8	16.1	0.8	20.6	3.0	0.4	2.6	87.3	6.9	79.4	70.3
MGL9	18.9	20.9	0.9	20.9	5.5	0.9	4.6	85.0	5.5	79.1	42.4
MGL10	17.7	20.1	0.9	19.1	4.1	0.4	3.7	91.0	10.1	80.9	56.8
MGL11	13.8	15.6	0.9	17.0	2.1	0.4	1.7	81.3	4.4	83.0	111.1
MGL12	19.1	21.2	0.9	20.5	6.1	0.6	5.5	90.1	9.1	79.6	46.0
MGL13	20.5	22.6	0.9	17.5	6.8	0.7	6.1	90.2	9.3	82.5	80.8
MGL14	18.8	20.9	0.9	21.6	5.5	0.6	4.9	88.5	7.7	78.4	49.1
MGL15	20.4	23.9	0.9	15.8	9.1	0.8	8.4	91.7	11.0	84.2	62.5
MGL16	21.2	24.0	0.9	15.7	8.7	0.7	8.0	91.9	11.4	84.3	34.0
MGL17	22.8	25.6	0.9	20.6	12.2	1.2	11.0	90.2	9.2	79.4	52.3
MGL18	22.0	23.4	0.9	19.5	7.1	0.6	6.5	92.0	11.5	80.5	56.3
MGL19	19.7	16.4	1.2	20.8	4.0	0.5	3.5	87.1	6.7	79.2	32.3
MGL20	22.7	26.9	0.9	20.8	12.0	0.9	11.1	92.9	13.1	79.2	31.3
C.D.	0.84	0.92	0.04	0.76	0.60	0.07	0.42	1.31	0.88	0.76	-
SE(m)	0.30	0.33	0.01	0.26	0.22	0.024	0.15	0.46	0.31	0.26	-
SE(d)	0.43	0.46	0.02	0.37	0.31	0.03	0.21	0.65	0.43	0.37	-
C.V.	4.95	5.21	4.77	2.43	13.36	6.24	4.34	0.9	6.17	0.56	-

Table 4.6 Physical parameters of aonla fruits accessions from Mizoram.

Accession	Fruit Length (mm)	Fruit Diameter (mm)	L/D Ratio	Dry Matter content (%)	Fruit weight (g)	Stone weight (g)	Pulp weight (g)	Pulp%	Pulp stone ratio	Moisture (%)	Yield (kg/tree)
MZR1	17.17	17.27	0.99	17.55	4.52	0.85	3.67	81.15	5.16	82.45	41.36
MZR2	15.21	16.44	0.93	19.44	2.27	0.61	1.66	72.63	2.74	80.56	79.25
MZR3	15.62	18.47	0.85	18.15	5.98	0.94	5.04	84.06	5.39	81.85	59.34
MZR4	17.76	20.33	0.87	15.34	6.25	0.61	5.64	90.03	9.47	84.66	66.14
MZR5	18.90	24.25	0.78	20.50	5.75	0.62	5.12	89.16	8.23	79.50	68.35
MZR6	17.14	19.08	0.90	21.00	4.12	0.66	3.47	84.01	5.29	79.00	101.05
MZR7	16.36	18.87	0.87	21.80	5.26	0.59	4.67	88.73	7.88	78.20	68.85
MZR8	19.92	22.89	0.87	16.18	4.32	0.58	3.74	86.50	7.29	83.82	55.06
MZR9	13.42	14.67	0.92	18.88	3.21	0.57	2.64	82.06	4.60	81.12	74.32
MZR10	16.68	18.17	0.92	17.02	4.11	0.69	3.42	83.13	5.72	82.98	56.95
MZR11	17.98	22.10	0.81	22.00	5.35	0.71	4.64	86.08	6.55	78.00	55.42
MZR12	23.47	24.85	0.95	17.60	8.87	0.92	7.95	89.67	8.73	82.40	54.32
MZR13	17.93	19.71	0.91	17.10	5.17	0.52	4.65	89.94	8.94	82.90	58.23
MZR14	20.36	21.30	0.98	19.26	5.74	0.57	5.15	90.00	9.04	80.74	67.84
MZR15	14.93	15.81	0.95	18.05	2.51	0.33	2.17	86.76	6.57	81.95	76.82
MZR16	16.33	17.53	0.93	22.57	7.00	1.54	5.45	77.90	3.53	77.43	54.83
MZR17	16.60	18.82	0.88	22.73	3.39	0.65	2.74	80.62	4.21	77.28	65.85
MZR18	17.25	18.79	0.92	19.57	4.67	0.46	4.21	90.21	9.26	80.43	163.54
MZR19	16.45	19.17	0.86	20.34	5.34	0.55	4.79	89.61	8.70	79.66	127.51
MZR20	12.78	15.09	0.85	20.79	2.67	0.36	2.31	86.61	6.51	79.22	109.45
C.D.	0.80	0.80	0.03	0.72	0.51	0.08	0.50	1.91	1.28	0.72	-
SE(m)	0.29	0.29	0.01	0.25	0.18	0.03	0.18	0.67	0.45	0.25	-
SE(d)	0.41	0.40	0.02	0.36	0.25	0.04	0.25	0.94	0.63	0.36	-
C.V.	5.33	4.74	3.75	2.27	6.40	7.30	7.33	1.35	11.59	0.54	-

Table 4.7 Physical parameters of aonla fruits accessions from Tripura.

Accession	Fruit Length (mm)	Fruit Diameter (mm)	L/D Ratio	Dry Matter content (%)	Fruit weight (g)	Stone weight (g)	Pulp weight (g)	Pulp%	Pulp stone ratio	Moisture (%)	Yield (kg/tree)
TRP1	17.80	20.72	0.86	19.55	5.92	0.67	5.25	88.75	7.89	80.45	49.51
TRP2	20.80	21.35	0.98	18.39	6.62	0.64	5.98	90.35	9.37	81.61	100.39
TRP3	20.34	23.13	0.88	17.67	6.23	0.72	5.52	88.50	7.72	82.33	65.34
TRP4	19.29	22.27	0.87	20.44	5.99	0.55	5.44	90.87	9.97	79.56	38.21
TRP5	19.05	18.82	1.01	21.14	4.25	0.52	3.73	87.74	7.23	78.86	45.32
TRP6	18.77	21.38	0.88	23.07	7.36	0.70	6.66	90.44	9.46	76.93	48.32
TRP7	17.01	21.04	0.81	20.12	7.13	0.96	6.17	86.51	7.62	79.88	77.08
TRP8	19.91	20.96	0.95	20.72	7.73	0.87	6.86	88.74	7.88	79.28	68.14
TRP9	17.41	18.77	0.93	18.69	3.98	0.74	3.24	81.38	5.16	81.32	78.21
TRP10	16.59	18.17	0.92	16.77	3.73	0.57	3.16	84.71	6.91	83.23	34.65
TRP11	15.30	17.20	0.89	17.66	4.21	0.48	3.73	88.70	7.85	82.34	57.25
TRP12	17.47	20.40	1.00	19.36	5.00	0.44	4.56	91.19	10.53	80.64	41.95
TRP13	17.74	21.38	0.83	18.67	6.25	0.59	5.66	90.59	9.68	81.34	79.82
TRP14	14.96	17.87	0.84	20.68	3.47	0.40	3.06	88.34	7.58	79.32	54.91
TRP15	15.64	16.97	0.93	17.82	5.15	0.65	4.50	87.27	6.91	82.18	32.66
TRP16	17.19	17.95	0.96	18.32	5.97	0.69	5.28	88.49	8.43	81.68	64.36
TRP17	17.51	18.94	0.92	16.26	5.35	0.53	4.82	90.11	9.12	83.74	64.25
TRP18	17.73	21.63	0.82	18.49	6.73	0.74	5.99	88.95	8.06	81.52	57.35
TRP19	18.39	21.15	0.87	19.68	6.26	0.63	5.63	89.99	9.01	80.32	43.51
TRP20	20.30	22.10	0.92	19.11	7.18	0.59	6.59	91.77	11.22	80.89	64.89
C.D.	0.80	0.87	0.04	0.55	0.38	0.07	0.35	1.24	1.22	0.55	-
SE(m)	0.41	0.31	0.01	0.19	0.13	0.03	0.12	0.43	0.43	0.19	-
SE(d)	0.29	0.44	0.02	0.27	0.19	0.04	0.17	0.61	0.60	0.27	-
C.V.	5.05	4.58	4.71	1.74	4.03	6.85	4.19	0.84	8.79	0.41	-

Table 4.8 Comparison of physical parameters of aonla fruits accessions from all sites.

State		Fruit Length (mm)	Fruit Diameter (mm)	L/D Ratio	Dry Matter content (%)	Fresh wt. (g)	Stone wt. (g)	Pulp wt. (g)	Pulp%	Pulp stone ratio	Moisture Content (%)	Yield (kg/tree)
Meghalaya	Range	12.77-24.72	15.57- 28.04	0.79-1.2	14.09-21.9	2.14-12.24	0.37-1.2	1.74 - 11.14	81.25-92.91	4.39-13.1	78.1-85.91	31.25-111.1
	Average	19.26	21.07	0.91	18.83	6.44	0.66	5.79	88.82	8.62	81.17	57.33
Mizoram	Range	12.78-23.47	14.67-24.85	0.78-0.99	15.34-22.73	2.27-8.87	0.33-1.54	1.66-7.95	72.63-90.21	2.74-9.47	77.28-84.66	41.36-163.54
	Average	17.11	19.18	0.89	19.29	4.83	0.67	4.16	85.44	6.69	80.71	75.22
Tripura	Range	14.96-20.8	16.97- 23.13	0.81-1.01	16.26-23.07	3.47-7.73	0.4-0.96	3.06-6.86	81.38-91.77	5.16-11.22	76.93-83.74	32.66-100.39
	Average	17.96	20.11	0.90	19.13	5.72	0.63	5.09	88.67	8.38	80.87	58.31
C.D.		0.809	0.86	0.036	0.667	0.435	0.074	0.417	1.507	1.136	0.66	
SE(m)		0.291	0.309	0.013	0.238	0.155	0.027	0.149	0.537	0.405	0.24	
SE(d)		0.412	0.438	0.018	0.336	0.22	0.038	0.21	0.76	0.573	0.33	

C.V.	5.086	4.864	4.502	2.159	4.749	7.041	5.139	1.062	8.881	0.51	

*CD and CV of each parameter are calculated for 60 accessions combined

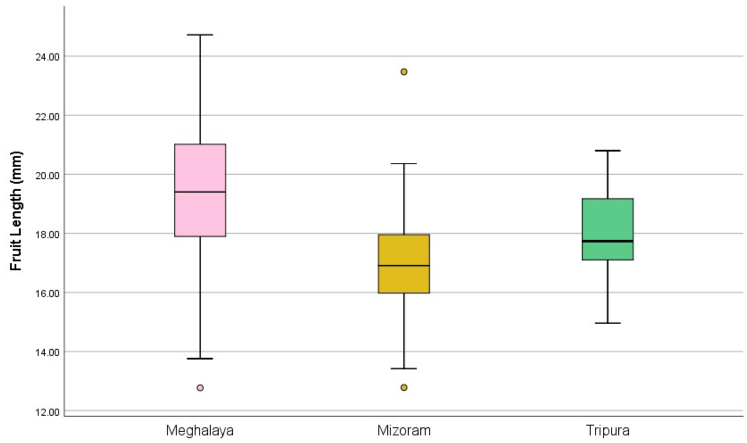


Figure 4.2 Boxplot of fruit length from Meghalaya,Mizoram and Tripura.

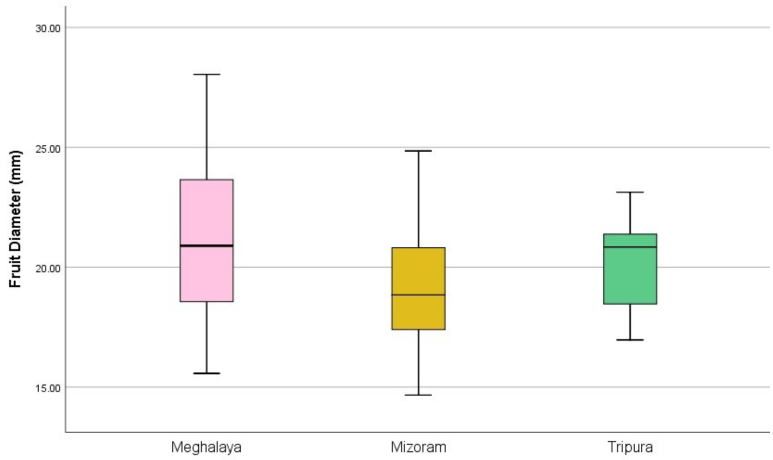


Figure 4.3 Boxplot of fruitdiameter from Meghalaya,Mizoram and Tripura.

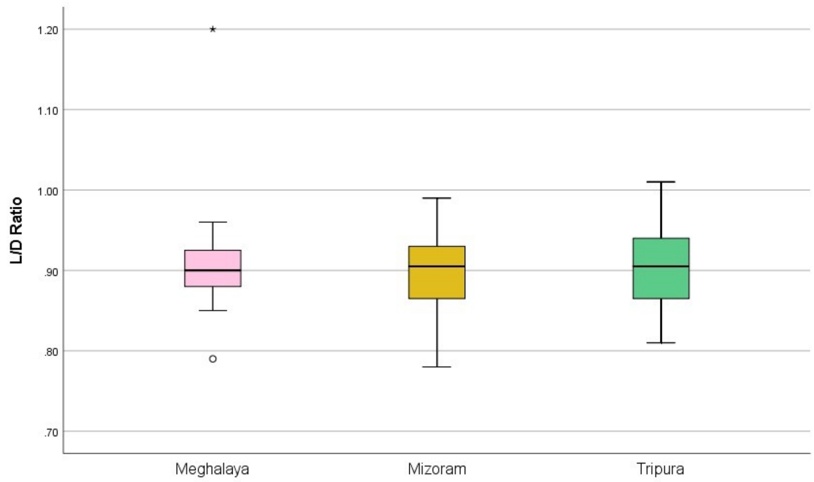


Figure 4.4 Boxplot of fruit length and diameter ratio from Meghalaya, Mizoram and Tripura.

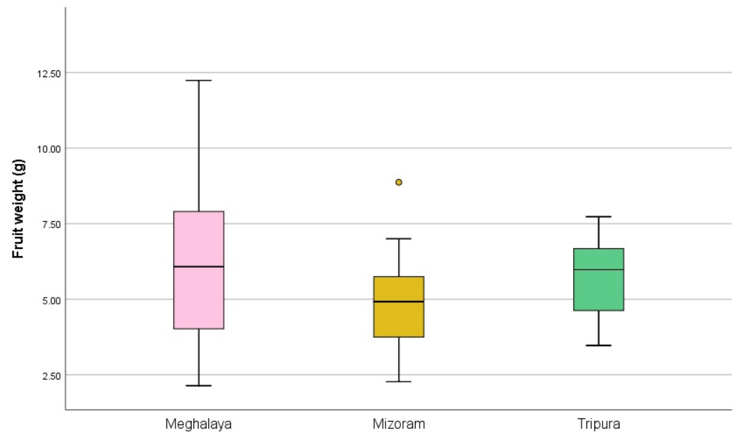


Figure 4.5 Boxplot of fruit weight from Meghalaya, Mizoram and Tripura.

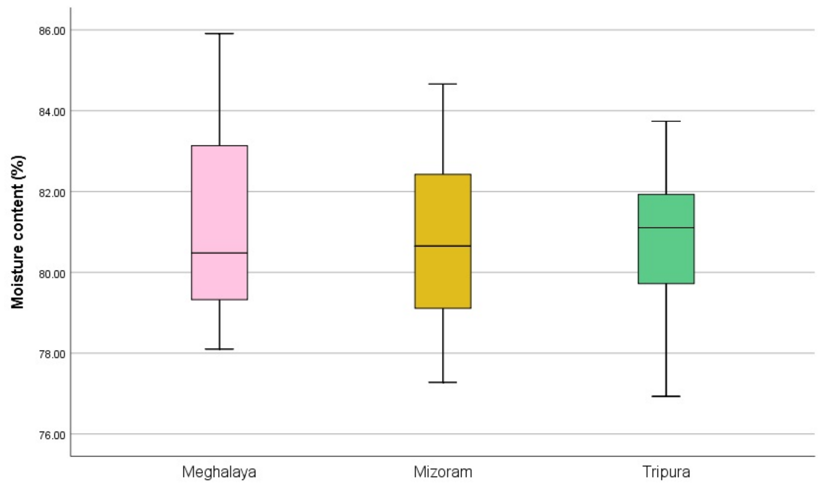


Figure 4.6 Boxplot of moisture content from Meghalaya, Mizoram and Tripura.

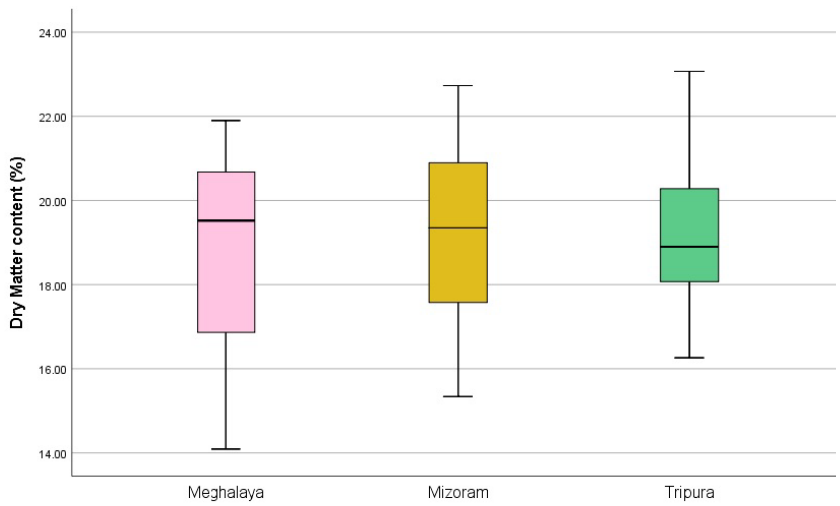


Figure 4.7 Boxplot of dry matter content from Meghalaya, Mizoram and Tripura.

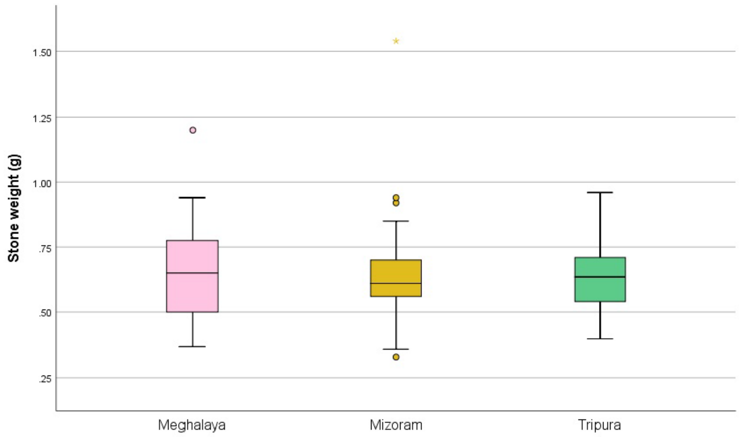


Figure 4.8 Boxplot of stone weight from Meghalaya, Mizoram and Tripura.

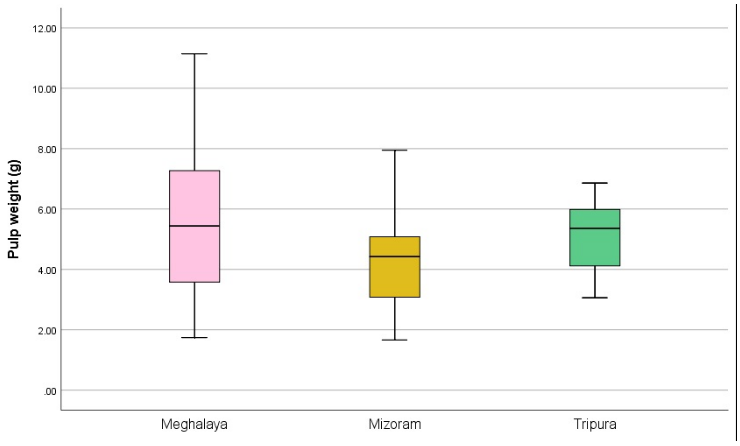


Figure 4.9 Boxplot of pulp weight from Meghalaya, Mizoram and Tripura.

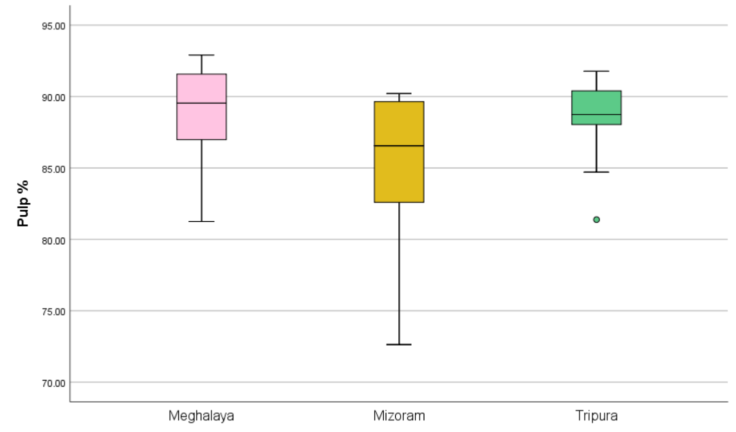


Figure 4.10 Boxplot of pulp% from Meghalaya, Mizoram and Tripura.

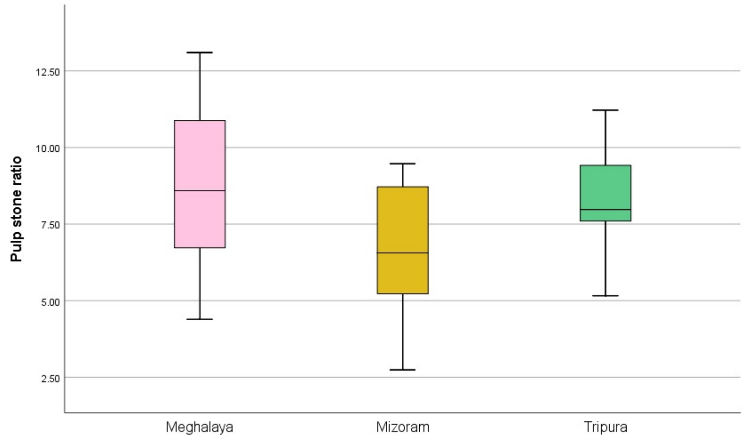


Figure 4.11 Boxplot of pulp stone ratio content from Meghalaya, Mizoram and Tripura.

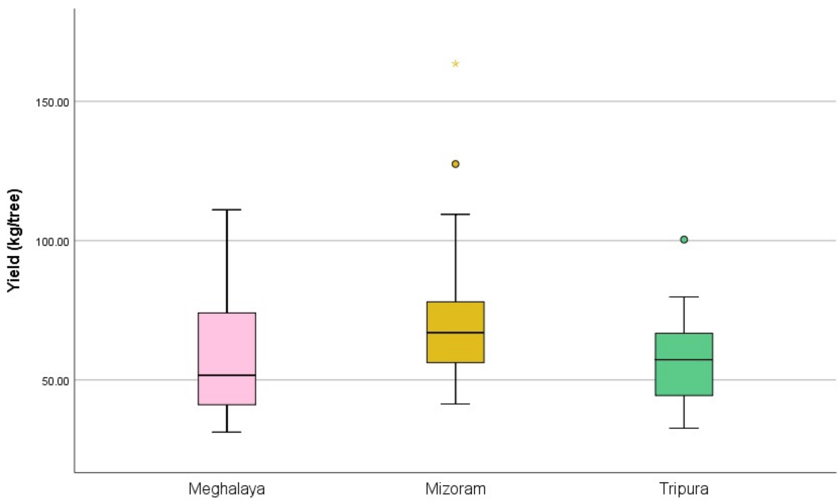


Figure 4.12 Boxplot of fruit yield from Meghalaya, Mizoram and Tripura.

4.2 Bio-Chemical parameters of aonla accessions

Phytochemical tests are useful for identifying the chemical components in plant materials, which can lead to their quantitative measurement. These phytochemical constituents contribute to the medicinal properties of plant species. Evaluating the physicochemical qualities of fruit raw materials is critical for establishing their feasibility for various applications, such as direct consumption and technical processing, as well as the quality of the resultant products (Curi *et al.*, 2018). In the current study, a preliminary phytochemical screening was conducted on *Phyllanrthus emblica* fruits using different chemical reagents. The qualitative analysis of these plant parts confirmed the presence of several primary metabolites, including ascorbic acids, proteins and phenols.

4.2.1 Total Soluble Solids (TSS)

During the maturation process, the TSS content of fruits increases, serving as a maturity index for some crops. Generally, fruits with higher TSS content are sweeter compared to those with lower TSS content. The TSS levels in fruit are closely influenced by climate, nutrition regimes, and other cultural practices. Additionally, soil moisture and nitrogen levels, fruit load, and the photosynthesis capacity of trees also affect the TSS content of the fruit (Erkan and Dogan, 2019). Total Soluble Solids (TSS) is a crucial quality parameter due to their direct effect on the taste of fruit. In the present investigation it was observed that among all the studied accessions, we observe a significant variation in the biochemical parameters across different accessions and the different observation on TSS of aonla fruits from the three states are presented in Table 4.9 (Meghalaya), 4.10 (Mizoram), 4.11 (Tripura) and 4.12 (Combine). For instance, the TSS ranges from 7.5° in MGL5 to 18° brix in MGL2. Others accessions namely MZR2 (17.67° brix), TRP14 (17.50° brix), TRP6 (17.17 °brix) and MZR9 (14.83 °brix) also showed high TSS. While, MGL4 (7.67 °brix), TRP11 (8.17° brix), MGL10 (8.33 °brix) and TRP15 (8.73°brix) showed less TSS too. Out of the three states the average TSS was recorded highest from Mizoram (12.29 °brix), followed by Tripura (12.21 °brix) and the minimum TSS was found from Meghalaya (11.47 °brix). The boxplot in Figure 4.13 shows that Meghalaya and Mizoram have similar TSS distributions, with wide ranges and comparable medians. Both regions show a large variation in TSS values and Tripura displays a narrower spread in TSS values, indicating more consistency in sweetness levels. The variation in total soluble solids (TSS) can be attributed to the different genetic compositions of the individual accessions. Fruits growing in arid regions with limited water tend to accumulate more dry matter and have lower moisture content, which may lead to higher TSS levels in the fruits (Meghwal and Azam, 2015).

The study closely aligns with the finding of Singh *et al.* (2016), where the highest TSS was recorded from Photok (Longleng) region with 21.30°Brix and the lowest TSS from Tanshiqui (Mon) region of north east India with 10.0 °Brix. In a study by Kumari *et al.* (2024) the lowest TSS was recorded in wild aonla with 5.4 °Brix and the highest TSS was observed in Krishna with 15.3 °Brix. But, Kumar and Khatkar (2015) observed that Desi fruits had the highest total soluble solids (TSS) at 15.06 °Brix, while Chakaiya fruits had the lowest at 12.1 °Brix. Gocher *et al.* (2020) also recorded highest TSS at 14.18 °Brix in Desi fruits from among different aonla cultivars under valley condition of Garhwal Himalaya and the lowest in Chaikaya at 9.26 °Brix.

4.2.2 Titratable Acidity (TA)

Titratable acidity (TA) is a vital factor in determining the quality and flavour of fruits, as it reflects the total concentration of organic acids in the juice, influencing taste, nutritional value, and marketability. The level of acidity impacts flavour balance and consumer preference, with optimal acidity enhancing sweetness and perceived freshness. Fruits with appropriate acidity levels tend to have better shelf stability and quality, extending their marketability and shelf life. Genetic and environmental factors play roles in determining acidity levels, with breeding programs and cultivation practices influencing the fruit's acidity and overall quality (Dondini *et al.* 2022; Dorostkar and Moradinezhad, 2022; Manzoor *et al.* 2023; Mengist*et al.* 2022; Nóbrega *et al.* 2021).

The various observations regarding the titratable acidity (TA) of aonla fruits from the three states are shown in Table 4.9 (Meghalaya), Table 4.10 (Mizoram), Table 4.11 (Tripura), and Table 4.12 (Combined). Notably, all the Tables showed significant differences were observed in titratable acidity, with levels ranging from 1.65% to 4.90%. The highest acidity was recorded in MGL19 at 4.90%, followed by TRP20 at 4.40%, MZR14 at 4.35%, TRP3 at 4.22%, and MGL11 at 4.18%. In contrast, the lowest acidity was found in MGL17 at 1.65%, with other accessions showing relatively lower acidity levels, including MZR9 (1.66%), TRP16 (1.71%), MGL13 (1.75%), and MGL18 (1.81%). A comparable average of titratable acidity was obtained from all the three states, 2.96% from Tripura, 2.66% from both Meghalaya and Mizoram. The boxplot (figure 4.14) shows total acidity percentages for Meghalaya, Mizoram, and Tripura, with median acidity around 2.5% for each. All three regions have a similar range (1.5–4%) and interquartile spread (2–3.5%), with Meghalaya having one outlier near 5%.

These results align with the research by Bulo *et al.* (2024), which reported a similar acidity range for wild aonla, between 3.20% and 0.70%, from northeast India. Additionally, Sharma and Gupta (2023) documented a consistent acidity value of 3.07% in aonla collected from the Himalayan regions of India. From the evaluation of aonla cultivars, the acidity ranged from 0.66% to 1.71%, where the highest was recorded in the wild variety (Kumari *et al.,* 2024). Maholiya *et al.* (2015) also conducted a study on four cultivars: Kanchan, Krishna, Chakaiya, and NA 7. According to their findings, the Kanchan cultivar exhibited the highest percent acidity at 2.13%, whereas the Chakaiya cultivar had the lowest percent acidity at 1.79%.

4.2.3 Ascorbic Acid

Ascorbic acid, commonly known as vitamin C, is a key component in the nutritional profile of Indian gooseberry, making it a vital fruit for both dietary and health purposes. The ascorbic acid content in different aonla (gooseberry) accessions showed significant variation. The various observations on the ascorbic acid of aonla fruits from the three states are presented in Table 4.9 (Meghalaya), Table 4.10

(Mizoram), Table 4.11 (Tripura), and Table 4.12 (Combined data). The lowest recorded value was 180 mg/100 g in the MGL15 accession. Other accessions with relatively low ascorbic acid contents included MZR9 (195.0 mg/100 g), MGL13 (206.3 mg/100 g), MZR15 (214.6 mg/100 g), and MZR6 (235.6 mg/100 g). On the other hand, the highest ascorbic acid content was found in the MZR10 accession, with a value of 1392.5 mg/100 g. This was followed closely by MGL14 (1255.3 mg/100 g), MGL20 (1224.4 mg/100 g), MZR1 (1219.3 mg/100 g), and TPRTRP7 (1176.1 mg/100 g). State wise, the highest average of ascorbic acid was obtained from Tripura (751.67 mg/100g) and the lowest from Mizoram (666.56 mg/100g). The boxplot in figure 4.15 shows that Meghalaya and Mizoram have higher and more variable ascorbic acid content than Tripura, which shows a more compact distribution, implying that fruits from Meghalaya and Mizoram offer a broader range of vitamin C levels. The significant variations among aonla accessions may be due to genetic diversity, environmental conditions, such as soil type, climate, and agricultural practices, as well as the maturity stage at harvest, which also play crucial roles in influencing the vitamin C content. Post-harvest handling and processing methods, along with the correlation between ascorbic acid and phenolic compounds, also further affect the retention and stability of vitamin C in the fruit (Galasheva *et al.,* 2023; Lee and Kader, 2000; Pandey *et al.,* 2016; Tripathi *et al.,* 2020) .

The observations are consistent with the earlier reports of Singh *et al.* (2016) who recorded an average ascorbic acid content of 375.0 to 1428.5 mg/100 ml in wild aonla fruits from North east India. In another study by Bhattacherjee *et al.* (2020), they notably observed a very high ascorbic acid content in wild aonla (1278.31 mg 100 g^{-1}) as compared to other aonla cultivars. Whereas, Naithani *et al.* (2020) recorded the ascorbic acid of aonla population in between 191.13 and 495.21 mg 100 g^{-1} from Garhwal Himalaya, which are comparatively lower from our findings. Pandey *et al.* (2014) also observed significant variations in ascorbic acid of aonla from different accession collected from Madhya Pradesh, which ranged in between 347.67 and 632.33 mg/100 g pulp. The vitamin c content in aonla cultivars showed lower value as compared to the present findings, mostly ranging between 498.81 and 559.61 mg/100 g (Tewari *et al.,* 2019).

4.2.4 Total Sugar

Total sugar content is crucial for selecting superior accessions of fruits like Indian gooseberry due to its significant impact on fruit quality, nutritional value, and marketability. Higher sugar levels enhance taste and consumer acceptance, offer greater nutritional benefits, and improve economic value. The data presented in Table 4.9 (Meghalaya), Table 4.10 (Mizoram), Table 4.11 (Tripura), and Table 4.12 (Combined data) showed significant variation in total sugar among the aonla accessions. The total sugar ranges from 3.898 in TRP16 to 13.056 in MZR14. Mizoram recorded the highest average total sugar at 8.31%, with Tripura close behind at 8.26% and Meghalaya at 8.10%. The boxplot in figure 4.16 indicates that Mizoram has the highest variability in sugar content, as indicated by its larger interquartile range (IQR) and broader range, potentially due to environmental or cultivation differences. Meghalaya has the most consistent sugar levels, with a narrower IQR, and only one significant outlier, suggesting uniformity in the sugar content among its samples. Tripura shows moderate variability, with a central tendency (median) lower than that of Meghalaya and Mizoram.

Our study resonates well with the compelling findings of Hazarika and Laltluangkimi, (2019), Singh *et al.* (2016) and Singh *et al.* (2022), who reported total sugar of the aonla accessions in the values of 5.59% to 13.08%, 7.50% to 13.68%, and 6.39% to 11.87%, respectively, demonstrating a consistent trend across the research. Variation in total sugars was observed among aonla cultivars, with Maholiya *et al*. (2015) reporting total sugar levels ranging from 3.49% to 4.68%. Additionally, Gocher *et al*. (2020) found that, in their evaluation of aonla cultivars and wild varieties, the Wild (Desi) had the lowest total sugar content at 6.75%, while the Chakaiya variety had the highest at 8.37%. Temperature and solar radiation, or luminosity, are two climate variables that have an impact on fruit sugar content. While the light that is absorbed by photosynthesis Light energy is transformed by the plants into chemical energy, creating substances that are photo-assimilated, including sugars (Taiz and Zeiger, 2010).

4.2.5 Reducing Sugar

The study of reducing sugar (glucose and fructose) parameters in fruits is crucial for assessing their nutritional value, flavor, ripeness, and quality. High reducing sugar content enhances energy value and sweetness, influences harvest timing, and impacts post-harvest quality and product processing. Research in this area aids in cultivar selection and optimizing agricultural practices to improve fruit quality (Kader, 2002; Boyer and Liu, 2004). A significant difference was observed in the reducing sugar of aonla accessions studied as presented in Table 4.9 (Meghalaya), Table 4.10 (Mizoram), Table 4.11 (Tripura), and Table 4.12 (Combined data), the value varies as low as 2.47% to high as 9.10%. The highest value was recorded from Mizoram in accessions MZR14 which are closely tailed by MGL19 (8.17%) from Meghalaya, followed by two accessions from Tripura i.e. TRP20 (7.81%) and TRP19 (7.44%), another accession from Mizoram just trailed behind at 6.53% in MZR5 accessions. While the lowest was recorded from TRP16 from Tripura, other accessions from Mizoram and Meghalaya also showed low value in reducing sugar namely MZR153 at 3.43%, MZR18 at 4%, MGL12 at 3.97% and MGL8 at 3.51. Minimal variation in reducing sugar percentages across the three locations was recorded, with Tripura (5.37%) showing a slight edge over Meghalaya (5.36%) and Mizoram (5.25%) showing a slightly lower content than the other two. The boxplots included in Figure 4.17 showed that Meghalaya and Mizoram have similar distributions and medians, but Mizoram's data appears more consistent, with fewer outliers and a narrower IQR. Tripura shows the widest range, indicating variability in reducing sugar content among its samples, possibly due to environmental or varietal differences.

The variation in reducing sugar content of aonla (Indian gooseberry) across different regions of India has been well-documented, with Hazarika and Laltluangkimi (2019) reporting a range of 1.29% to 6.16% in accessions from the northeastern regions. In contrast, Pandey *et al.* (2016) found higher values, ranging from 4.15% to 9.17%, in accessions from other parts of India, potentially due to different environmental or genetic factors. Similarly, Bakshi *et al.* (2015) observed a narrower range of 1.78% to 2.19% in their study. The relatively narrow range observed in their study might be due to the selection of accessions with more consistent sugar profiles or could reflect less variation in the environmental and genetics conditions where these samples were collected.

4.2.6 Non Reducing Sugar

The data of non-reducing sugars, which are significant for specific dietary needs, are shown in Table 4.9 (Meghalaya), Table 4.10 (Mizoram), Table 4.11 (Tripura), and Table 4.12 (Combined data). The highest was recorded in MZR16 at 5.71%, while MZR9 has the lowest at 0.53%. Other accessions like MZR17 (5.59%), TRP11 (5.1%), MGL15 (5.08%) and MZR10 (4.53%) also showed considerably high non reducing sugar value, whereas accessions like MZR6 (0.59%), MGL13 (0.66%), TRP9 (0.92%) and TRP7 (1.04%) showed low non reducing sugar values. Mizoram (2.9%) exhibits the highest average of non-reducing sugars, while Meghalaya (2.60%) shows the lowest. Boxplot in figure 4.18 illustrates that Mizoram displayed a marginally higher median and a broader interquartile range compared to Meghalaya and Tripura, indicating greater variability in non-reducing sugar levels. Tripura, with an IQR slightly narrower than Mizoram, had a median similar to Mizoram's, indicating that while the central value of non-reducing sugar is comparable, Tripura's variability is somewhat lower. Meghalaya, on the other hand, exhibited the lowest median and a narrower IQR.

The results of the present study, which show reducing sugars in the range of 4.52% to 6.96%, indicate a significant variation compared to previous studies from different regions of India. The values obtained in our study are notably higher than those reported by Pandey *et al*. (2008) and Pandey *et al*. (2016), which found reducing sugar levels ranging from 2.29% to 4.62% and 2.19% to 4.45%, respectively. Similarly, Bakshi *et al*. (2015) reported a narrower range of 3.07% to 3.41%. However, our results fall within the upper range of the values reported by Hazarika and Laltluangkimi (2019) for Mizoram, where reducing sugar levels were observed between 1.29% and 9.37%. This suggests regional variations in reducing sugar content, possibly due to differences in environmental conditions, cultivation practices, or varietal differences of the samples studied.

4.2.7 Phenol

Phenol content in fruits is essential due to the health benefits of phenolic compounds, which have strong antioxidant properties that help reduce oxidative stress linked to chronic diseases such as cardiovascular disease, diabetes, and cancer (Aguilera *et al.,* 2016). These compounds also offer anti-inflammatory effects, protect against cardiovascular issues, and possess antimicrobial and antitumor properties. Fruits are a major source of these bioactive compounds, providing essential vitamins and minerals, with different fruits offering various types and concentrations of phenolic (Saleem *et al.,* 2022). Research into phenolic content can enhance agricultural practices, aid in developing functional foods, and inform public health recommendations, promoting the consumption of phenol-rich fruits for better health.

The data shown in Tables 4.9 (Meghalaya), 4.10 (Mizoram), 4.11 (Tripura), and 4.12 (Combined) indicates that the phenol contents differs considerably across the different aonla accessions.The phenol content, expressed in GAE mg/100g, was meticulously analyzed, unveiling that the most elevated concentrations were found in MGL16, boasting an impressive 3,201.4 mg/100g, closely followed by TRP12 at 2,979.6 mg/100g, MGL17 at 2,924.8 mg/100g, TRP17 at 2,870.5 mg/100g, and MZR7 at 2,598.2 mg/100g. On the other end of the spectrum, the lowest phenol levels were discerned in MZR1 with 857.3 mg/100g, MGL2 at 806.5 mg/100g, MGL8 at 756.5 mg/100g, MZR16 at 706.9 mg/100g, and finally, MGL13 with 687.7 mg/100g. The average phenolic content also varies among the states. Tripura has the highest concentration of phenol at 1599.26 mg/100g, followed by Mizoram with 1391.59 mg/100g, and Meghalaya with the lowest at 1366.13 mg/100g. Meghalaya shows the widest range and highest variability, while Mizoram has the lowest variability. Tripura displays a broad range but lacks extreme outliers as illustrated in figure 4.19 Boxplot (figure 4.19).

The phenolic content observed in our study, ranging from 1443.6 to 3809.6 GAE mg/100g, is consistent with findings from other studies in India. Specifically, our results fall within the range reported by Singh *et al*. (2016) for the northeastern region, where phenolic content varied between 944.85 to 4969.50 GAE mg/100g. This suggests a similarity in phenolic composition across different regions of the country. The high phenol content reported by Parveen and Khatkar (2015) at 25.33 to 31.80%, and Bhattacherjee *et al*. (2020) at 12.25 to 58.21 mg/g further supports the presence of significant phenolic compounds in similar samples. The variation in total polyphenol content among different varieties may be partly attributed to differences in maturity stages, genetic factors, and agronomic conditions (Hilton and Palmer-Jones, 1973; Zheng and Wang, 2001). Our findings underscore the substantial phenolic content in the studied samples, aligning well with existing literature and highlighting the importance of regional variations in phenolic content across India.

4.2.8 Protein

The protein content in fruits is generally low compared to other food groups like vegetables, legumes, and animal products. However, understanding the importance of protein in fruits can provide insights into their nutritional value and role in a balanced diet (Lozano, 2006). The analysis of protein content across various accessions unveiled some fascinating variations, pinpointing promising candidates for advanced breeding and selection. The data shown in Tables 4.9 (Meghalaya), 4.10 (Mizoram), 4.11 (Tripura), and 4.12 (Combined) also indicates the proteins differs considerably across the different aonla accessions. At the forefront were the accessions MGL1, boasting the highest protein content at 6.24%, followed closely by MGL20 at 5.97%, MGL8 at 5.92%, MZR19 at 5.84%, and MGL14 at 5.82%. These accessions emerge as key players for enhancing protein yield in future cultivars. Conversely, the accessions with the lowest protein content were MGL3 at 2.19%, MZR13 at 2.31%, MZR8 at 2.56%, MGL12 at 2.65%, and MGL13 at 2.73%. Tripura has the highest average protein content at 4.27%, followed by Meghalaya at 3.96%, and Mizoram at 3.79%. Meghalaya and Tripura have similar median protein levels, but Meghalaya shows a slightly broader IQR and Mizoram have the most consistent protein content, while Meghalaya and Tripura show greater variability as shown in the boxplot of figure 4.20. The findings suggest a significant range in protein content among the accessions.

The protein content in the samples analyzed in this study ranged from 2.19% to 6.24%, which is within the range reported in previous studies but shows some variability. For instance, Bulo *et al*. (2024) reported a broader range of 2.06% to 8.03% in different accessions from Arunachal Pradesh, North East India, indicating potential genetic or environmental influences. The average protein content reported by Muzaffar *et al*. (2023) was 3.27%, slightly lower than the range observed in this study. The variability showed the importance of considering genetic and environmental factors in protein content analysis and a further research to identify accessions with optimal protein content for specific applications may be considered.

4.2.9 TSS and T. Acidity Ratio

The acidity of aonla is a crucial factor in assessing its organoleptic quality. Total Acidity (TA) is commonly used to express the fruit's acidity. When combined, these characteristics provide an indication of the sweet-acid balance in a fruit, which can be measured using the Sugar/Acid (S/A) ratio. This parameter reflects the relative amounts of sugars and acids in the fruit, with a balanced ratio indicating a fruit that is more appealing to consumers. For instance, an acceptable strawberry flavour typically requires a minimum Total Soluble Solids (TSS) of 7% and a maximum TA of 0.8% (Manning, 1996).

The data's provided in Tables 4.9 (Meghalaya), 4.10 (Mizoram), 4.11 (Tripura), and 4.12 (Combined) shows significant variability in TSS and T. Acidity ratio among different accessions. The highest TSS: Acidity content was observed in accession MZR9 at 8.91, followed by MZR2 with 8.29, and MGL18 with 7.66. Accessions TRP16 and MGL14 also showed relatively high TSS levels at 6.95 and 6.88, respectively. On the other hand, the lowest values were recorded in accessions MGL11 and MZR14, both at 2.11, followed by MGL19 at 2.33, MGL7 at 2.36, and TRP20 at 2.70. Among the states, Mizoram has the highest TSS and Acidity Ratio at 4.94%, Meghalaya follows with a 4.73% ratio, showing a slightly lower sweetness-acidity balance and Tripura has the lowest at 4.31%. The boxplot in figure 4.21 revealed that Meghalaya has the widest range of TSS acidity ratio, while Mizoram and Tripura have similar median values but slightly different ranges. This wide range in TSS: T. Acidity from 2.11 to 8.91 highlights the diversity in sweetness and flavour potential among the accessions, which could significantly impact their organoleptic quality and consumer preference.

When compared to previous findings, the results align well within the ranges reported by other researchers. Singh *et al*. (2016) observed a slightly broader range of 2.64 to 9.72, indicating that the present study's samples encompass both the lower and upper limits of the ratio. This similarity suggests consistency in the general profile of the fruits analysed across different studies, despite potential variations in environmental conditions, cultivars, or post-harvest handling. Pandey *et al*. (2008) reported a narrower range of 3.22 to 7.35, which falls entirely within the present study's findings. This narrower range could indicate a more specific selection of fruit types or conditions in their study, suggesting that the broader range observed here may result from a more diverse set of samples.

Table 4.9 Qualitative characteristics of aonla fruit accessions from Meghalaya

Accession	**TSS (°Brix)**	**T. Acidity (%)**	**Ascorbic Acid (mg/100g)**	**TS (%)**	**RS (%)**	**NRS (%)**	**Phenol (mg/100g)**	**Protein (%)**	**TSS : Acidity**
MGL1	12.17	2.13	433.78	7.61	5.67	1.85	1220.30	6.24	5.71
MGL2	18.00	3.37	827.10	7.32	5.71	1.53	806.50	3.60	5.34
MGL3	14.00	2.82	630.00	6.27	4.89	1.31	865.30	2.19	4.97
MGL4	7.67	2.60	637.58	9.01	5.13	3.69	1025.40	3.15	2.96
MGL5	7.50	1.88	180.00	8.83	5.17	3.47	931.50	3.18	4.01
MGL6	9.83	2.77	590.00	7.61	5.46	2.04	1624.10	3.04	3.55
MGL7	9.67	4.14	935.09	5.61	4.32	1.22	1148.30	3.17	2.36
MGL8	11.47	3.03	790.00	5.51	3.51	1.89	756.50	5.92	3.79
MGL9	11.50	2.26	453.75	8.23	5.56	2.54	880.40	4.72	5.14
MGL10	8.33	2.26	914.45	8.45	5.61	2.70	932.40	3.43	3.69
MGL11	8.83	4.18	1085.00	8.24	5.46	2.64	938.80	3.38	2.11
MGL12	12.83	1.96	257.78	6.98	3.97	2.86	1218.70	2.65	6.55
MGL13	12.00	1.75	206.28	6.01	5.31	0.66	687.70	2.73	6.85
MGL14	14.67	2.13	1255.33	8.13	4.46	3.49	1977.10	5.82	6.88
MGL15	10.50	3.03	950.00	10.35	5.01	5.08	1204.30	4.46	3.48
MGL16	11.70	2.35	464.89	7.81	6.39	1.35	3201.40	3.01	5.01
MGL17	10.17	1.65	834.27	9.48	5.29	3.98	2924.80	4.68	6.16

Accession	TSS (°Brix)	T. Acidity (%)	Ascorbic Acid (mg/100g)	TS (%)	RS (%)	NRS (%)	Phenol (mg/100g)	Protein (%)	TSS : Acidity
MGL18	13.83	1.81	589.87	9.59	5.58	3.82	1138.70	5.12	7.66
MGL19	11.17	4.90	842.46	12.24	8.17	3.86	2095.20	2.75	2.33
MGL20	13.50	2.22	1224.44	8.71	6.46	2.14	1745.20	5.97	6.12
C.D.	0.85	0.42	31.31	0.60	0.30	0.56	99.24	0.49	0.59
SE(m)	0.30	0.21	10.94	0.21	0.10	0.20	34.66	0.17	0.21
SE(d)	0.42	0.15	15.46	0.30	0.15	0.28	49.02	0.24	0.29
C.V.	4.47	9.47	2.69	4.46	3.34	13.01	4.40	7.50	7.52

Table 4.10 Qualitative characteristics of aonla fruit accessions from Mizoram.

Accession	TSS (°Brix)	T. Acidity (%)	Ascorbic Acid (mg/100g)	TS (%)	RS (%)	NRS (%)	Phenol (mg/100g)	Protein (%)	TSS: Acidity
MZR1	14.50	2.11	1219.29	7.73	4.18	3.38	857.30	4.32	6.86
MZR2	17.67	2.13	550.77	9.10	5.95	3.00	1148.80	3.31	8.29
MZR3	10.07	2.09	657.33	6.60	5.46	1.08	876.40	4.30	4.82
MZR4	13.33	3.20	1042.70	8.12	5.86	2.15	1215.50	2.76	4.17
MZR5	12.83	2.35	313.90	9.14	6.53	2.48	2528.60	2.84	5.47
MZR6	9.17	2.01	235.29	5.46	4.84	0.59	1465.60	3.09	4.57
MZR7	14.33	2.23	471.14	7.63	5.47	2.06	2598.20	3.52	6.42
MZR8	9.33	2.35	596.67	10.02	5.66	4.14	1390.40	2.56	4.01
MZR9	14.83	1.66	195.00	5.36	4.80	0.53	1108.40	4.35	8.91
MZR10	12.67	3.50	1392.50	9.68	4.92	4.53	894.00	4.59	3.62
MZR11	12.00	2.65	674.26	6.25	4.58	1.59	1559.40	4.08	4.54
MZR12	10.83	2.21	620.36	9.72	5.50	4.00	1470.60	3.62	4.90
MZR13	13.43	3.93	975.00	9.71	6.33	3.21	1023.60	2.31	3.42
MZR14	9.17	4.35	1053.55	13.06	9.10	3.75	1520.90	3.17	2.11
MZR15	10.50	2.22	214.58	4.96	3.43	1.45	1018.80	4.72	4.73
MZR16	10.83	2.90	448.13	11.33	5.32	5.71	706.90	2.85	3.73
MZR17	10.33	3.07	537.50	10.55	4.66	5.59	1135.50	3.32	3.37

MZR18	12.97	2.13	689.60	8.37	4.00	4.15	2105.30	4.80	6.10
MZR19	13.07	3.03	581.88	7.09	4.38	2.57	2076.40	5.84	4.32
MZR20	13.97	3.16	861.71	6.28	4.11	2.06	1131.10	5.48	4.43
C.D.	0.78	0.19	20.31	0.72	0.43	0.80	103.08	0.44	0.38
SE(m)	0.27	0.07	7.09	0.25	0.15	0.28	36.01	0.15	0.13
SE(d)	0.38	0.09	10.03	0.36	0.21	0.40	50.92	0.22	0.19
C.V.	3.82	4.23	1.84	5.26	4.89	16.68	4.48	6.97	4.63

Table 4.11 Qualitative characteristics of aonla fruit accessions from Tripura.

Accession	**TSS (°Brix)**	**T. Acidity (%)**	**Ascorbic Acid (mg/100g)**	**TS (%)**	**RS (%)**	**NRS (%)**	**Phenol (mg/100g)**	**Protein (%)**	**TSS: Acidity**
TRP1	11.33	3.03	729.60	9.24	4.62	4.39	1553.00	2.97	3.74
TRP2	11.83	3.16	558.75	7.70	5.18	2.40	863.70	3.05	3.76
TRP3	13.83	4.22	579.38	10.74	6.47	4.06	1714.80	3.49	3.28
TRP4	14.83	3.63	716.43	7.50	5.89	1.54	2457.00	5.09	4.09
TRP5	10.83	3.12	1085.93	9.01	4.32	4.46	1338.70	5.49	3.48
TRP6	17.17	2.77	683.90	6.75	4.84	1.82	1149.90	5.58	6.23
TRP7	13.00	2.26	1176.11	6.32	5.22	1.04	1298.70	2.89	5.74
TRP8	10.67	2.56	592.36	8.74	6.38	2.24	1207.30	4.31	4.17
TRP9	12.00	2.73	690.23	6.01	5.04	0.92	2272.70	4.04	4.40
TRP10	13.00	2.21	1158.06	7.64	4.40	3.08	926.00	3.94	5.88
TRP11	8.17	2.13	382.22	9.84	4.48	5.10	1537.00	4.57	3.83
TRP12	13.33	3.93	774.17	9.41	6.12	3.12	2979.60	3.66	3.40
TRP13	9.17	3.33	300.70	10.37	5.61	4.52	1548.20	3.26	2.75
TRP14	17.50	3.12	677.58	7.23	5.46	1.69	1258.70	4.93	5.62
TRP15	8.73	2.43	1165.28	6.85	5.23	1.54	956.80	3.26	3.59
TRP16	11.83	1.71	700.65	3.90	2.47	1.36	2256.80	5.18	6.95
TRP17	13.07	2.86	664.38	6.60	4.3	2.13	2870.50	3.88	4.58

					5				
TRP18	12.50	2.52	370.22	7.33	6.00	1.26	1044.40	4.89	4.97
TRP19	9.50	3.20	1022.96	11.77	7.44	4.11	1252.30	5.31	2.97
TRP20	11.87	4.40	1004.44	12.32	7.81	4.28	1499.10	5.53	2.70
C.D.	1.12	0.20	63.98	0.82	0.38	0.84	111.89	0.70	0.57
SE(m)	0.39	0.07	22.35	0.29	0.13	0.29	39.08	0.25	0.20
SE(d)	0.55	0.10	31.60	0.41	0.19	0.42	55.27	0.35	0.28
C.V.	5.53	4.16	5.15	6.03	4.26	18.47	4.23	9.97	8.01

Table 4.12 Comparison of biochemical properties of aonla accessions from Meghalaya, Mizoram and Tripura.

States		**TSS (°Brix)**	**T. Acidity (%)**	**TSS: Acidity**	**Ascorbic Acid (mg/100g)**	**TS (%)**	**RS (%)**	**NRS (%)**	**Phenol (mg/100g)**	**Protein (%)**
Meghalaya	Range	7.50 - 18.0	1.65 – 4 .90	2.11 – 7.66	180.0 – 1255.33	5.51 – 12.24	3.51 - 8.17	0.66 – 5.08	687.70 – 3201.4	2.19 – 6.24
	Average	11.47	2.66	4.73	705.10	8.10	5.36	2.60	1366.13	3.96
Mizoram	Range	9.17 - 17.67	1.66 - 4.35	2.11 - 8.91	195.0 - 1392.50	4.96 - 13.06	3.43 - 9.10	0.53 - 5.71	706.90 - 2598.20	2.31 - 5.84
	Average	12.29	2.66	4.94	666.56	8.31	5.25	2.90	1391.59	3.79
Tripura	Range	8.17 - 17.50	1.71- 4.40	2.70 - 6.95	300.70 - 1176.11	3.90 - 12.32	2.47- 7.81	0.92 - 5.10	863.70 - 2979.60	2.89 - 5.58
	Average	12.21	2.96	4.31	751.67	8.26	5.37	2.75	1599.26	4.27
$CD_{0.05}$		0.90	0.28	41.87	0.7	0.36	0.72	101.4	0.54	0.51
SE(m)		0.32	0.1	14.93	0.25	0.13	0.26	36.2	0.19	0.18
SE(d)		0.45	0.14	21.12	0.35	0.18	0.36	51.1	0.27	0.25
C.V.		4.61	6.26	3.66	5.26	4.15	16.15	4.3	8.31	6.69

*CD and CV of each parameter are calculated for 60 accessions combined.

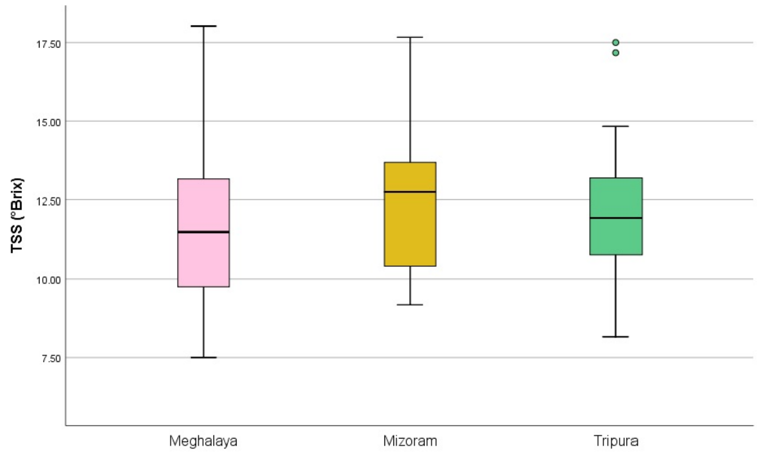


Figure 4.13 Boxplot of TSS from Meghalaya, Mizoram and Tripura.

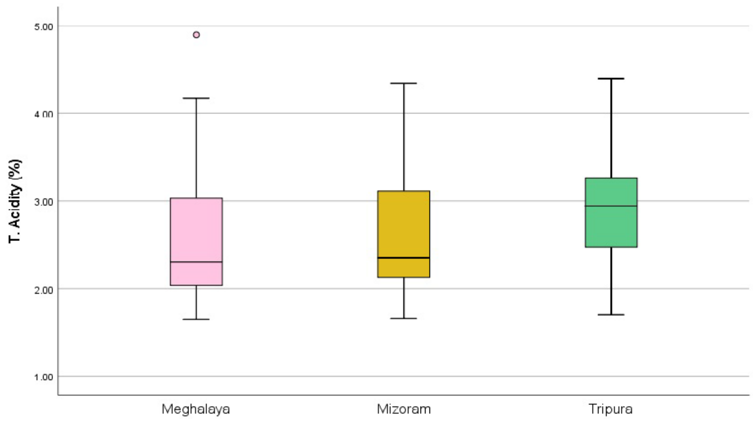


Figure 4.14 Boxplot of titrable acidity from Meghalaya, Mizoram and Tripura.

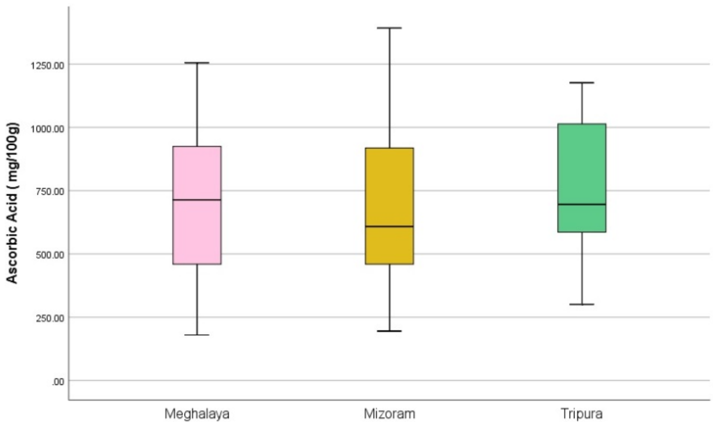


Figure 4.15 Boxplot of ascorbic acid from Meghalaya, Mizoram and Tripura.

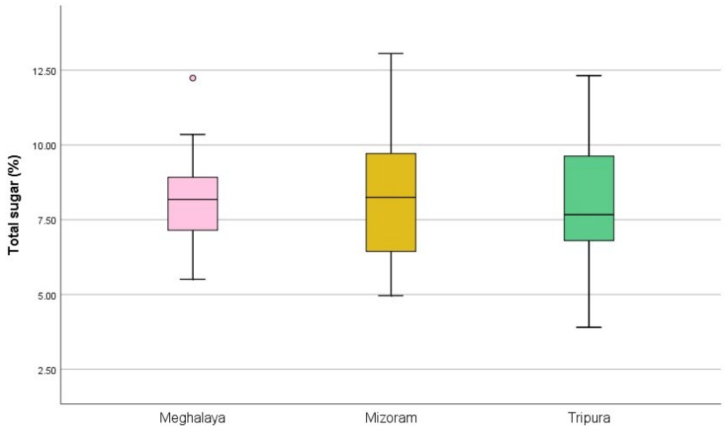


Figure 4.16 Boxplot of total sugar from Meghalaya, Mizoram and Tripura.

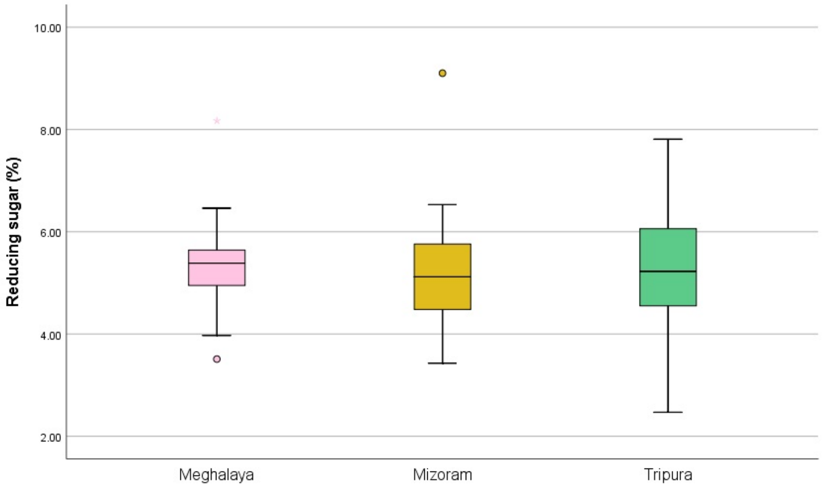


Figure 4.17 Boxplot of reducing sugar from Meghalaya, Mizoram and Tripura.

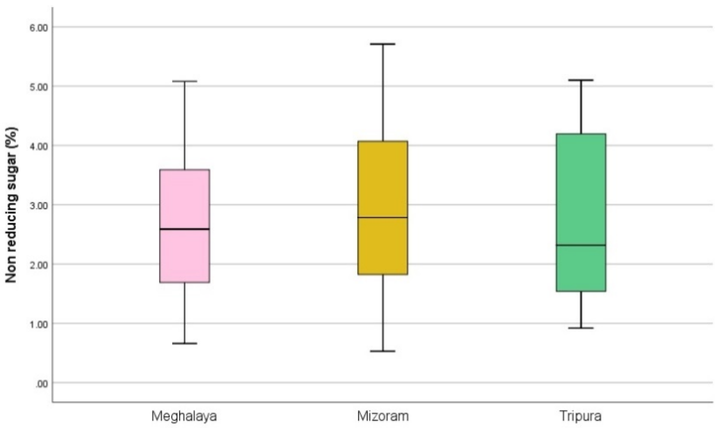


Figure 4.18 Boxplot of non reducing sugar from Meghalaya, Mizoram and Tripura.

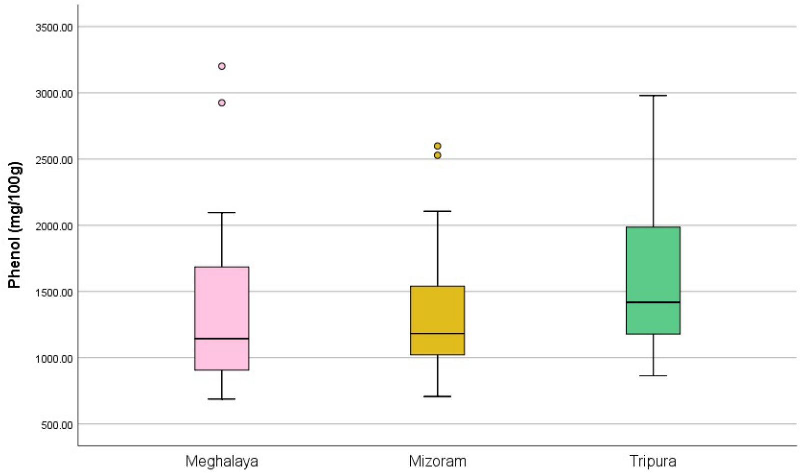


Figure 4.19 Boxplot of phenol content from Meghalaya, Mizoram and Tripura.

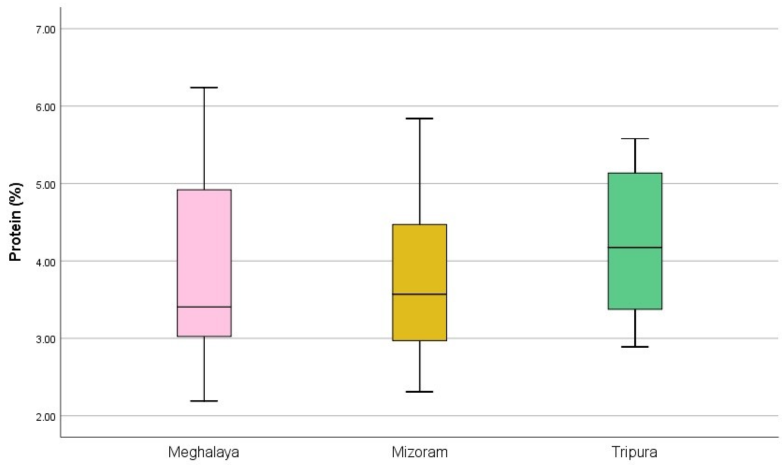


Figure 4.20 Boxplot of protein content from Meghalaya, Mizoram and Tripura.

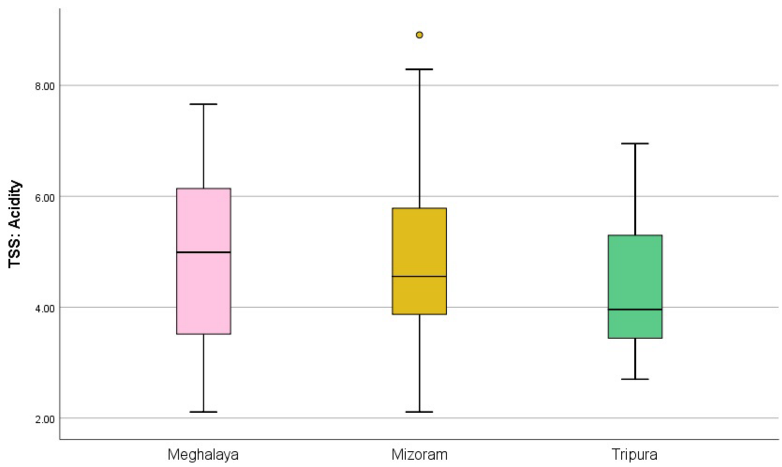


Figure 4.21 Boxplot of TSS and T. acidity ratio from Meghalaya, Mizoram and Tripura.

4.3 Mineral Content of aonla fruits

Minerals play a vital role in maintaining optimal bodily function and overall health. Fruits, highly esteemed in human diets for their rich vitamin and mineral content, are particularly valuable sources of essential minerals. Their contribution to health extends beyond just providing vitamins; they are integral to supporting various physiological processes and overall well-being (Sajib *et al.*, 2014). Around 98% of the body's calcium (Ca) and 80% of its phosphorus (P) are stored in the skeleton. A deficiency in these essential minerals can compromise the immune system, making the body more vulnerable to infections (Hendricks, 1998). The content of mineral elements in plants depends to a high degree on the soil's abundance, including the intensity of fertilisation (Kruczek, 2005). The minerals content of selected accessions are shown in Table 4.13, 4.14, 4.15 and 4.16.

4.3.1 Calcium

Calcium makes the major element of bones and teeth. It also participates in muscle contractions, conduction of nerve impulses and cell membrane permeability, blood coagulation. Moreover, calcium is a co-factor of numerous enzymes, e.g. those active in glycogenesis. Because of rapidly increasing mass of the body, including bones, a particularly high demand for calcium and phosphorus occurs between the ages of 1-3 and 10-15 years (Szotowa *et al.*, 1996). Recommended Dietary Allowance for Calcium varies between 700–1200 mg/day throughout life, as stated both at the international level by the United States Department of Agriculture (DRIs - USDA) In our present studies significant variation was observed in the values of Calcium (Table 4.13, 4.14, 4.15 and 4.16), the highest value among the accessions was recorded from Mizoram states in the accessions MZR12 at 74.53 mg/100g subsequently by TRP4 at 66.45, MGL3 at 55.80, MGL13 at 55.24 and TRP10 at 53.14 mg/100g. Whereas the minimum calcium was also recorded from Mizoram state in MZR15 at 9.6 mg/100g, accessions like TRP20 at 10.61 and MGL4 at 11.84 mg/100g also showed less calcium values. Among the states the average calcium was found maximum from Meghalaya with 31.09 mg/100g followed by Tripura with 29.46 mg/100g and the lowest was recorded from Mizoram at 28.98 mg/100g.

Meghalaya has the highest median calcium content, while Mizoram shows the narrowest range with one outlier. Tripura has a wider calcium distribution without any outliers (Figure 4.22).

Compared to previous studies, the calcium content found in this study shows both similarities and discrepancies. For instance, Motalab *et al*. (2022) reported a calcium content of 26.40 mg/100g in aonla fruits from Bangladesh, while Parveen and Khatkar (2015) found a range of 17.84 to 28.40 mg/100g in samples from Hisar, Haryana. A notably higher value was observed by Raju *et al*. (2023) in Karnataka, with a reported calcium content of 128 mg/100g.

4.3.2 Magnesium

Magnesium is crucial for maintaining healthy muscles, nerves, bones, and stable blood sugar levels. It plays a key role in the proper functioning of muscles and nerves, helps regulate blood sugar and blood pressure, and supports the production of proteins, bones, and DNA (Abobatta, 2020). The study on magnesium content (Table 4.13, 4.14, 4.15 and 4.16) revealed that there was wide range of variation among different accessions of aonla. Among the accessions analysed, TRP7 exhibited the highest magnesium content at 27.58 mg/100g, followed closely by TRP8 with 26.31. MGL11 also recorded a high magnesium level at 26.03, while MZR11 and MZR17 had magnesium contents of 25.17 and 24.91 mg/100g, respectively. Conversely, the study also identified the accessions with the lowest magnesium content. MGL5 had the lowest level at13.6 mg/100g, MZR20, MGL10, TRP9 and MZR18 followed closely with magnesium contents of 14.36, 15.23, 15.43 and 15.83 mg/100g respectively. In comparison betwwen the three states, Meghalaya has the highest average magnesium level at 20.32 mg, Tripura follows closely with an average of 19.97 mg, Mizoram has the lowest average magnesium level among the three states at 19.47 mg. The variability and central tendencies of magnesium content in these three states are highlighted in a boxplot (Figure 4.23).

The present study found that the magnesium content in *Phyllanthus emblica* fruits ranged from 13.6 to 27.58 mg/100g, indicating a moderate level compared to previous findings from different regions. In Bangladesh, Motalab *et al*. (2022)

reported a significantly higher magnesium content of 76.40 mg/100g, which may be due to differences in soil composition, climate, or agricultural practices. In contrast, Raju *et al*. (2023) reported a much lower magnesium content of 8 mg/100g in Karnataka, India, suggesting potential variations in environmental conditions or analytical methods. However, another study from Karnataka by Sajid *et al*. (2014) found amagnesium content of 78 mg/100g, similar to the findings in Bangladesh.

4.3.3 Iron

Iron is a mineral naturally found in various foods and is crucial for hemoglobin, a protein in red blood cells that carries oxygen from the lungs to the tissues (Wessling-Resnick, 2014). Additionally, as part of myoglobin, another oxygen-carrying protein, iron plays a role in muscle metabolism and maintaining healthy connective tissue (Aggett, 2012). Including iron-rich fruits in a balanced diet can help meet nutritional requirements, especially for individuals who may not get sufficient iron from animal sources. According to USDA the daily recommended intake of iron is 8mg for adult male and 18mgfor adult female. The iron content in the fruits of *Phyllanthus emblica* accessions shows notable variation (Table 4.13, 4.14, 4.15 and 4.16). Among the accessions with the highest iron levels, MZR12 leads with 8.43 mg/100g of iron, followed by TRP13 with 5.67 mg/100g, and both MZR6 and MZR15 at 5.15 mg/100g each. MGL5 is close behind with 5.07 mg/100g. On the other end of the spectrum, the accessions iron content include TRP12 with the lowest at 0.73 mg/100g, accessions of MZR5 and MGL19, both at 1.00 mg/100g, MGL2 at 0.99 mg/100g, MGL3 at 0.92 mg/100g also showed low value of Iron contents. Mizoram has the highest average iron content at 3.24, Tripura follows with an average iron content of 2.51, and Meghalaya has the lowest average iron content at 2.12. The variability and central tendencies of magnesium content in these three states are shown in a boxplot graph (Figure 4.24).

The iron content in *Phyllanthus emblica* fruits, as observed in the present study, highlights a broader variability compared to other reported values. For instance, in Bangladesh, Motalab *et al*. (2022) found an iron content of 0.87 mg/100g, while Parveen and Khatkar (2015) reported a range of 1.77 to 3.10

mg/100g in Hisar, Haryana. In Sri Lanka, Abeysuriya *et al*. (2020) documented an iron content of 0.7 mg/100g, and Raju *et al*. (2023) observed 1.12 mg/100g in Karnataka.

4.3.4 Potassium

Potassium, which is the most prevalent cation inside cells, is a crucial nutrient found naturally in various foods. It is present in all body tissues and is necessary for proper cell function due to its role in regulating intracellular fluid volume and electrochemical gradients across cell membranes. Low potassium levels can lead to higher blood pressure, increased risk of kidney stones, greater bone turnover, elevated urinary calcium loss, and higher sensitivity to salt (IOM, 2005; Stone *et al*., 2016). For the healthy adult, the USDA Recommended Daily Allowance (RDA) for potassium intake not more than 4700 mg respectively per day. The potassium content across various accessions of *Phyllanthus emblica* shows notable variation (Table 4.13, 4.14, 4.15 and 4.16), reflecting the diverse nutrient profiles within this species. Among the accessions analysed, CPG-6 stands out with the highest potassium concentration at 2.09, followed closely by KCP1 at 1.91, KAM-1 at 1.69, TURA-4 at 1.63, and LNL3 at 1.61. These accessions represent the top five in terms of potassium accumulation. Contrariwise, the accessions with the lowest potassium was recorded in CPG-1 with 0.62 followed closely by WNG-2 with 0.64, TSP-4 with 0.65, TSP-3 with 0.71 and NKL1 with 0.76. State wise, the potassium content was recorded to be almost similar with Mizoram at 1.2%, Meghalaya at 1.18% and Tripura at 1.15%. Boxplot in figure 4.25 revealed that Tripura has both a higher median and wider spread in potassium percentages compared to Meghalaya and Mizoram, Meghalaya shows slightly more variability than Mizoram due to its outlier, but both have lower medians than Tripura.

The potassium content in *Phyllanthus emblica* fruits, as observed in the present study, showed closed proximity with previous findings reported by Bulo *et al*. (2024) from the Northeast region of India, which noted a potassium content ranging from 8.17 to 23.1 mg/g (0.817% to 2.31%). Conversely, Pandey *et al*. (2008) found lower potassium levels in the Panna Forests of Madhya Pradesh, ranging from

0.39% to 1.09%. The present finding shows a moderate variability in potassium content that likely reflects differences in geographic location and environmental conditions.

4.3.5 Phosphorus

Phosphorus is a crucial micronutrient involved in many physiological functions. It is found in nucleic acids, high-energy molecules (such as ATP, ADP, GTP, and GDP), phospholipids, and biological membranes. Phosphorus is vital for energy metabolism, intracellular signaling, and maintaining acid-base balance (Vorland *et al*., 2017; Ciosek *et al*., 2021). The analysis of phosphorous content in different accessions of *Phyllanthus emblica r*eveals significant variation as presented in Table 4.13, 4.14, 4.15 and 4.16. Among the top five accessions, TRP5 exhibits the highest phosphorous content at 1.307%, followed by TRP16 at 1.187%, MZR13 at 1.000%, MGL14 at 0.367%, and MGL9 at 0.357%. On the other hand, the accessions with the lowest phosphorous content include NKL1 at 0.053%, WNG-3 at 0.067%, WNG-2 and WNG-1 both at 0.070%, and UMR-3 at 0.073%. The average phosphorus levels in the three states are relatively low, with all three states showing values below 0.25%. The boxplot illustrated in figure 4.26 revealed lower median and narrower range of phosphorus levels was recorded from Meghalaya, an outlier and higher median in phosphorus content was found from Mizoram, and higher median and wider range, along with outliers in phosphorus levels was recorded from Tripura.

The analysis of phosphorus content in *Phyllanthus emblica* fruits revealed a range of 0.073% to 1.307%. This finding is consistent with the broader literature, particularly the study conducted by Pandey *et al*. (2008), which reported phosphorus levels in the Panna Forests of Madhya Pradesh ranging from 0.12% to 1.72%. The lower end of our findings shows that certain environmental or genetic factors may limit phosphorus accumulation in some fruits, while the upper range aligns closely with previous studies, indicating that *Phyllanthus emblica* has the potential to be a significant source of this essential nutrient.

Table 4.13 Minerals content in aonla fruits from Meghalaya.

Accession	Calcium (mg /100g)	Magnesium (mg /100g)	Iron (mg /100g)	Potassium (%)	Phosphorous (%)
MGL1	15.13	17.31	2.12	1.01	0.12
MGL2	36.61	21.78	0.99	0.93	0.09
MGL3	55.80	22.66	0.92	0.65	0.08
MGL4	11.84	19.14	2.04	0.97	0.09
MGL5	22.30	13.60	5.07	1.01	0.13
MGL6	20.36	20.04	2.26	0.92	0.14
MGL7	15.76	18.73	1.93	1.53	0.11
MGL8	24.21	20.36	1.63	0.90	0.11
MGL9	47.11	21.85	2.03	0.62	0.36
MGL10	22.27	15.23	1.77	1.28	0.16
MGL11	42.96	26.03	1.42	1.26	0.11
MGL12	27.04	21.23	1.88	1.41	0.14
MGL13	55.24	21.64	1.72	1.07	0.07
MGL14	30.74	21.82	1.07	1.47	0.37
MGL15	31.06	22.59	2.84	1.35	0.14
MGL16	33.77	20.06	2.85	2.09	0.17
MGL17	20.46	21.23	1.88	1.69	0.14
MGL18	38.30	20.71	4.22	1.02	0.08
MGL19	42.02	22.53	1.00	1.27	0.07
MGL20	28.88	17.93	2.79	1.24	0.13
C.D.	0.90	0.97	0.24	0.03	N/A
SE(m)	0.31	0.34	0.08	0.01	0.08
SE(d)	0.44	0.48	0.12	0.01	0.12
C.V.	1.74	2.89	6.85	1.35	N/A

Table 4.14 Minerals content in aonla fruits from Mizoram.

Accession	Calcium (mg /100g)	Magnesium (mg /100g)	Iron (mg /100g)	Potassium (%)	Phosphorous (%)
MZR1	18.94	18.00	1.75	1.26	0.11
MZR2	19.69	17.56	2.97	1.52	0.09
MZR3	13.61	17.86	1.76	1.07	0.11
MZR4	17.86	21.33	2.61	1.17	0.12
MZR5	17.71	20.38	1.00	1.14	0.10
MZR6	42.36	20.16	5.15	1.06	0.13
MZR7	51.41	20.24	3.58	1.11	0.11

MZR8	13.79	17.23	3.61	0.91	0.11
MZR9	21.69	16.15	3.78	0.95	0.10
MZR10	22.11	20.98	1.76	1.61	0.11
MZR11	31.33	25.17	2.86	1.27	0.18
MZR12	74.53	22.53	8.43	1.47	0.11
MZR13	26.43	17.98	2.01	1.04	1.00
MZR14	13.38	17.04	1.90	1.04	0.12
MZR15	9.60	19.83	5.15	0.96	0.11
MZR16	43.38	21.85	1.73	1.16	0.07
MZR17	36.63	24.91	3.21	1.49	0.13
MZR18	45.57	15.83	4.27	1.22	0.10
MZR19	37.97	20.09	4.22	1.05	0.08
MZR20	21.67	14.36	3.04	1.55	0.07
C.D.	0.74	2.39	0.21	0.04	0.04
SE(m)	0.26	0.83	0.07	0.01	0.01
SE(d)	0.37	1.18	0.10	0.02	0.02
C.V.	1.54	7.42	3.93	2.04	16.215

Table 4.15 Minerals content in aonla fruits from Tripura.

Accession	Calcium (mg /100g)	Magnesium (mg /100g)	Iron (mg /100g)	Potassium (%)	Phosphorous (%)
TRP1	17.76	17.01	1.41	1.05	0.08
TRP2	16.50	19.32	3.34	1.91	0.15
TRP3	17.31	16.50	1.81	1.02	0.13
TRP4	66.45	21.98	3.60	1.18	0.09
TRP5	31.33	21.38	2.08	1.16	1.31
TRP6	45.51	22.07	1.80	1.03	0.10
TRP7	41.48	27.58	2.66	1.04	0.09
TRP8	42.01	26.31	3.75	0.84	0.09
TRP9	22.79	20.80	2.88	1.17	0.13
TRP10	53.14	22.25	2.55	0.71	0.08
TRP11	27.41	17.53	2.32	1.58	0.13
TRP12	14.96	19.35	0.73	0.83	0.14
TRP13	27.01	21.15	5.67	0.64	0.07
TRP14	18.10	17.40	2.85	1.32	0.08
TRP15	17.22	17.14	2.71	1.39	0.16
TRP16	25.83	20.77	1.80	1.16	1.19
TRP17	33.88	21.38	1.58	0.76	0.05
TRP18	18.43	17.75	2.38	1.63	0.08

TRP19	41.43	15.43	3.17	0.97	0.15
TRP20	10.61	16.21	1.07	1.51	0.13
C.D.	0.66	0.74	0.38	0.05	0.06
SE(m)	0.23	0.26	0.32	0.02	0.02
SE(d)	0.23	0.36	0.19	0.02	0.03
C.V.	1.34	2.23	9.11	2.45	15.04

Table 4.16 Comparison of minerals content in aonla fruits from all the sites.

States		Calcium (mg /100g)	Magnesium (mg /100g)	Iron (mg /100g)	Potassium (%)	Phosphorous (%)
Meghalaya	Range	11.84 - 55.80	13.60 - 26.03	0.92 - 5.07	0.62 - 2.09	0.07 - 0.37
	Average	31.09	20.32	2.12	1.18	0.14
Mizoram	Range	9.60 – 74.53	14.36 – 25.17	1.0 – 8.43	0.91- 1.61	0.07 - 1
	Average	28.98	19.47	3.24	1.2	0.15
Tripura	Range	10.61 – 66.45	15.43 – 27.58	0.73 – 5.67	0.64 – 1.91	0.05 - 1.31
	Average	29.46	19.97	2.51	1.15	0.22
$CD_{0.05}$		0.77	1.54	0.27	0.04	0.14
SE(m)		0.27	0.55	0.10	0.01	0.05
SE(d)		0.39	0.78	0.14	0.02	0.07
C.V.		1.59	4.78	6.44	1.97	51.69

*CD and CV of each parameter are calculated for 60 accessions combined

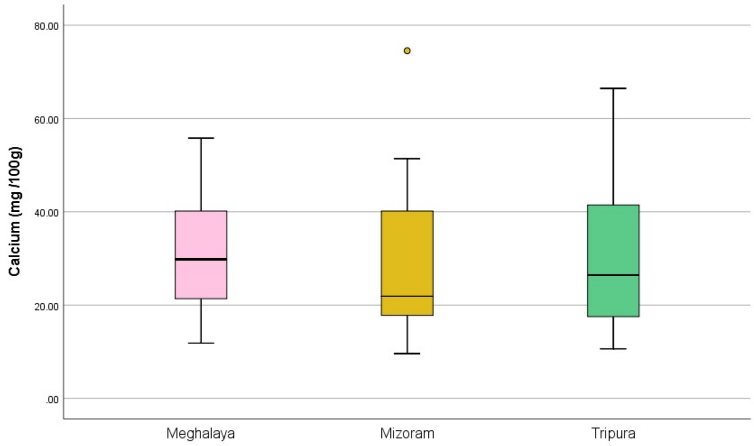


Figure 4.22 Boxplot of calcium from Meghalaya, Mizoram and Tripura.

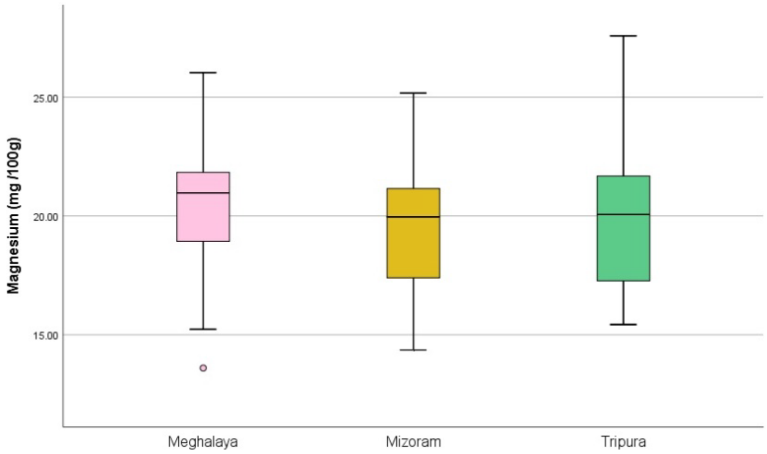


Figure 4.23 Boxplot of magnesium from Meghalaya, Mizoram and Tripura.

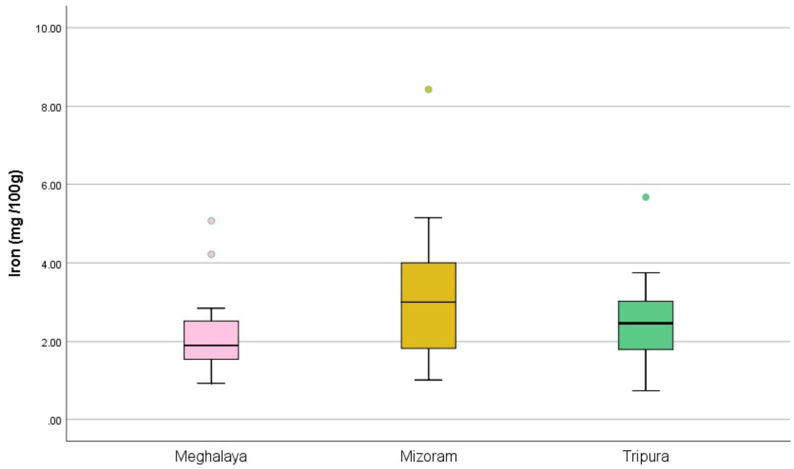


Figure 4.24 Boxplot of iron from Meghalaya, Mizoram and Tripura.

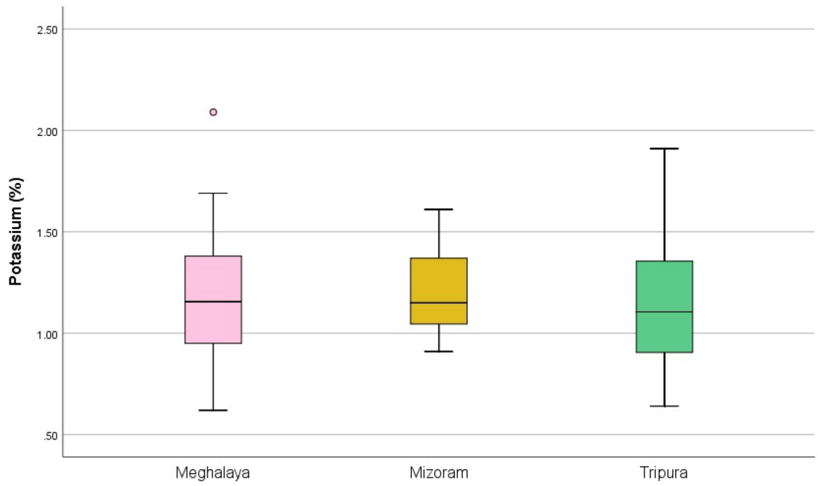


Figure 4.25 Boxplot of potassium from Meghalaya, Mizoram and Tripura.

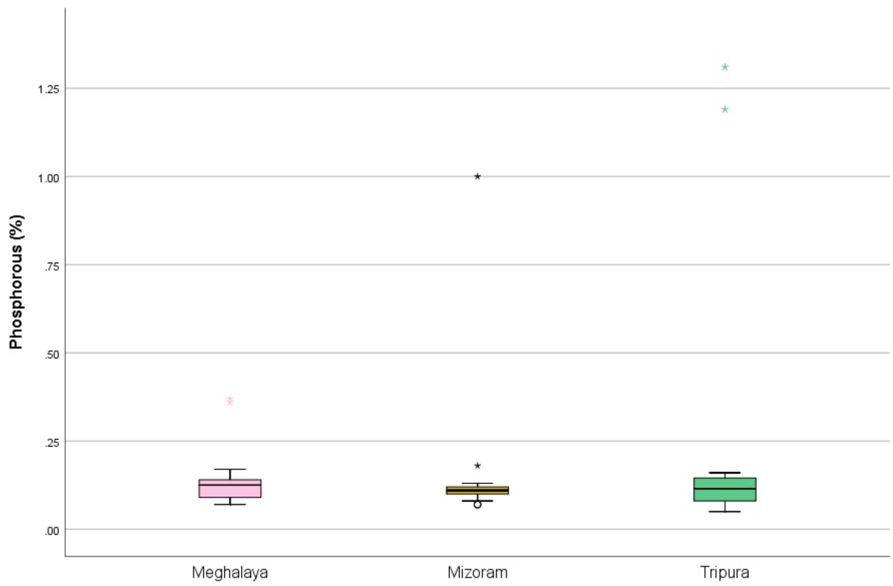
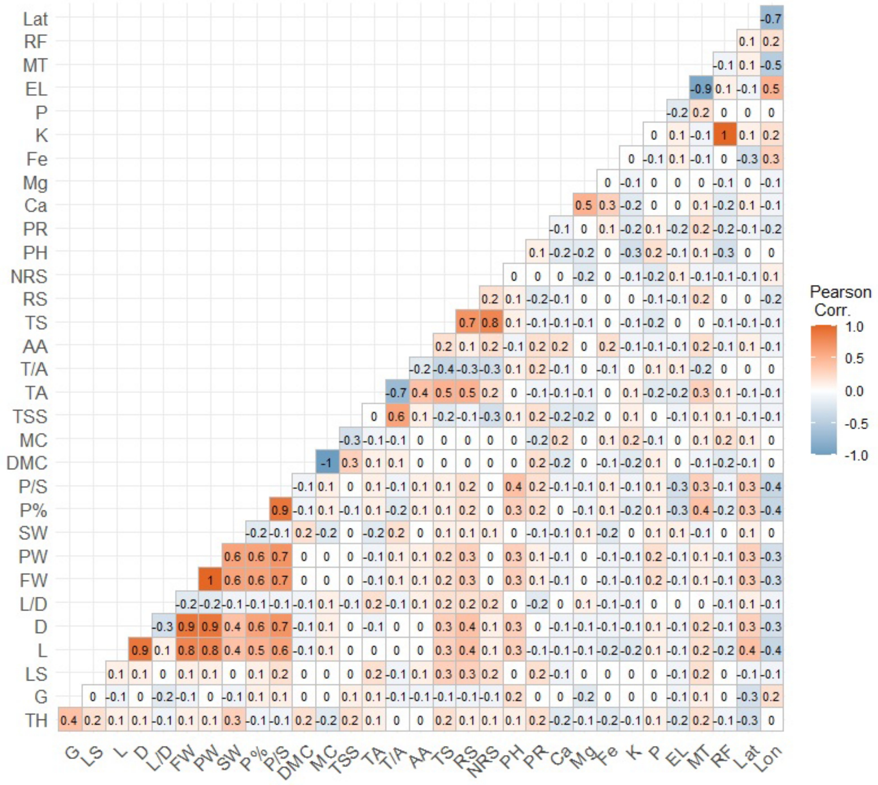


Figure 4.26 Boxplot of phosphorous from Meghalaya, Mizoram and Tripura.

4.4 Correlation

A study observed a significant negative correlation between elevation and the pulp percentage and pulp stone ratio of aonla fruits. Positive relationship was observed in fruit length, diameter, weight and pulp weight with the latitude, whereas same parameters were negatively correlated with longitudes (Figure 4.27). However, Naithani *et al.* (2020) found no link between altitude and the physicochemical properties of aonla fruits in the Garhwal Himalayas, but Latitude showed significantly positive significant relationship with moisture content and Vitamin C, the Longitude also showed positive relationship with fruit weight. Significant correlation between potassium and rainfall was observed from the study, whereas a negative correlation between phenol and rainfall was recorded. The mean temperature was positively correlated with Titratable acidity, pulp stone ratio and pulp%, whereas Anand *et al*. (2022) recorded a significant positive correlation of fruit length and fruit width with the temperature in *Citrus sinensis*, but no significant relation was recorded in rainfall.

The study revealed that Total Soluble Solids (TSS) had a positive correlation with titratable acidity (TA) and dry matter content (DMC), while titratable acidity was positively associated with ascorbic acid, reducing sugar, and non-reducing sugar. Additionally, fruit weight and pulp weight showed a positive relationship with stone weight and pulp percentage (Figure 4.27). Calcium was positively correlated with both magnesium and iron. Maity *et al.* (2019) also found a positive link between TSS and phosphorus content in *Punica granatum* L., while titratable acidity was linked to ascorbic acid, total sugar, and reducing sugar. In contrast, this study did not find a direct correlation between phenol and ascorbic acid or proteins in aonla fruits. Still, a positive relationship between phenol and ascorbic acid was observed, along with a negative correlation between phenol and proteins. Furthermore, fruit weight was positively correlated with reducing sugar and phenol content in aonla fruits, although Aliman *et al.* (2020) reported a negative correlation between fruit weight and total phenol content in highbush blueberry and wild bilberry fruits.



Abbreviation: TH – Tree height, G – Girth, LS – Leaf size, L- Fruit Length, D – Fruit diameter, LD – Length Diameter Ratio, FW – Fresh Weight, PW – Pulp Weight, SW – Stone weight, PP – Pulp Percentage, PS – Pulp Stone Ratio, DMC - Dry matter content, TSS –Total Soluble Sugar, TA - Titratable acidity, TTA – TSS TA Ratio, AA - Ascorbic acid, TS - Total sugar, RS - Reducing sugar, NRS - Non reducing sugar, Ph – Phenol, Pro – Protein, Ca - Calcium, Mg - Magnesium, Fe - Iron, K - Potassium, P – Phosphorous, EL – Elevation, MT – Mean temperature, RF – Rainfall, Lat - Latititude, Lon - Longitude.

Figure 4.27 Correlation matrixes of fruit parameters with elevation, latitude, longitude, rainfall and temperature.

4.5 PCA

Variation among the accessions characteristics were assessed using PCA. PCA is an approach for finding patterns in data and expressing the data to show both its similarities and differences. In this present study the PCA (Table 4.17 and Figure 4.28) indicated that morphological traits and physio-chemical traits were classified into 13 main components accounting for 77.35% of total variance. The PCA1 explained 15% of total variance and showed positive and significant correlation with pulp weight, fruit diameter, fruit weight, fruit length, pulp%, stone weight, pulp stone ratio and fruit length and diameter ratio, which are mostly fruit size component. PCA 2 accounted for 9.77% of total variance with negative and significant correlations with Titratable acidity, total sugar, non-reducing sugar, reducing sugar and ascorbic acid, which are mostly bio-chemical traits. PCA3 and PC4 explained 8.02% and 6.89% of the total variation with both positive and negative significant correlations with dry matter content, moisture content, and tree height harvest maturity, TSS, Ca and Mg. This is the characters which showed the most variation among the accessions and the most influence on differentiating accessions. Mirheidari *et al*. (2022b) studied Z. *mauritiana* accessions from Iran and reported that PCA place the characters into 12 components which account 75.07% of the total variance. Fruit length, fruit breadth, fruit weight, fruit flesh firmness, fruit stone length, stone width, stone thickness, and fruit stone weight were all related to the PC1, which accounted for 16.46% of the overall variance, our findings was more or less similar to their findings. The scatter plot made using PC1 and PC2 revealed the variation in phenotypes among accessions. The accessions varied significantly in the PC1 in terms of pulp weight, fruit diameter, fruit weight, fruit length, pulp percentage , stone weight, pulp stone ratio and fruit length and diameter ratio. In the PC2, the accessions showed a gradual increase titratable acidity, total sugar, non-reducing sugar, reducing sugar and ascorbic acid.

Multiple clusters of accessions show that the majority of the seedlings come from various sources of origin. This finding indicates that factors other than geographic distance may be accountable for divergence, and accessions originating from the same location could have diverse genetic architecture or vice versa (Majumder *et al*., 2013).

Table 4.17 Eigenvalues of the principal component axes from the PCA of morpho-phytochemicals characters in the studied aonla accessions

Character	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
FL	0.89	-0.01	-0.06	0.17	0.04	-0.13	0.19	-0.01	0.07	0.07	0.03	0.00	-0.04
D	0.91	0.15	-0.13	0.08	-0.05	-0.04	0.02	0.03	-0.05	0.03	0.07	0.03	-0.07
L/D	-0.08	-0.41	0.13	0.25	0.24	-0.05	0.42	-0.08	0.24	0.09	-0.08	-0.09	0.14
FW	0.91	0.23	-0.11	0.04	-0.01	-0.21	-0.05	-0.03	-0.04	-0.03	0.06	0.10	0.05
PW	0.92	0.21	-0.14	0.01	-0.01	-0.18	-0.04	-0.04	-0.04	-0.04	0.06	0.08	0.04
SW	0.43	0.33	0.27	0.36	-0.04	-0.49	-0.12	0.12	-0.05	0.07	0.07	0.22	0.15
P%	0.69	-0.07	-0.35	-0.34	0.03	0.31	0.04	-0.17	-0.07	-0.15	-0.01	-0.15	-0.04
P/S	0.78	-0.06	-0.35	-0.29	0.04	0.26	0.07	-0.10	0.00	-0.14	0.05	-0.06	-0.04
DMC	-0.03	0.34	0.67	-0.28	0.27	-0.12	0.04	-0.19	-0.29	-0.04	0.26	-0.18	-0.01
MC	0.03	-0.34	-0.67	0.28	-0.27	0.12	-0.04	0.19	0.29	0.04	-0.26	0.18	0.01
TSS	-0.06	0.42	0.23	-0.46	0.08	-0.06	0.27	0.15	0.37	0.15	0.03	0.20	0.06
TA	0.10	-0.70	0.37	-0.28	-0.09	0.12	0.06	-0.18	-0.06	-0.02	0.05	0.14	0.04
T/A	-0.11	0.76	-0.12	-0.03	0.15	-0.15	0.20	0.22	0.37	0.07	-0.01	-0.03	0.05
AA	0.10	-0.37	0.02	-0.33	0.28	-0.12	-0.19	-0.01	0.06	0.09	0.13	0.56	0.21
TS	0.41	-0.64	0.43	0.20	0.09	0.02	-0.11	0.21	0.06	0.10	-0.02	-0.09	0.03
RS	0.47	-0.50	0.27	0.00	-0.08	-0.19	0.15	-0.09	0.22	0.16	0.04	-0.24	0.06
NRS	0.20	-0.49	0.38	0.27	0.19	0.17	-0.27	0.36	-0.09	0.00	-0.07	0.06	-0.01
PH	0.40	0.15	0.03	-0.11	0.05	0.52	0.30	-0.09	-0.07	0.28	-0.13	-0.06	0.21
PR	0.06	0.27	0.06	-0.38	0.42	0.17	-0.20	-0.05	0.25	-0.19	-0.19	0.21	-0.32
Ca	-0.17	-0.10	-0.36	0.19	0.16	0.02	-0.42	-0.46	0.08	0.22	0.18	0.14	0.29
Mg	-0.16	0.05	-0.14	0.40	0.34	-0.12	-0.11	-0.57	0.17	-0.09	0.33	0.06	0.02
Fe	-0.08	-0.15	-0.31	-0.38	0.14	-0.02	-0.39	0.03	0.03	0.37	0.15	-0.24	0.13

Character	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
K	-0.21	-0.12	-0.08	-0.06	-0.35	-0.17	0.17	0.42	0.11	-0.36	0.28	0.12	0.14
P	0.17	0.33	0.00	0.09	0.01	0.11	0.15	-0.16	-0.11	-0.36	-0.03	0.02	0.34
Tree Shape	-0.05	0.32	0.20	0.29	-0.52	0.40	0.01	-0.03	-0.09	0.10	0.15	0.07	0.24
Foliage	0.04	0.23	0.28	0.34	-0.31	0.43	-0.15	0.07	0.22	-0.11	0.04	-0.07	0.30
Leaf Shape	0.00	-0.01	-0.35	0.45	-0.07	0.10	0.25	0.06	0.00	0.21	0.41	-0.05	-0.43
Leaf Size (cm)	0.25	-0.21	0.20	-0.06	0.02	0.16	-0.25	-0.04	0.51	-0.33	0.07	-0.17	-0.08
Leaf Apex	0.03	0.09	-0.24	-0.27	0.34	0.30	0.05	0.40	0.02	0.35	0.04	0.12	0.21
Leaf Surface	0.12	-0.30	0.21	-0.37	-0.24	-0.13	0.49	-0.05	0.02	0.10	0.24	0.04	0.06
Fruit Shape	-0.02	-0.13	0.12	0.34	0.25	0.23	0.38	-0.21	0.38	0.03	0.08	0.19	-0.08
Fruit colour	0.34	0.11	0.03	0.09	0.09	0.05	-0.39	0.42	0.04	0.08	0.35	-0.18	-0.04
Fruit Surface	-0.15	0.05	-0.06	-0.38	-0.33	-0.13	-0.17	-0.07	0.47	-0.02	0.20	-0.36	0.13
Fruit Stalk	-0.27	0.08	0.01	0.13	0.51	0.23	0.18	0.19	-0.11	0.15	0.35	-0.10	-0.06
Stone Shape	0.01	-0.04	0.02	0.11	0.53	0.38	0.03	0.19	-0.06	-0.48	0.17	0.00	0.12
Harvest Maturity	0.22	0.37	0.40	0.24	0.21	0.07	-0.12	-0.14	0.13	0.26	-0.40	-0.20	0.02
TH	0.18	0.24	0.57	0.00	-0.20	0.12	-0.23	-0.01	0.22	0.11	0.07	0.26	-0.26
G	-0.01	0.11	0.13	-0.20	-0.55	0.46	-0.12	-0.19	-0.07	0.16	0.19	0.22	-0.22
Eigen value	5.70	3.71	3.05	2.62	2.47	1.99	1.85	1.69	1.48	1.37	1.27	1.18	1.04
% of variance	15.00%	9.77%	8.02%	6.89%	6.49%	5.23%	4.86%	4.43%	3.89%	3.60%	3.34%	3.10%	2.74%
Cumulative	15.00%	24.77%	32.79%	39.68%	46.17%	51.40%	56.26%	60.69%	64.58%	68.19%	71.52%	74.62%	77.35%

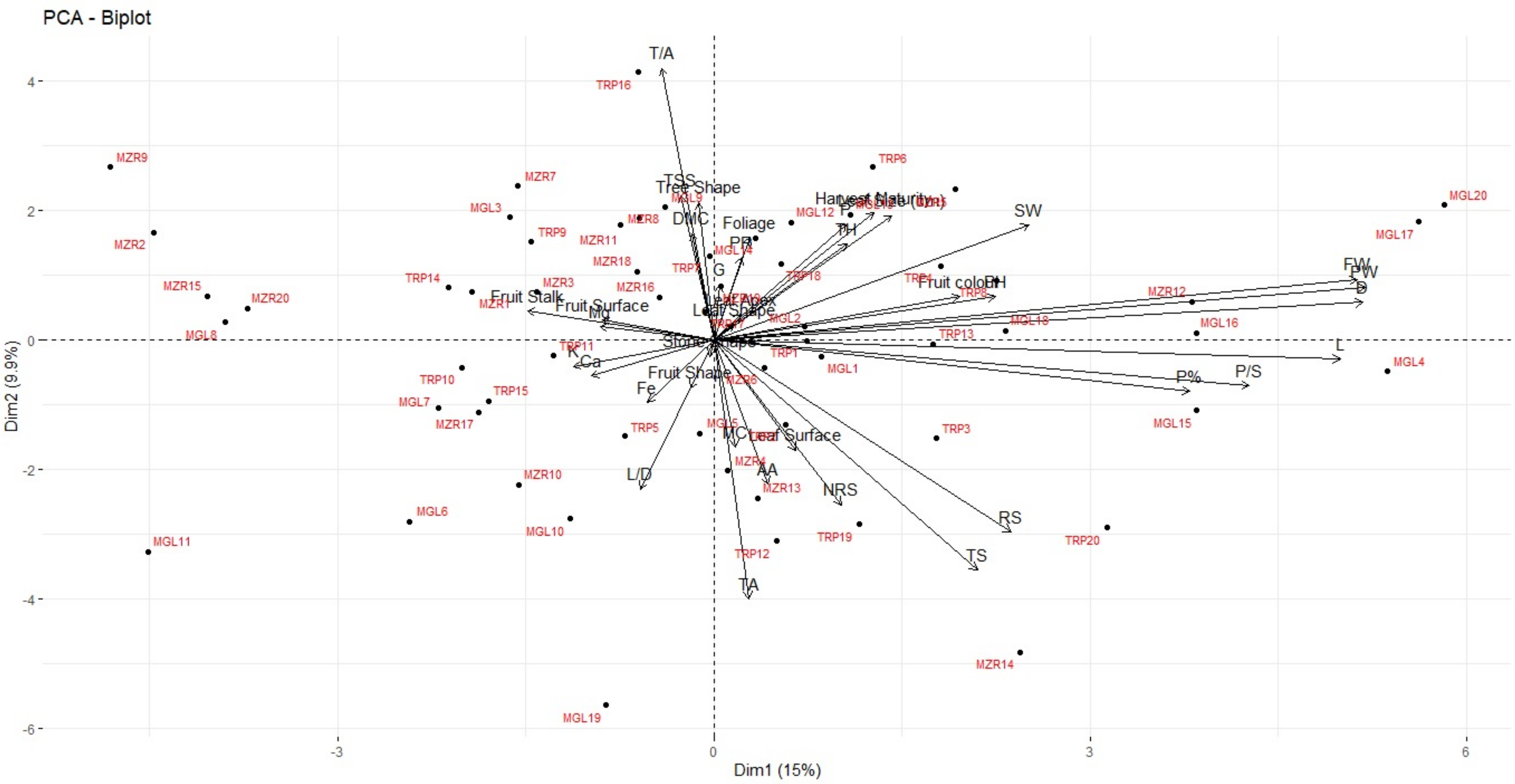


Figure 4.28 Scatter biplot for the studied aonla accessions based on PC1/PC2

4.6 Cluster analysis

A cluster analysis was performed using Euclidean distance and Ward's method, which grouped the accessions into two main clusters based on their morphological and physio-chemical characteristics (as shown in Fig. 2). The first cluster (Cluster I) included 14 accessions, making up 23.33% of the total, while the second cluster (Cluster II) comprised 46 accessions, representing 76.66% of the total, which shared similar traits. Each of these clusters was further divided into subgroups: I-A, I-B, II-A, and II-B. Cluster I-A consisted of 2 accessions, I-B had 12, II-A contained 30, and II-B included 16 accessions. In terms of geographical distribution, Cluster I contained 5 accessions from Meghalaya, 5 from Tripura, and 4 from Mizoram. Meanwhile, Cluster II included 15 accessions each from Meghalaya and Tripura, along with 16 from Mizoram. The distribution of aonla accessions across different cluster groups, as determined through cluster analysis, is presented in figure 4.29 and Table 4.18. Singh *et al*. (2024) analyzed 49 aonla accessions using fourteen different parameters and grouped them into five main clusters, focusing on fruit traits. Similarly, Bulo *et al*. (2024) studied 30 wild aonla accessions, classifying them into four primary clusters. Three of these clusters were further divided into two subclusters. Sharma *et al.* (2002) and Bala *et al.* (2009) also recorded similar results which are consistent with the present studies.

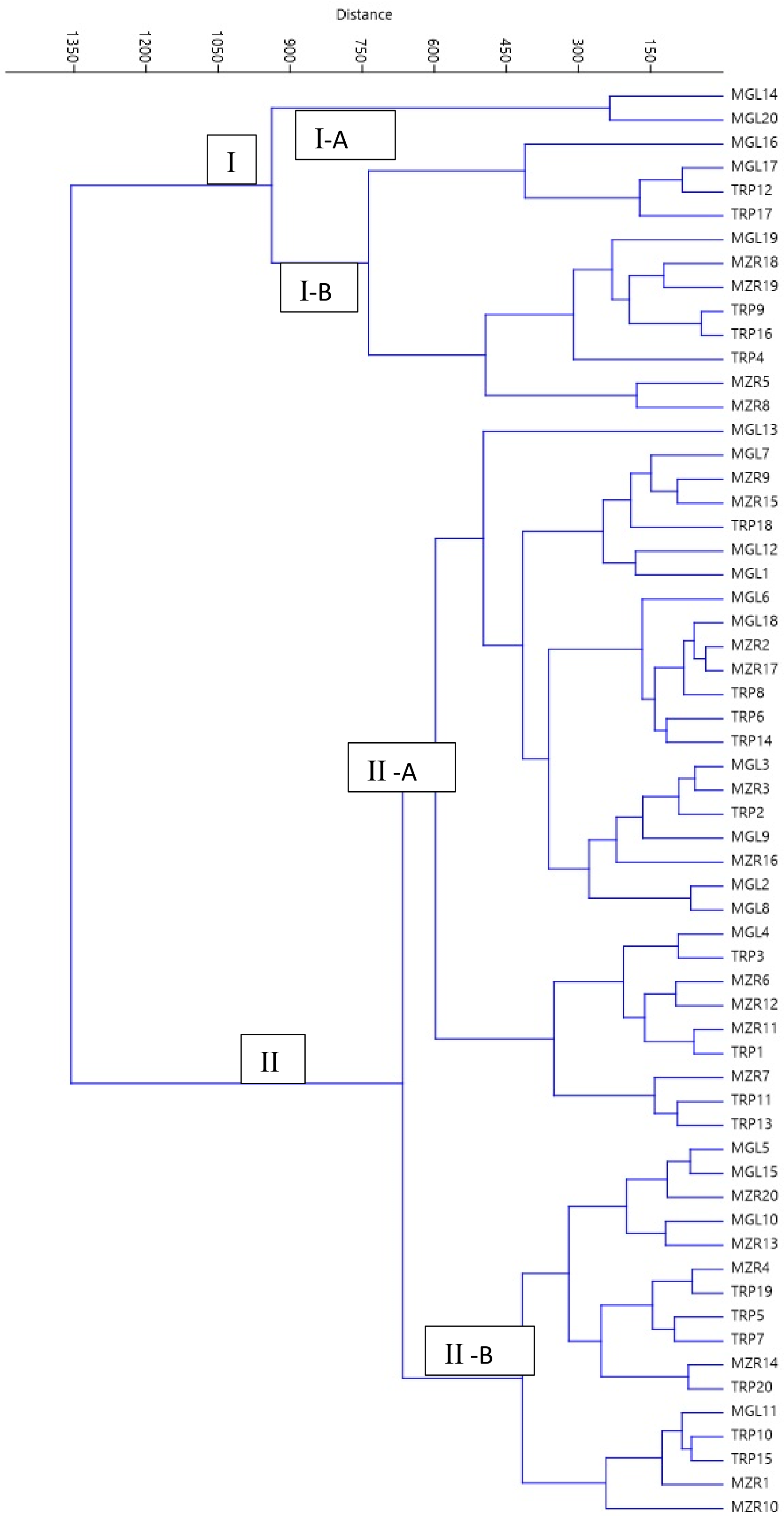


Figure 4.29 Ward cluster analysis of the studied aonla accessions based on morphological and phyto-chemical traits using Euclidean distances.

Table 4.18 Distribution of 60 accessions of bael into diferent cluster based on cluster analysis.

Cluster	Group	Accessions	No. of Accessions
1	1A	MGL -14; 20	2
	1B	MGL – 16;17;19 MZR – 18;19;5;8 TRP – 12;17;9;16;4	12
2	2A	MGL –3;7;12;1;6;18;3;9;2;8;4 MZR – 9;15;2;17;3;16;6;12;11;7 TRP – 18;8;16;14;2;3;1;11;13	30
	2B	MGL –5;15;10;11 MZR – 20;13;4;14;1;10 TRP – 19;5;7;20;10;15	16

4.8 Selection of Promising Accessions

The data presented in Table 4.19 illustrates the weighted scores of various aonla fruit accessions, assessed on both physical and biochemical characteristics. These accessions were evaluated based on multiple attributes, including fresh weight, pulp-to-stone ratio, yield, TSS (Total Soluble Solids), ascorbic acid content, total sugar, phenol, and protein content. Each accession has a total weighted score, reflecting its overall performance across these traits.

Top Performers: Several accessions emerged as top performers with the highest total weighted scores, indicating strong overall qualities. MZR20 leads with a score of 862, followed by MGL17 at 766, MZR19 at 754, TRP20 at 736, and MZR18 at 730. These accessions excel across most categories, suggesting a harmonious combination of desirable physical and biochemical traits, making them prime candidates for further evaluation or commercial use.

High Fresh Weight: Accessions such as MGL6, MGL17, and TRP6 showcase high scores in fresh weight, each scoring above 300. This characteristic is advantageous for market appeal and processing purposes, as larger or heavier fruits are often preferred for their substantial yield and consumer attractiveness.

High Pulp-to-Stone Ratio and Yield: Accessions like MGL20 and TRP2 stand out for their high pulp-to-stone ratios and yield scores. A high pulp-to-stone ratio is particularly beneficial for processing, as it indicates a greater proportion of edible fruit relative to the stone. These accessions may therefore be preferred in industries where maximizing usable fruit content is key.

Higher Nutrient Content: Accessions with elevated levels of ascorbic acid, phenols, and protein, such as MZR19, MZR18, and MGL16, highlight the potential for greater nutritional benefits. High ascorbic acid levels, for instance, are valuable for enhancing the antioxidant properties of the fruit, while phenols contribute to health-promoting qualities. These accessions could appeal to health-conscious consumers and be marketed for their superior nutritional content.

Balanced Properties: Some accessions, like MZR4 and TRP3, display consistently moderate to high scores across all categories, indicating a balanced blend of physical and biochemical characteristics. Such accessions are valuable as they demonstrate versatility and adaptability, offering both good yield and quality without sacrificing one trait for another.

The accessions with high weighted scores and balanced attributes exhibit promising potential for both commercial production and nutritional benefits. Each top-performing accession offers unique strengths, from physical appeal to nutritional richness, making them suitable candidates for a variety of consumer and industry preferences.

Table 4.19 Weighted ranged score of the accessions based on physical and biochemical properties of aonla fruits.

Accession	Fresh weight	Pulp stone ratio	Yield	TSS	Ascorbic Acid	Total sugar	Phenol	Protein	Total Weighted Range scored
MGL1	120	140	30	48	8	32	8	80	466
MGL2	120	80	30	120	56	32	8	32	478
MGL3	120	80	30	84	32	32	8	8	394
MGL4	30	80	30	12	32	56	8	8	256
MGL5	30	80	120	12	8	56	8	8	322
MGL6	300	200	120	12	32	32	32	8	736
MGL7	120	200	120	12	56	8	8	8	532
MGL8	30	80	120	48	56	8	8	80	430
MGL9	120	80	30	48	8	32	8	56	382
MGL10	30	140	30	12	56	32	8	32	340
MGL11	30	20	210	12	56	32	8	32	400
MGL12	120	140	30	84	8	32	8	8	430
MGL13	120	140	120	48	8	8	8	8	460

Accession	Fresh weight	Pulp stone ratio	Yield	TSS	Ascorbic Acid	Total sugar	Phenol	Protein	Total Weighted Range scored
MGL14	120	80	30	84	80	32	56	80	562
MGL15	210	200	30	48	56	56	8	56	664
MGL16	210	200	30	48	8	32	80	8	616
MGL17	300	140	30	48	56	56	80	56	766
MGL18	120	200	30	84	32	56	8	56	586
MGL19	30	80	30	48	56	80	56	8	388
MGL20	300	200	30	84	80	56	32	80	862
MZR1	30	20	30	84	80	32	8	56	340
MZR2	30	20	120	120	32	56	8	32	418
MZR3	120	80	30	12	32	32	8	56	370
MZR4	120	140	120	84	56	32	8	8	568
MZR5	120	140	120	84	8	56	56	8	592
MZR6	30	20	210	12	8	8	32	8	328
MZR7	120	80	120	84	8	32	80	32	556
MZR8	30	80	30	12	32	56	32	8	280
MZR9	30	20	120	84	8	8	8	56	334
MZR10	30	80	30	48	80	56	8	56	388
MZR11	120	80	30	48	32	32	32	32	406
MZR12	210	140	30	48	32	56	32	32	580
MZR13	120	140	30	84	56	56	8	8	502
MZR14	120	140	120	12	56	80	32	8	568
MZR15	30	80	120	48	8	8	8	56	358
MZR16	120	20	30	48	8	80	8	8	322
MZR17	30	20	120	48	32	56	8	32	346
MZR18	30	140	300	84	32	32	56	56	730

Accession	Fresh weight	Pulp stone ratio	Yield	TSS	Ascorbic Acid	Total sugar	Phenol	Protein	Total Weighted Range scored
MZR19	120	140	210	84	32	32	56	80	754
MZR20	30	80	210	84	56	32	8	80	580
TRP1	120	80	30	48	32	56	32	8	406
TRP2	120	140	210	48	32	32	8	8	598
TRP3	120	80	120	84	32	56	32	32	556
TRP4	120	140	30	84	32	32	56	56	550
TRP5	30	80	30	48	56	56	32	80	412
TRP6	210	140	30	120	32	32	8	80	652
TRP7	120	80	120	84	80	32	8	8	532
TRP8	210	80	120	48	32	56	8	56	610
TRP9	30	20	120	48	32	8	56	32	346
TRP10	30	80	30	84	80	32	8	32	376
TRP11	30	80	30	12	8	56	32	56	304
TRP12	120	200	30	84	32	56	80	32	634
TRP13	120	140	120	12	8	56	32	32	520
TRP14	30	80	30	120	32	32	8	56	388
TRP15	120	80	30	12	80	32	8	32	394
TRP16	120	140	120	48	32	8	56	56	580
TRP17	120	140	30	84	32	32	80	32	550
TRP18	120	140	30	48	8	32	8	56	442
TRP19	120	140	30	12	56	80	8	80	526
TRP20	120	200	120	48	56	80	32	80	736

Acute apex

Obtuse apex

Oblong leaf shape

Oval leaf shape

Sparse foliage

Dense foliage

Plate 4.1 Leaflet apex, shapes and Foliage density of aonla accessions.

Erect shape

Drooping shape

Spreading shape

Semi-Spreading shape

Plate 4.2 Various Tree Shape of aonla accessions.

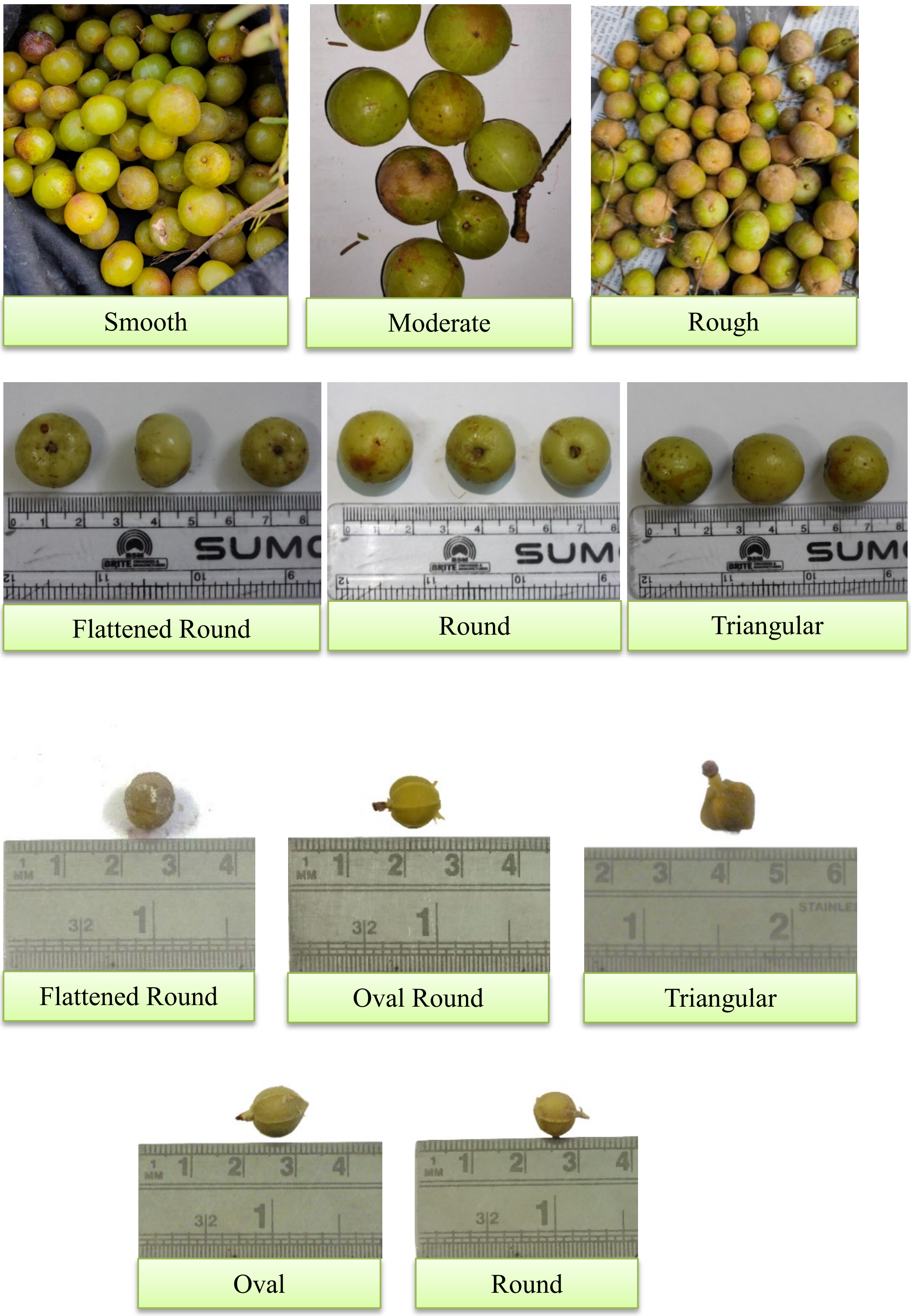


Plate 4.3 Fruit surface, shape and stone shape of the aonla accessions

Chapter 5

Summary and Conclusion

The study "Morpho-Chemical Characterization of *Phyllanthus emblica* L. in Wild Conditions across Selected Regions of North East India" explores the morphological diversity, chemical properties, and adaptability of aonla across various regions in Northeast India. Conducted from 2018 to 2022 at Mizoram University, this research emphasizes the remarkable variability among aonla accessions, offering insights into their potential for selective breeding, conservation, and sustainable utilization. Tree girth ranged from 20 to 132 cm, with an average of 60.8 cm. The majority of accessions exhibited a spreading shape (45%) and sparse foliage (69.4%). Leaf shapes were predominantly oblong (68.3%) and most accessions had an acute leaf apex. Fruit shapes varied, with flattened round being the most common (53.33%), followed by round (38.33%) and triangular (8.33%). The fruit color primarily ranged from yellow-green to a rare orange-red, with smooth surfaces dominating (45 accessions). Fruit stalks were mostly thin (56.7%). Stone shapes included round, oval, and triangular. Maturity varied across accessions, with most being late-maturing (39 accessions). Fruit lengths ranged from 12.77 mm to 24.72 mm, with the longest fruits from Meghalaya. Similarly, fruit diameters ranged from 14.67 mm to 28.04 mm, with Meghalaya recording the largest average. Fruit weight varied from 2.14 g to 12.24 g, with Meghalaya having the heaviest fruits (average 6.44 g). Moisture content ranged from 76.93% to 85.91%, with Meghalaya having the highest average (81.17%). Pulp weight ranged from 1.66 g to 11.14 g, with Meghalaya also recording the highest average pulp weight (5.79 g). Pulp percentage ranged from 72.63% to 92.91%, with Meghalaya having the highest average (92.1%). The pulp-to-stone ratio varied from 2.74 to 13.01, with Meghalaya also showing the highest ratio.

Aonla yield ranged from 31.25 kg/tree to 163.54 kg/tree, with Mizoram yielding the most (75.22 kg/tree). Total soluble solids (TSS) ranged from 7.5°Brix to 18°Brix, with Mizoram having the highest average TSS (12.29°Brix). Titratable acidity varied from 1.65% to 4.90%, with Tripura showing the highest average acidity (2.96%). Ascorbic acid content ranged from 180 mg/100g to 1392.5 mg/100g, with Tripura having the highest average (751.67 mg/100g). Total sugar content ranged from 3.898% to 13.056%, with Mizoram showing the highest average (8.31%). Nutritional content varied significantly across accessions. Protein content ranged from 0.73% to 2.49%, with Tripura having the highest average (1.85%). Calcium content ranged from 9.6 mg/100g to 74.53 mg/100g, with Mizoram showing the highest average calcium content (31.09 mg/100g). Magnesium ranged from 13.6 mg/100g to 27.58 mg/100g, with Meghalaya having the highest average (20.32 mg/100g). Iron levels ranged from 0.73 mg/100g to 8.43 mg/100g, with Mizoram recording the highest average (3.24 mg/100g). Potassium content varied from 0.62% to 2.09%, with similar averages across the states. Phosphorus content ranged from 0.073% to 1.307%, with Mizoram having the highest median levels. The study also explored correlations between fruit characteristics and environmental factors, showing significant relationships between fruit weight, acidity, TSS, and other properties with rainfall, temperature, and elevation. Principal component analysis (PCA) identified 13 components explaining 77.35% of the variance, with PCA1 correlating strongly with fruit size traits. Cluster analysis revealed two main clusters based on geographical distribution. Top-performing accessions with superior physical and biochemical traits, such as high fresh weight, pulp-to-stone ratio, and nutrient content, included MZR20, MGL17, MZR19, TRP20, and MZR18.

Conclusion

The present study indicates a considerable variability in the morphological and biochemical characteristics of aonla across the states of Meghalaya, Mizoram, and Tripura. The analysis of polymorphic qualitative traits revealed significant variation in tree shape, foliage density, leaf characteristics, fruit shape, colour, surface, stalk, stone shape, and harvest maturity. Additionally, marked differences were found in fruit quantitative parameters, including fruit length, diameter, dry matter content, weight, pulp percentage, and yield. Biochemical and mineral content also exhibited notable variation among the different aonla accessions. Geographical factors such as location, elevation, and climate were found to significantly influence fruit size and weight, though some morphological and phyto-chemical traits remained unaffected by environmental conditions, suggesting a strong genetic influence on these characteristics.

Despite aonla being underutilized in the region, the study demonstrated its potential as a valuable source of ascorbic acid, sugars, and phenolic compounds, with significant implications for the pharmaceutical industry. Wild aonla fruits from the northeast showed distinct differences in size and chemical composition compared to commercial cultivars, particularly in terms of fruit weight, pulp percentage, total soluble solids, ascorbic acid, phenols, and mineral content. Notably, the antioxidant-related ascorbic acid and phenol content were found to be exceptionally high compared to aonla from other regions of the country. Principal component analysis (PCA) revealed 13 components explaining 77.35% of the variance in fruit traits, with fruit size traits being the most influential. Based on key attributes like fresh weight, pulp-to-stone ratio, yield, TSS, and nutrient content, five elite accessions (MZR20, MGL17, MZR19, TRP20, and MZR18) were identified. While standardized aonla varieties exist across India, the wide genetic diversity in the north eastern regions presents an opportunity for plant breeders to select superior traits for the development of improved varieties.

Future Scope of Work

Accession Conservation and Genetic Resource Management: Initiating conservation programs, such as seed banks and protected areas, especially for Northeast Indian aonla accessions, to preserve valuable genetic diversity and unique traits that can support resilience and adaptability in breeding.

Targeted Breeding Programs: Developing selective breeding programs focusing on high-heritability traits such as ascorbic acid, phenol levels, calcium, and pulp percentage to enhance nutritional value, resilience, and adaptability of aonla cultivars.

Breeding for Climate Adaptation: Advance breeding efforts targeting climate-resilient traits, including drought tolerance and morphological adaptations, to support cultivation in diverse and changing environmental conditions, especially in moisture-limited or semi-arid areas.

Agroforestry Integration and Sustainable Farming: Explore the integration of optimized aonla accessions into agroforestry systems, focusing on tree traits that provide shade, soil stabilization, and biodiversity enhancement, contributing to sustainable farming and ecosystem conservation

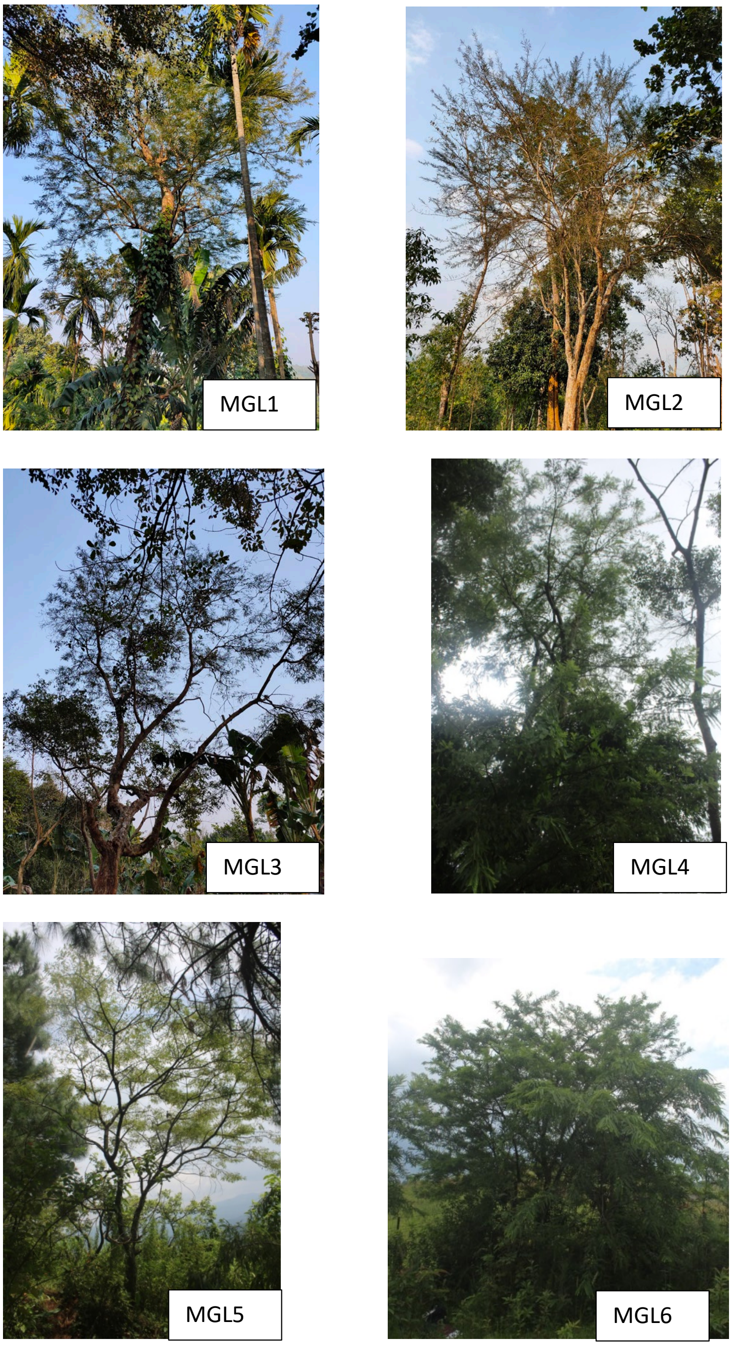


Plate 1: Selected *Phyllanthus emblica* accessions tree from Meghalaya (MGL1-MGL6)

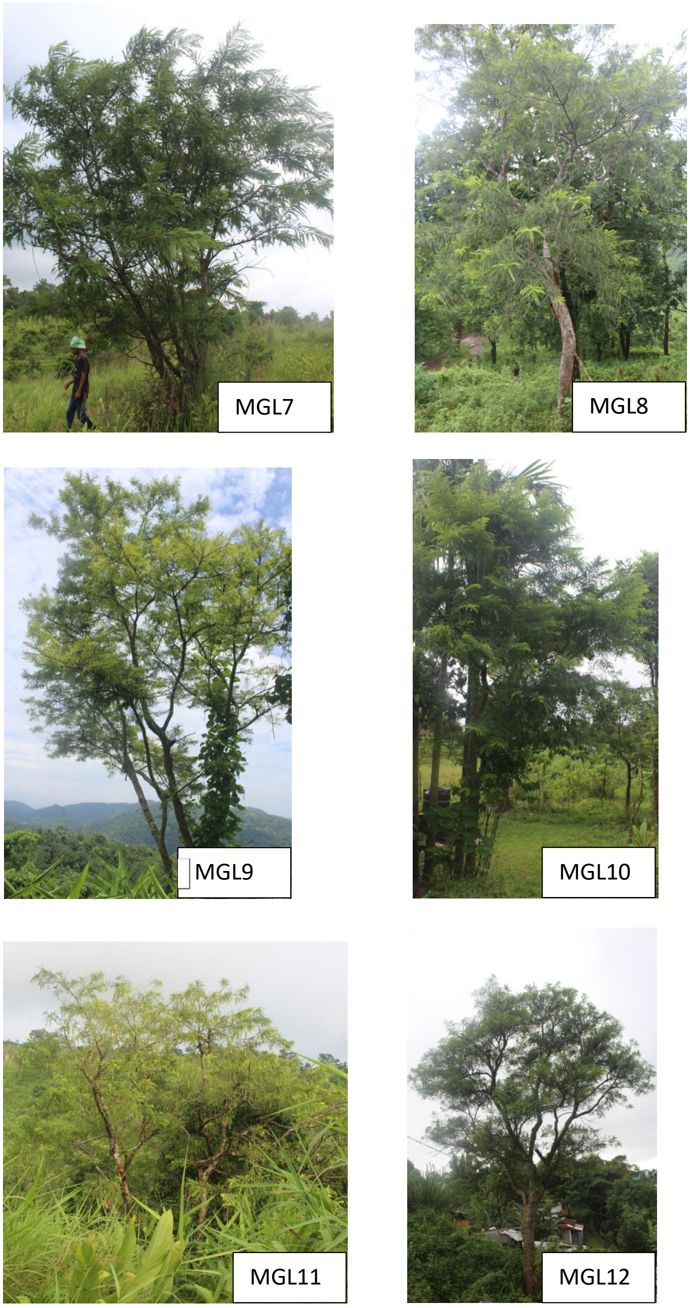


Plate 2: Selected *Phyllanthus emblica* accessions tree from Meghalaya (MGL7-MGL12)

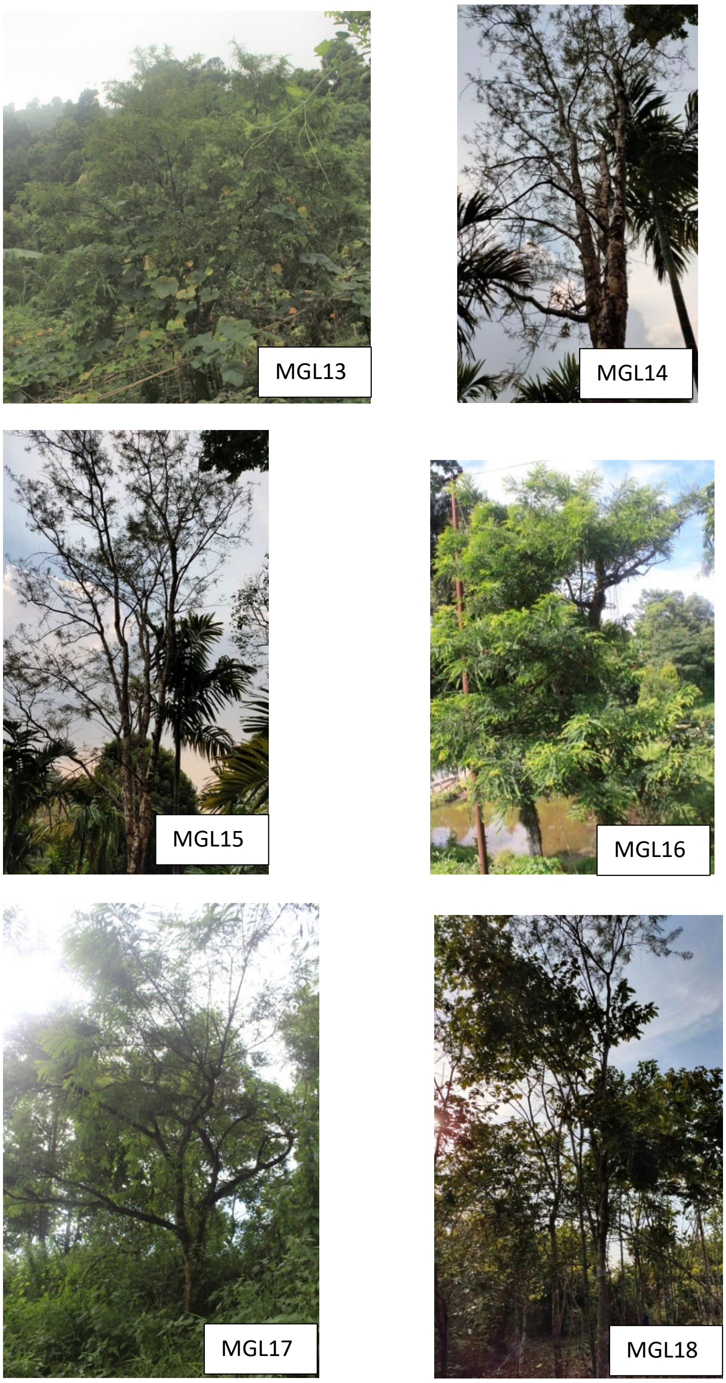


Plate 3: Selected *Phyllanthus emblica* accessions tree from Meghalaya (MGL13-MGL18)

Plate 4 Selected *Phyllanthus emblica* accessions from Meghalaya (MGL19-MGL20)

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Plate 5 Selected *Phyllanthus emblica* accessions from Mizoram (MZR1-MZR6)

Plate 6 Selected *Phyllanthus emblica* accessions from Mizoram (MZR7-MZR12).

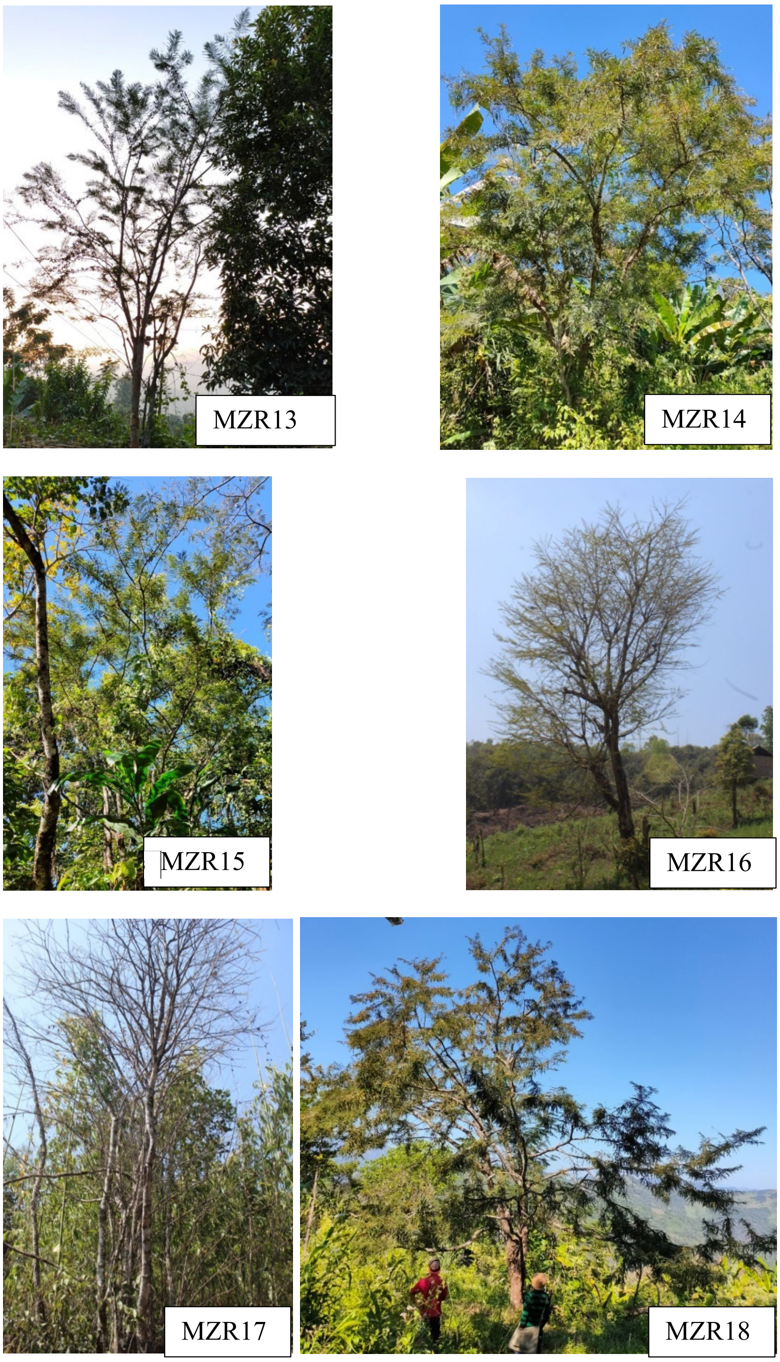


Plate 7 Selected *Phyllanthus emblica* accessions from Mizoram (MZR8-MZR18).

Plate 8 Selected *Phyllanthus emblica* accessions from Mizoram (MZR19-MZR20).

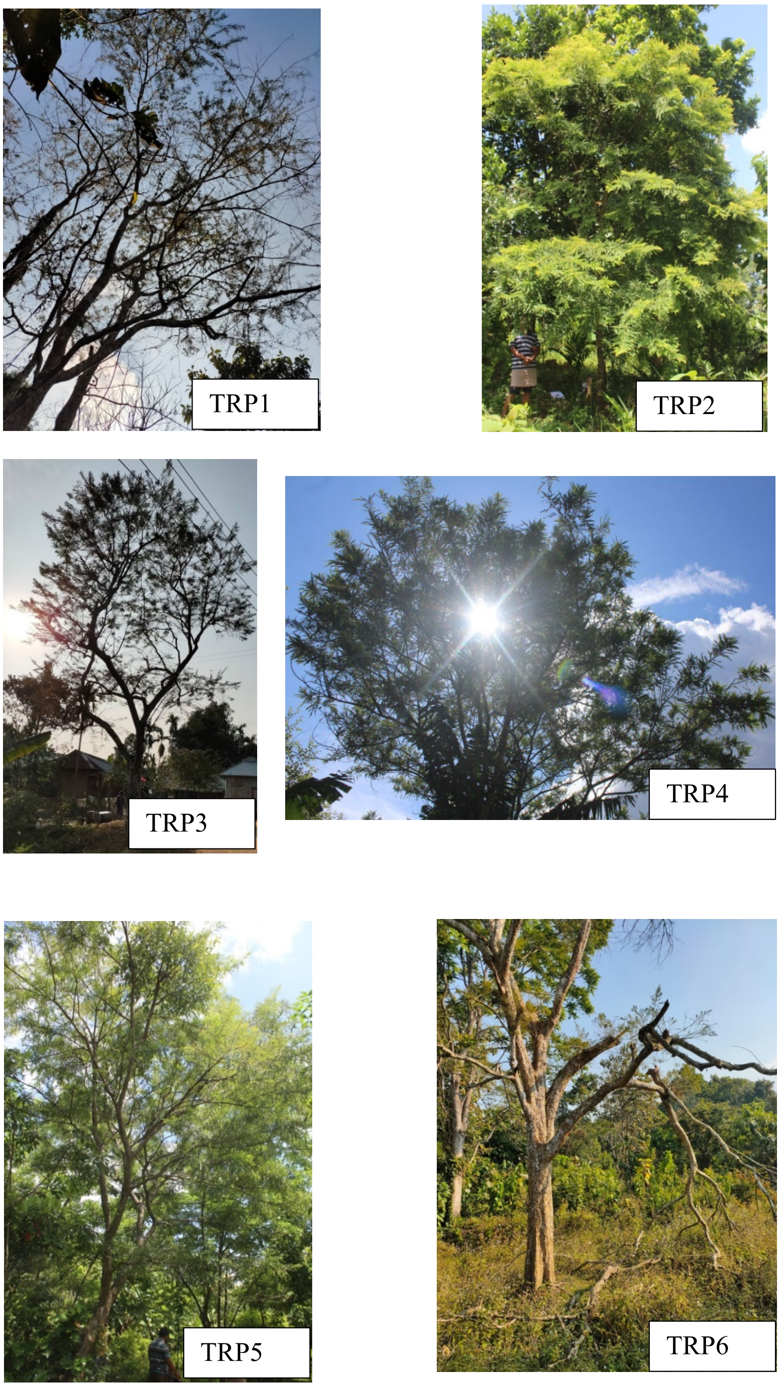


Plate 9 Selected *Phyllanthus emblica* accessions from Tripura (TRP1-TRP6).

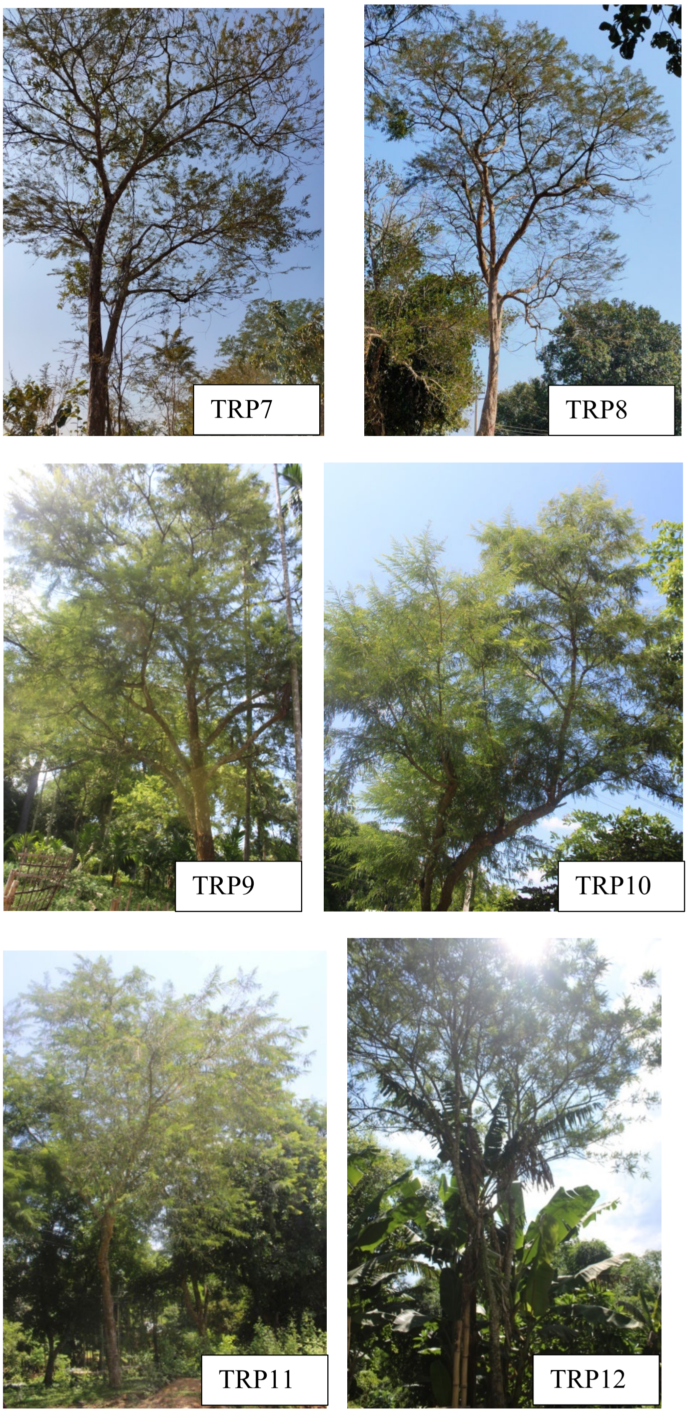


Plate 10 Selected *Phyllanthus emblica* accessions from Tripura (TRP7-TRP12).

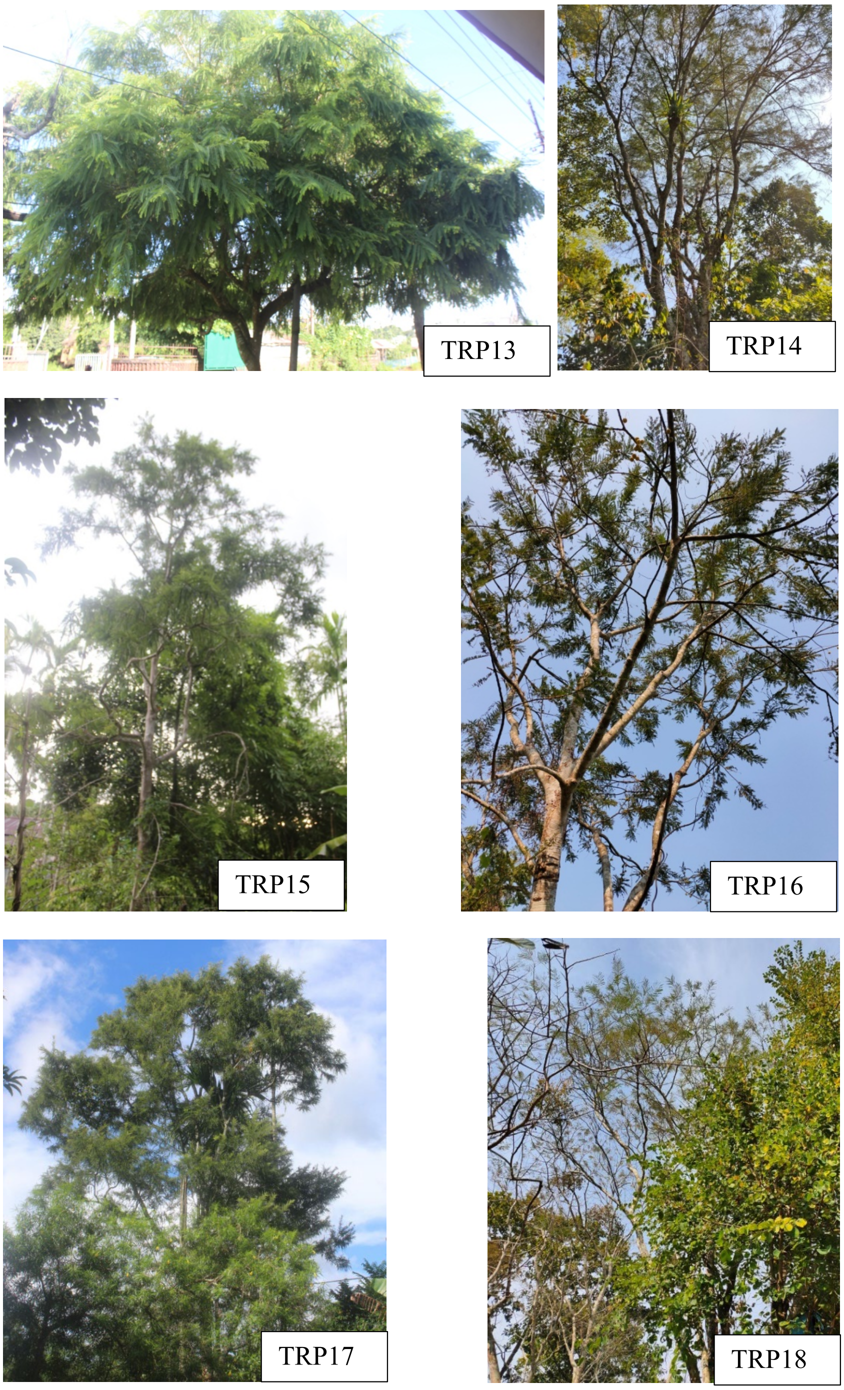


Plate 11 Selected *Phyllanthus emblica* accessions from Tripura (TRP13-TRP18).

Plate 12 Selected *Phyllanthus emblica* accessions from Tripura (TRP19-TRP20).

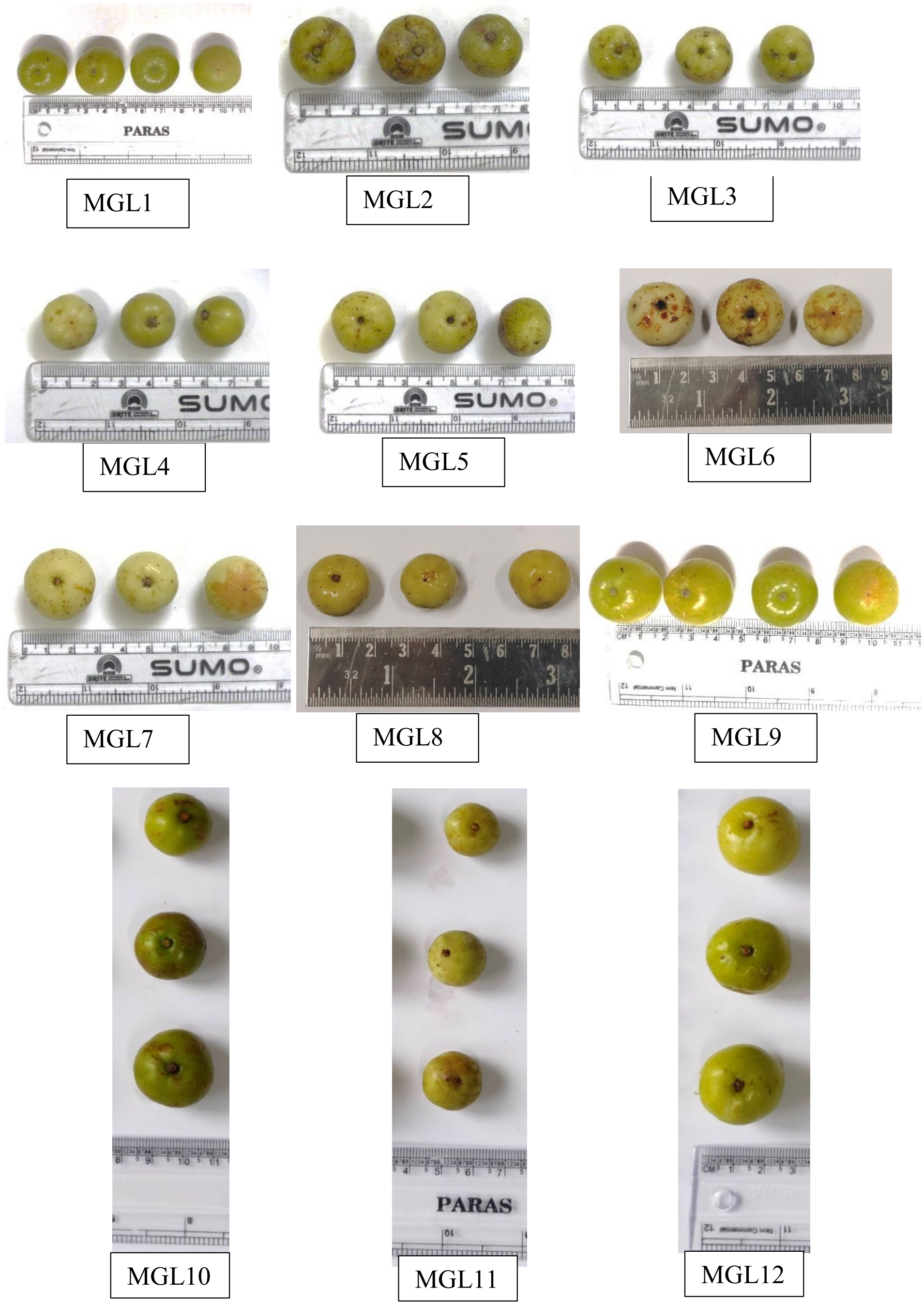


Plate 13 Fruits of *Phyllanthus emblica* accessions from Meghalaya (MGL1-MGL12).

MGL13

MGL14

MGL15

MGL16

MGL17

MGL18

MGL19

MGL20

Plate 14 Fruits of *Phyllanthus emblica* accessions from Meghalaya (MGL13-MGL20).

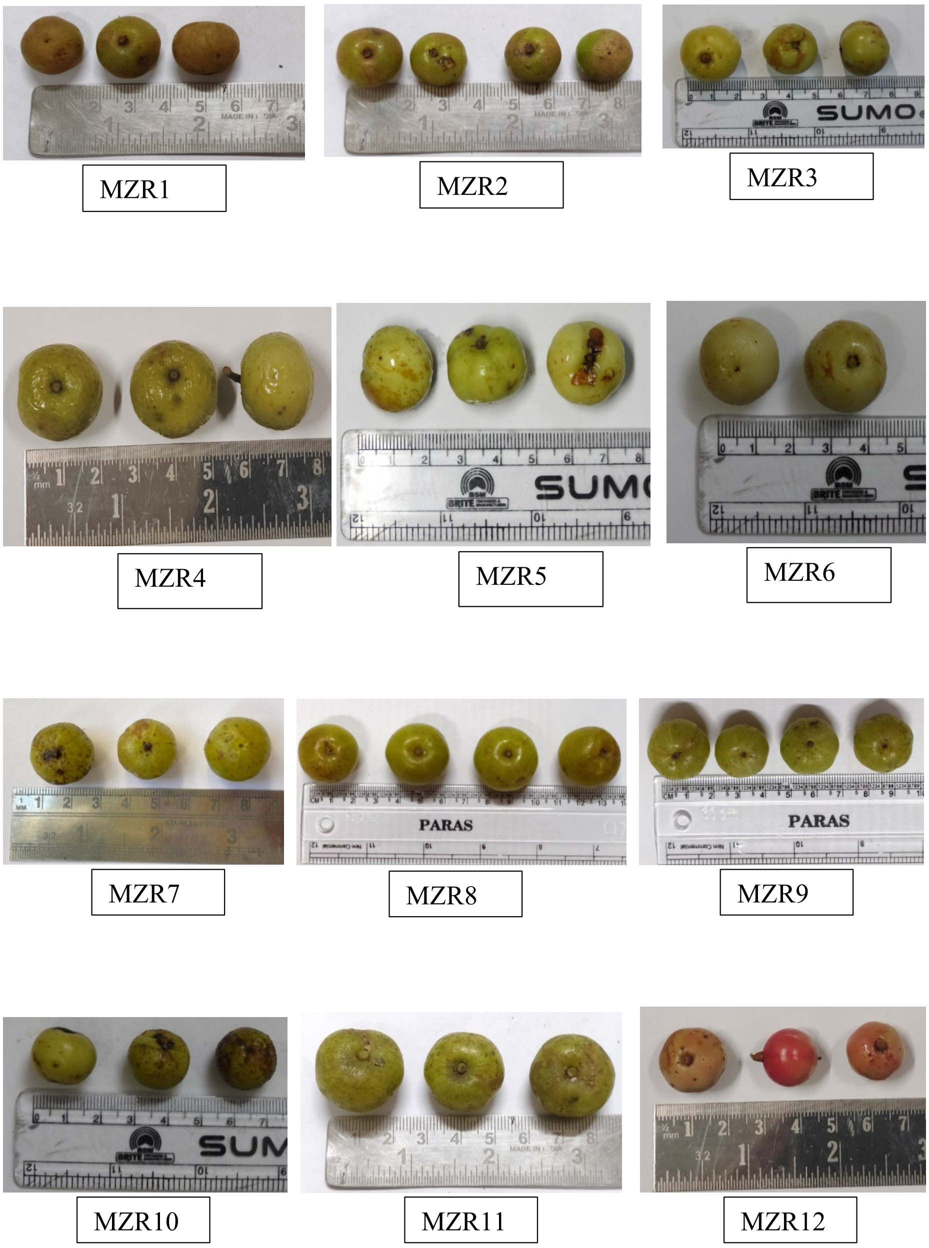


Plate 15 Fruits of *Phyllanthus emblica* accessions from Mizoram (MZR1-MZR12).

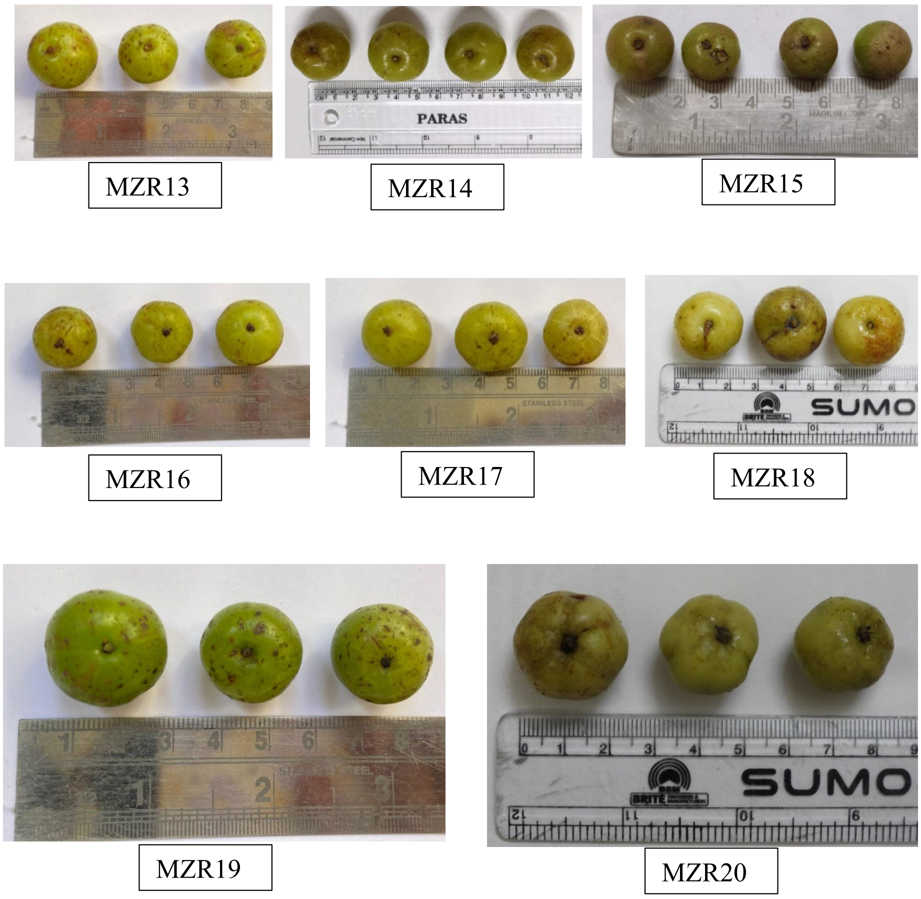


Plate 16 Fruits of *Phyllanthus emblica* accessions from Mizoram (MZR13-MZR20).

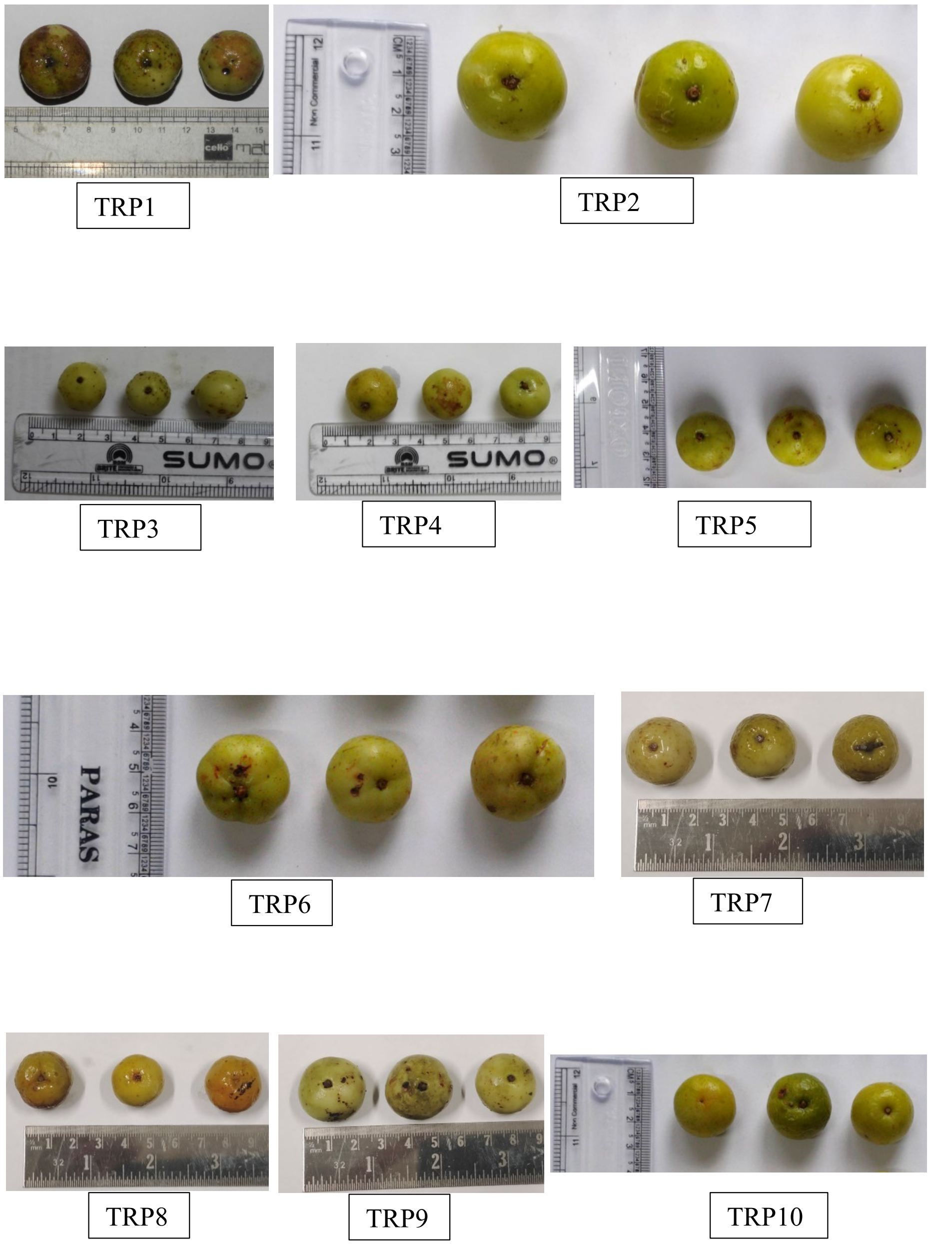


Plate 17 Fruits of *Phyllanthus emblica* accessions from Tripura (TRP1-TRP10).

TRP11

TRP12

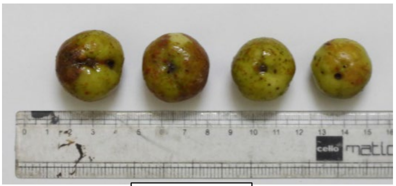
TRP13

TRP14

TRP15

TRP16

TRP17



TRP18

TRP19

TRP20

Plate 18 Fruits of *Phyllanthus emblica* accessions from Tripura (TRP11-TRP20).

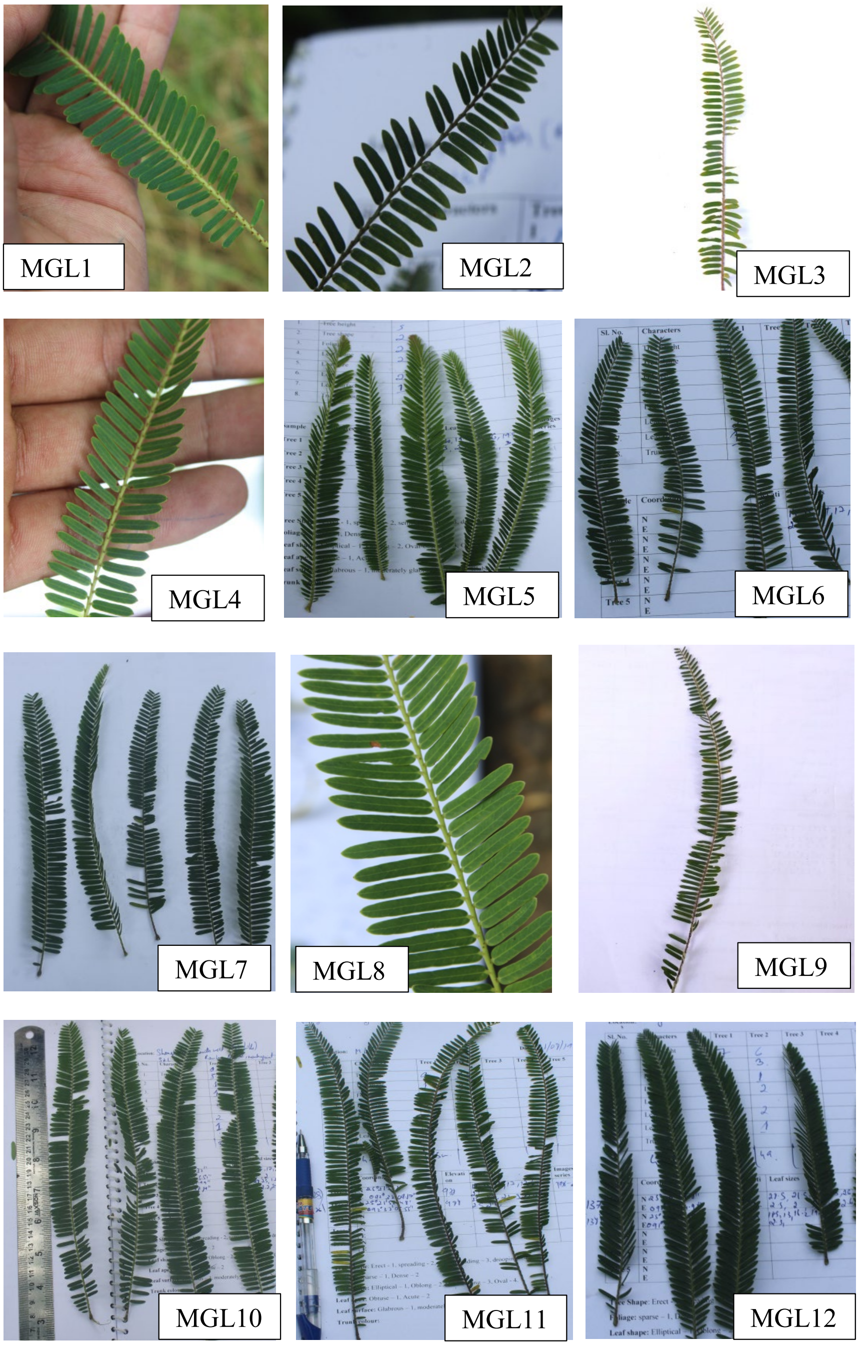


Plate 19 Leaflets of the selected *Phyllanthus emblica* accessions from Meghalaya (MGL1-MGL12)

Plate 20 Leaflets of the selected *Phyllanthus emblica* accessions from Meghalaya (MGL13-MGL20)

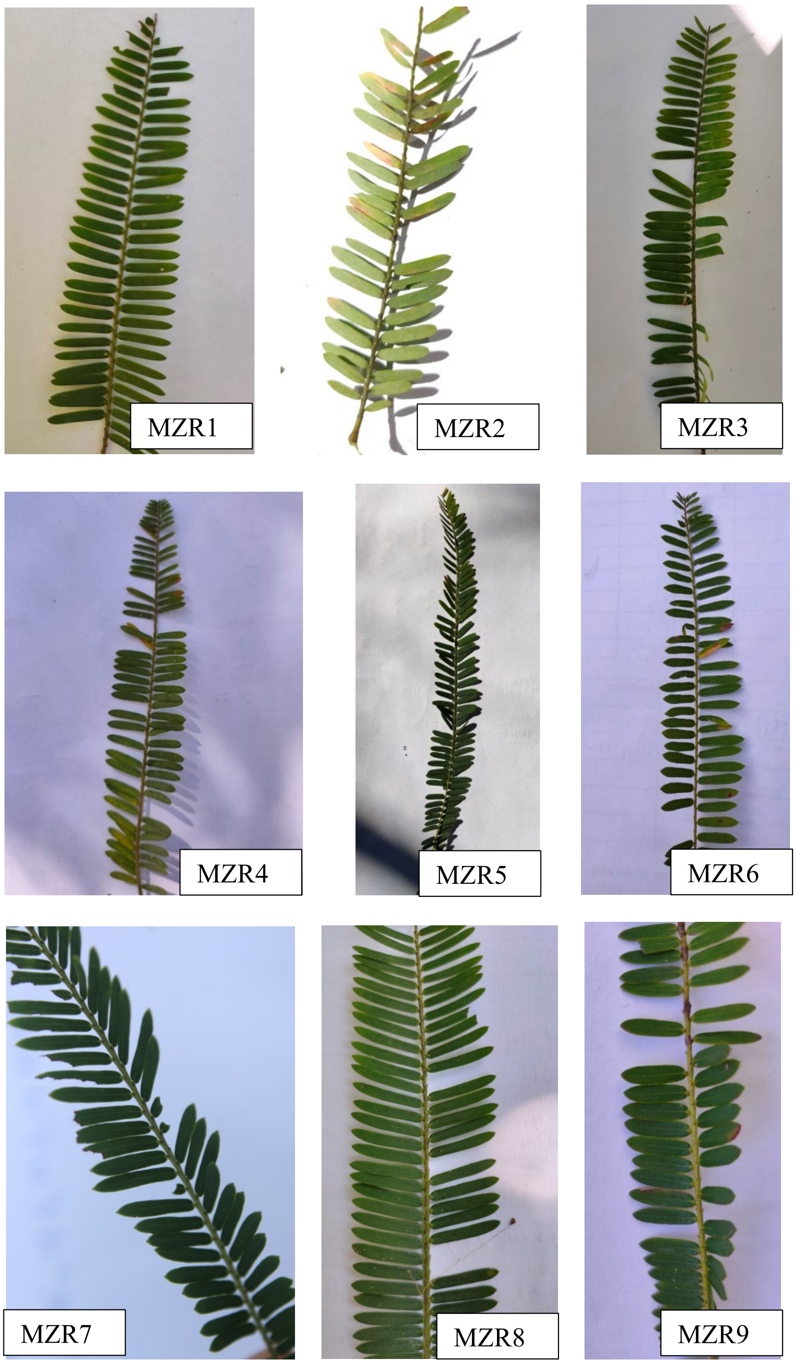


Plate 21 Leaflets of the selected *Phyllanthus emblica* accessions from Mizoram (MZR1-MZR9)

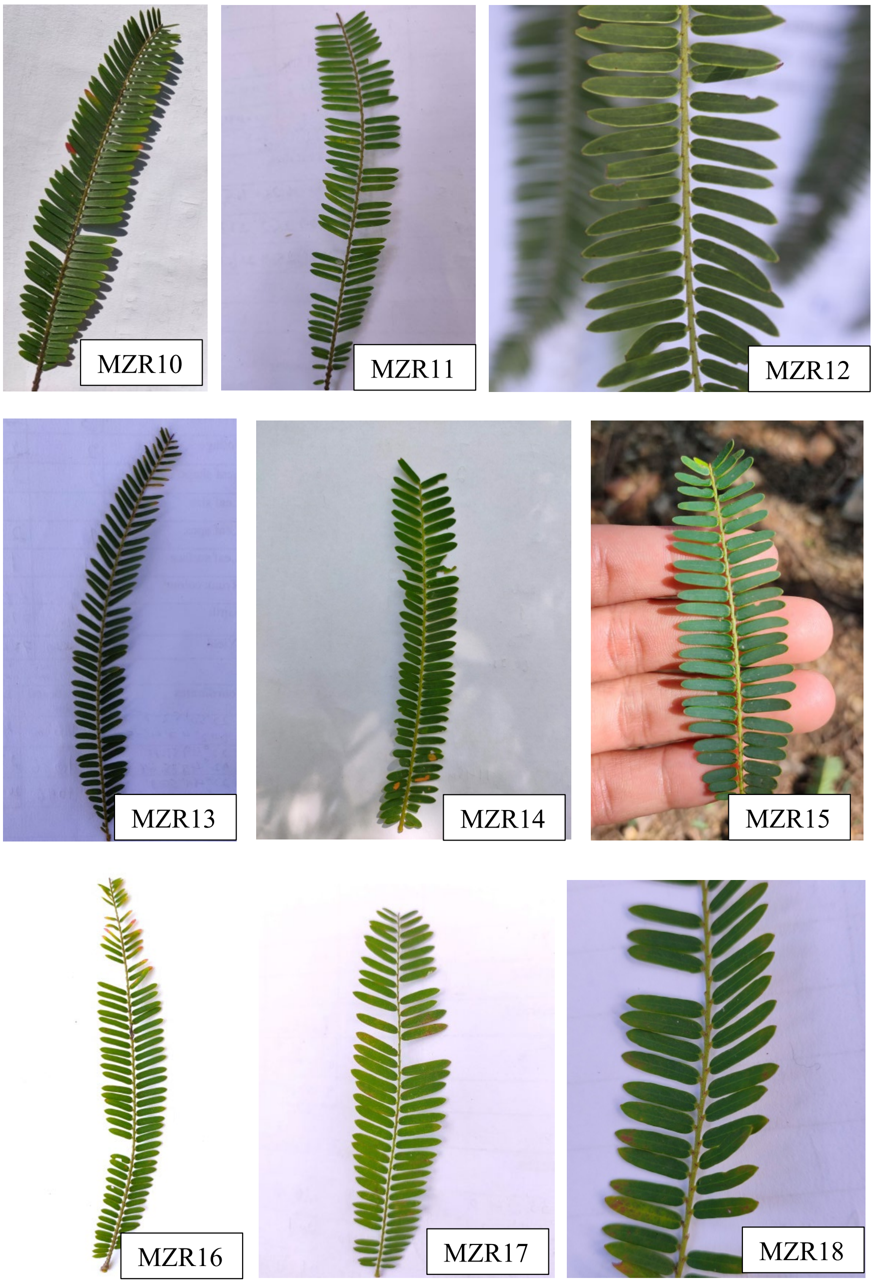


Plate 22 Leaflets of the selected *Phyllanthus emblica* accessions from Mizoram (MZR10-MZR18)

Plate 23 Leaflets of the selected *Phyllanthus emblica* accessions from Mizoram (MZR91-MZR20)

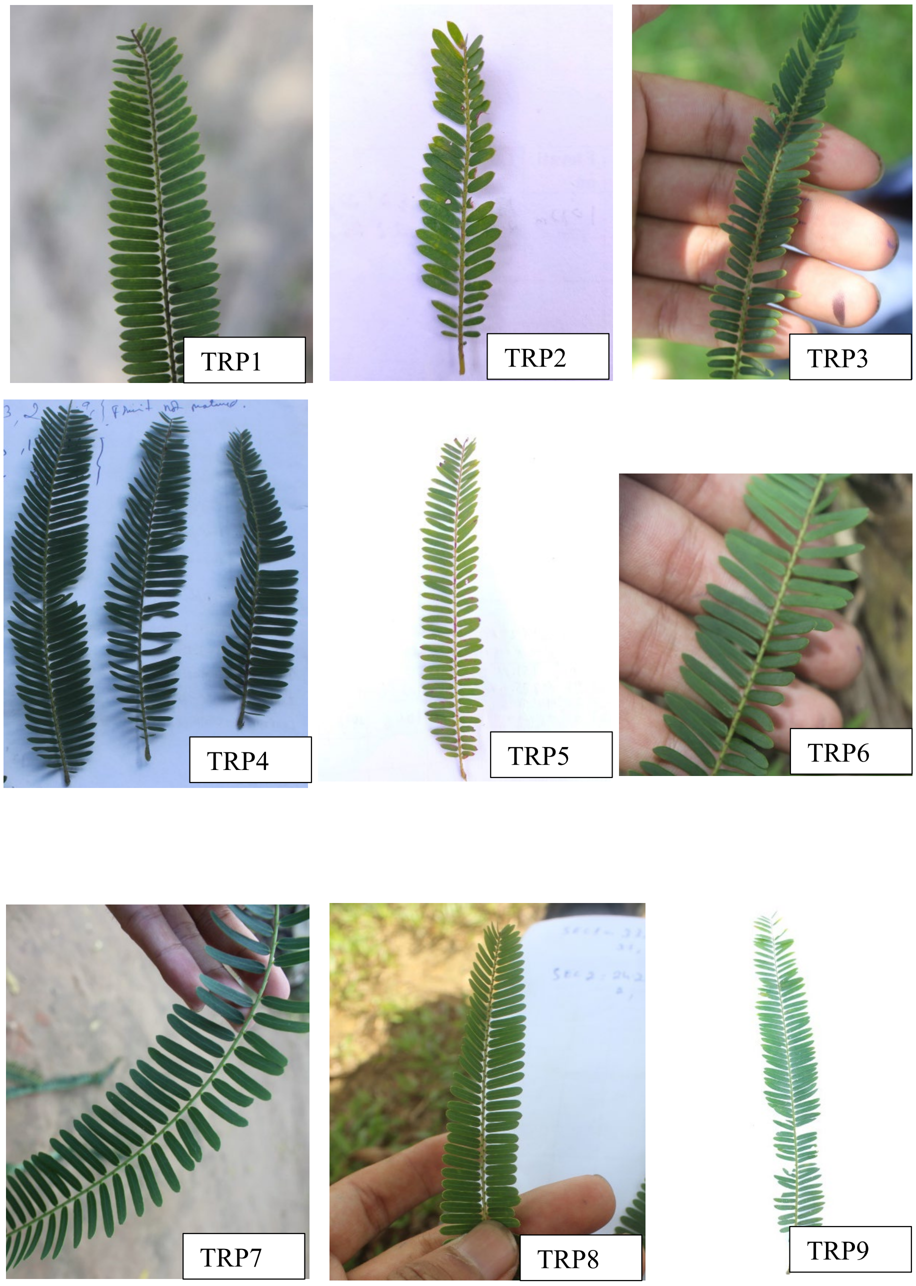


Plate 24 Leaflets of the selected *Phyllanthus emblica* accessions from Tripura (TRP1-TRP9)

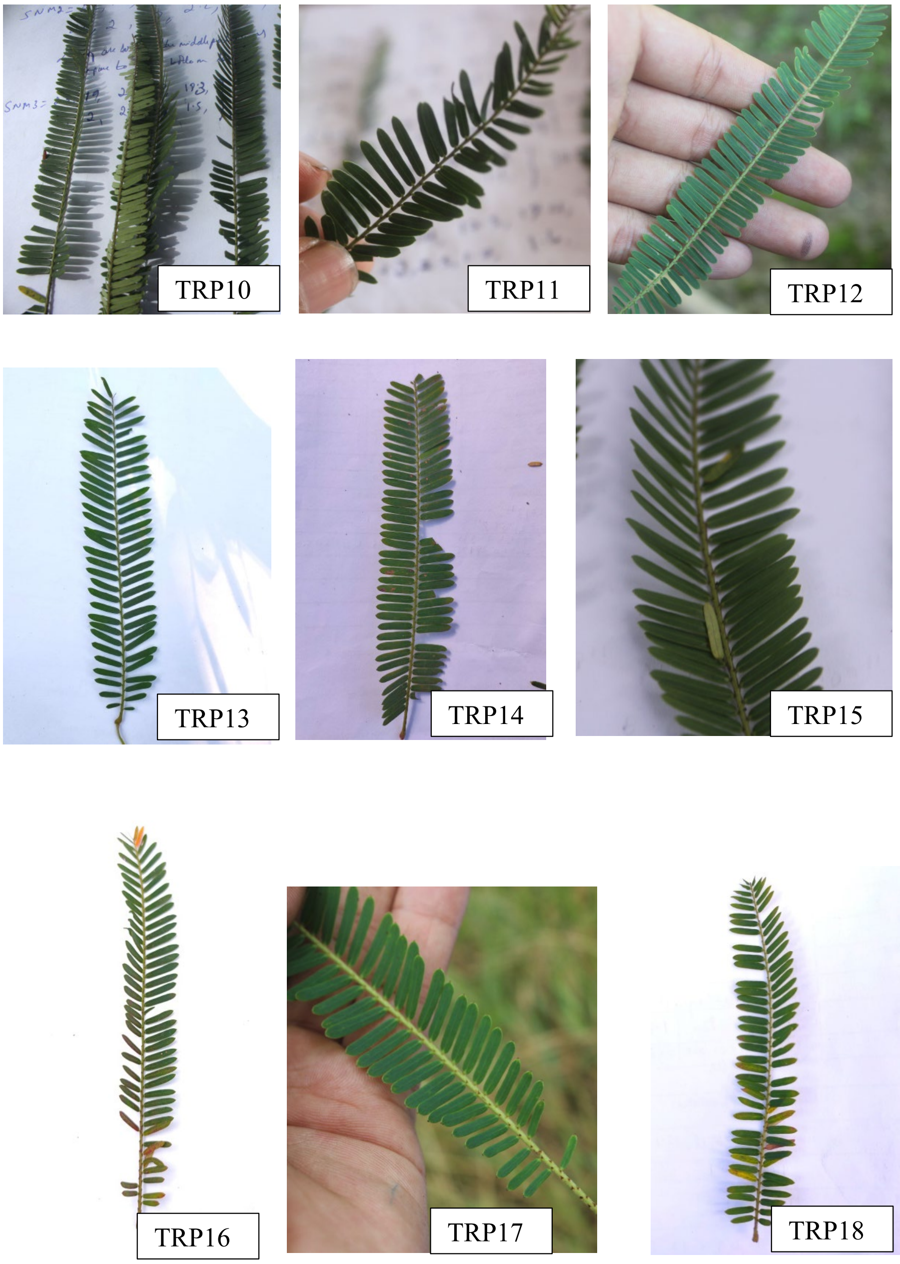


Plate 25 Leaflets of the selected *Phyllanthus emblica* accessions from Tripura (TRP10-TRP18)

Plate 26 Leaflets of the selected *Phyllanthus emblica* accessions from Tripura (TRP19-TRP20).

Plate 27 Harvesting of aonla fruits from selected genotypes.

Plate 28 Collection and storage of aonla fruits while transportation.

Plate 29 Sample preparation for analysis

Plate 30 Determination of ascorbic acid from aonla fruit samples by titration.

Plate 31 Estimation of phenol content by folin–ciocalteu method

Plate 32 Estimation of mineral content by dry ashing using AAS (atomic absorption spectrophotometry)

References

Abeysuriya, H. I., Bulugahapitiya, V. P., and Loku Pulukkuttige, J. (2020). Total vitamin C, ascorbic acid, dehydroascorbic acid, antioxidant properties, and iron content of underutilized and commonly consumed fruits in Sri Lanka. *International Journal of Food Science*, *2020*(1), 4783029.

Acharya, C. K., Khan, N. S., and Madhu, N. R. (2021). Medicinal uses of amla, *Phyllanthus emblica* L. (Gaertn.): a prospective review. *Mukt Shabd journal*, *10*, 311-315.

Aguilera, Y., Martin-Cabrejas, M. A., and González de Mejia, E. (2016). Phenolic compounds in fruits and beverages consumed as part of the mediterranean diet: their role in prevention of chronic diseases. *Phytochemistry reviews*, *15*, 405-423.

Ahmed, F., Hossain, A., Ahmed, N. U., Alam, M. J., and Islam, M. S. (2021). Genotypic Effects on Morphological Characterization of Fruit Traits in Mulberry. *European Journal of Agriculture and Food Sciences*, *3*(5), 81-89.

Ajibua, M. T., Iortsuun, D. N., Abubakar, B. Y., and Ibrahim, G. (2023). Comparative foliar epidermal, chemomicroscopic and physico-chemical evaluation of the leaves of Phyllanthus muellerianus and Phyllanthus fraternus in Zaria, Nigeria. *Journal of Advanced Education and Sciences*, *3*(5), 01-07.

Aliman, J., Michalak, I., Busatlic, E., Aliman, L., Kulina, M., Radovic, M., and Hasanbegovic, J. (2020). Study of the physicochemical properties of highbush blueberry and wild bilberry fruit in Central Bosnia. *Turkish Journal of Agriculture and Forestry, 44(2),* 156-168

Anand, J., Rawat, J. S., Rawat, V., Singh, B., Khanduri, V. P., Riyal, M. K., ... and Kumar, M. (2022). Climatic and altitudinal variation in physicochemical properties of *citrus sinensis* in India. *Land, 11(11),* 2033.

Anila, L., and Vijayalakshmi, N. (2002). Flavonoids from *Emblica officinalis* and *Mangifera indica* effectiveness for dyslipidemia. *Journal of Ethnopharmacology, 79*(1), 81–87.

Arora, R. K. (1998). *Promoting conservation and use of tropical fruit species in Asia.* Retrieved from http://www2.bioversityinternational.org

Asghar, S., Hasan, S., Khan, M. N., Hussain, T., Khalid, S., Siddique, I. M., Akhtar, A., Batoo, I., Rafique, R., Saleem, A., and Akhtar, J. (2022). Performance evaluation of selected cherry cultivars under climatic conditions of Murree Hills. *Plant Cell Biotechnology and Molecular Biology*, *23*(9-10), 37-43.

Ashiq, R. M., Ahmad, J. S., Uddin, S. S., Ghafoor, A., and Ahmad, Z. (2019). Morpho-biochemical chracterization of Amla (*Phyllanthus emblica* L.) and Tamarind (*Tamarindus indica* L.) germplasm from Pakistan. *Genetika*, *51*(2), 539-549.

Asmilia, N., Sutriana, A., Aliza, D., and Sudril, N. (2020). Anti-inflammatory activity of ethanol extract from malacca leaves (*Phyllanthus emblica*) in carrageenan induced male mice. *In E3S Web of Conferences 151,* 01066.

Aulakh, P. S., Kaur, A., Singh, J., and Thakur, A. (2013). Performance of aonla (*Emblica officinalis* Gaertn.) cultivars in Punjab. *Journal of Research, Punjab Agricultural University*, *50*(3), 110-13.

Bafna, P. A., and Balaraman, R. (2005).Anti-ulcer and anti-oxidant activity of pepti care, a herbomineral formulation. *Phytomedicine., 12(4),* 264-70.

Bairwa, P. K., Verma, R. S., Pal, H., Prakash, S., Kumar, S., and Shivran, B. C. (2020). Studies on physical characters of different cultivars of aonla (*Emblica officinalis* Gaertn). *Indian Journal of Pure and Applied Biosciences*, *8*(4), 631-634.

Bairwa, S. K., Maji, S., and Verma, N. K. (2022). Variability study of ber fruits (*Ziziphus mauritiana* Lamk.) collected from naturally grown plants through morphological characterization. *South Asian Journal of Experimental Biology, 12*(2).

Bajpai, M., Pande, A., Tewari, S. K., and Prakash, D. (2005). Phenolic contents and antioxidant activity of some food and medicinal plants. *International Journal of Food Sciences and Nutrition, 56*(4), 287–291.

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 Agricultural Sciences*, *85*(8), 1012-16.

Bala, S., Ram, S., Prasad, J. (2009). Studies on variability and genetic diversity in selected Aonla genotypes. *Indian Journal of Horticulture, 66(4)*, 433–437

Baliga, M. S., and Dsouza, J. J. (2011). Amla (*Emblica officinalis* Gaertn), a wonder berry in the treatment and prevention of cancer. *European Journal of Cancer Prevention, 20*(3), 225-239. https://doi.org/10.1097/CEJ.0b013e3283434114

Baliga, M. S., Prabhu, A. N., Prabhu, D. A., Shivashankara, A. R., Abraham, A., and Palatty, P. L. (2013). Antidiabetic and cardioprotective effects of Amla (*Emblica officinalis* Gaertn) and its phytochemicals: preclinical observations. *In Bioactive food as dietary interventions for diabetes* (pp. 583-600). Academic Press.

Baliga, M. S., Shivashankara, A. R., Thilakchand, K. R., Baliga-Rao, M. P., Palatty, P. L., George, T., & Rao, S. (2019). Hepatoprotective effects of the Indian Gooseberry (*Emblica officinalis* Gaertn): a revisit. *In Dietary interventions in liver disease* (pp. 193-201). Academic Press.

Baptista, M. S., Cadet, J., Greer, A., and Thomas, A. H. (2021). Photosensitization reactions of biomolecules: Definition, targets and mechanisms. *Photochemistry and Photobiology, 97*(6), 1456-1483.

Barrett, D. M., Beaulieu, J. C., and Shewfelt, R. (2010). Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. *Critical Reviews in Food Science and Nutrition*, *50*(5), 369-389.

Barthakur, N. N., and Arnold, N. P. (1991). Chemical analysis of the emblic (*Phyllanthus emblica* L.) and its potential as a food source. *Scientia Horticulturae*, *47*(1-2), 99-105.

Barwick, M. (2004). *Tropical and subtropical trees - A worldwide encyclopedic guide*.

Bharathi, M. D., and Thenmozhi, A. J. (2018). Attenuation of aluminum-induced neurotoxicity by tannoid principles of *Emblica officinalis* in Wistar rats.

International Journal of Nutrition, Pharmacology, Neurological Diseases, 8(2), 35-40.

Bhattacharya, S. K., Bhattacharya, A., Sairam, K., and Ghosal, S. (2002). Effect of bioactive tannoid principles of *Emblica officinalis* on ischemia-reperfusion-induced oxidative stress in rat heart. *Phytomedicine, 9*(2), 171–174.

Bhattacherjee, A. K., Dikshit, A., Pandey, D., and Singh, A. (2020). Characterization of ascorbic acid and phenolic compounds for identification of nutritionally rich cultivars and accessions of Indian gooseberry. *Fruits*, *75*(2), 71-77.

BhavaniSanker, K., Veeraragavathatham, D., Chezhiam, N., Vijayakumar, R. M., and Balasubramanian, A. (1999). BSR-1 A high yield amla variety for Tamil Nadu. *South Indian Horticulture*, *47*, 143-44.

Boyer, J., and Liu, R. H. (2004). Apple phytochemicals and their health benefits. *Nutritional Reviews*, *62*(2), 100-106.

Brimapureeswaran, R., and Anandakumar, S. (2015). Physical Properties and Pulp Efficiency of Aonla Fruit (*Emblica officinalis* gaertn). *International Journal for Science and Advance Research in Technology*, *1*(8), 2395-1052.

Bulo, U., Nimbolkar, P. K., Singh, S., Sahu, G. D., Wangchu, L., Das, S., and Pandey, D. K. (2024). Nutrient profiling of Wild Aonla (*Emblica officinalis* Gaertn.) populations in Northeast India: Assessing the potential of this fruit tree for ecological and human health restoration. *Journal of Food Composition and Analysis*, 125, 105814.

Chadha, K. L. (2013). *Handbook of horticulture* (12^{th} ed., pp. 140–142). ICAR New Delhi.

Chaiittianan, R., and Sripanidkulchai, B. (2014). Development of a nanoemulsion of *Phyllanthus emblica* L. branch extract. *Drug Development and Industrial Pharmacy, 40*(12), 1597–1606.

Chandra, A. S., Baby, R. G., and Radhamany, P. M. (2018). Comparative analysis on the morphological, phytochemical and pharmacological characters of five species of Phyllanthus L. *Abrahamia*, *4*(1), 9-15.

Chandra, R, Srivastava, R, Singh, A. S., Hore, D. K. and Govind, S. (1998). Collection of genetic diversity of aonla (*Emblica officinalis* L.) from Garo Hills of Meghalaya, India. *Indian Journal of Hill farming*, *11*(1-2), 116–23.

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*(1), 870-877.

Chaphalkar, R., Apte, K. G., Talekar, Y., Ojha, S. K., and Nandave, M. (2017). Antioxidants of *Phyllanthus emblica* L. Bark Extract Provide Hepatoprotection against Ethanol-Induced Hepatic Damage: A Comparison with Silymarin. *Oxidative medicine and cellular longevity*, *2017*(1), 3876040.

Chapman, D. F. (1987). Natural re-seeding and *Trifolium repens* demography in grazed hill pastures. II. Seedling appearance and survival. *Journal of Applied Ecology*, *24*, 1037-1043.

Chatterjee, A., Chatterjee, S., Biswas, A., Bhattacharya, S., Chattopadhyay, S., and Bandyopadhyay, S. K. (2012). Gallic acid enriched fraction of *Phyllanthus emblica* potentiates indomethacin-induced gastric ulcer healing via e-NOS-dependent pathway. *Evidence-Based Complementary and Alternative Medicine, 2012 (1),* 487380.

Chaurasia, A. K., Subramaniam, V. R., Krishna, B., and Sane, P. V. (2009). RAPD based genetic variability among cultivated varieties of aonla (Indian gooseberry, *Phyllanthus emblica* L.). *Physiology and Molecular Biology of Plants, 15*(2), 169–173.

Chen, H., Guo, A., Wang, J., Gao, J., Zhang, S., Zheng, J., Huang, X., Xi, J., Yi, K. (2020). Evaluation of genetic diversity within asparagus germplasm based on morphological traits and ISSR markers. *Physiology and Molecular Biology of Plants*, *26*,305-315.

Chiranjeevi, M. R., Muralidhara, B. M., Hongal, S., and Sneha, M. K. (2018). Physico-chemical characterization of aonla fruits grown under Bengaluru conditions. *International Journal of Current Microbiology and Applied Sciences*, *7*(3), 3611-3615.

Chopra, R. N., Chopra, I. C., Handa, K. L., and Kapur, L. D. (1958). Indigenous drugs of India, UN Dhur and sons Pvt. *Ltd., Calcutta*, *289*, 665.

Chopra, R. N., Nayar, S. L., and Chopra, I. C. (1992). *Glossary of Indian medicinal plants*. Council of Scientific & Industrial Research.

Chularojmontri, L., Suwatronnakorn, M., and Wattanapitayakul, S. K. (2013). *Phyllanthus emblica* L. enhances human umbilical vein endothelial wound healing and sprouting. *Evidence-Based Complementary and Alternative Medicine, 2013(1),* 720728.

Curi, P. N., Coutinho, G., Matos, M., et al. (2018). Characterization and marmalade processing potential of quince cultivars cultivated in tropical regions. *Revista Brasileira de Fruticultura, 40*(1), 1-7.

Dawson, I. K., Leakey, R., Clement, C. R., Weber, J., Cornelius, J. P., Roshetko, J. M., Vinceti, B., Kalinganire, A., Tchoundjeu, Z., Masters, E., and Jamnadass, R. (2014). The management of tree genetic resources and the livelihoods of rural communities in the tropics: Non-timber forest products, smallholder agroforestry practices, and tree commodity crops. *Forest Ecology and Management, 333*, 9-21. https://doi.org/10.1016/j.foreco.2014.01.021

Deka, B. C., Thirugnanavel, A., Patel, R. K., Nath, A., and Deshmukh, N. (2012). Horticultural diversity in North-East India and its improvement for value addition. *Indian Journal of Genetics and Plant Breeding, 72*(2), 157–167.

Dhale, D. A. (2012). Pharmacognostic evaluation of *Phyllantus emblica* Linn (Euphorbiaceae). *International Journal of Pharma and Bio Sciences*, *3*(3), 210-217.

Dhanalakshmi, S., Devi, R. S., Srikumar, R., Manikandan, S., and Thangaraj, R. (2007). Protective effect of Triphala on cold stress-induced behavioral and biochemical abnormalities in rats. *Yakugaku Zasshi, 127(11),* 1863-1867.

Dinesh, M., Roopan, S. M., Selvaraj, C. I., and Arunachalam, P. (2017). *Phyllanthus emblica* seed extract mediated synthesis of PdNPs against antibacterial, heamolytic and cytotoxic studies. *Journal of Photochemistry and Photobiology B: Biology, 167,* 64-71.

Directorate of Economics & Statistics, Mizoram. (2018). *Mizoram at a glance 2018* (pp. 1–159). Government of Mizoram. Retrieved December 3, 2024, from https://des.mizoram.gov.in/uploads/attachments/d75edc6c76ed33ba648a9b87cd50736e/pages-159-mizoram-at-a-glance-2018.pdf

Dondini, L., Domenichini, C., Dong, Y., Gennari, F., Bassi, D., Foschi, S., Lama, M., Adami, M., De Franceschi, P., Cervellati, C., Bergonzoni, L., Alessandri, S., & Tartarini, S. (2022). Quantitative trait loci mapping and identification of candidate genes linked to fruit acidity in apricot (*Prunus armeniaca* L.). *Frontiers in Plant Science, 13,* 838370. https://doi.org/10.3389/fpls.2022.838370

Dorostkar, M., and Moradinezhad, F. (2022). Postharvest quality responses of pomegranate fruit (cv. Shishe-kab) to ethanol, sodium bicarbonate dips, and modified atmosphere packaging. *Advances in Horticultural Science*, *36*(2), 107-117.

Drisya Ravi, R. S., Nair, B. R., and Siril, E. A. (2021). Morphological diversity, phenotypic and genotypic variance and heritability estimates in *Moringa oleifera* Lam.: a less used vegetable with substantial nutritional value. *Genetic Resources and Crop Evolution*, *68*(8), 3241-3256.

Ecevit, F. M., Şan, B., Dilmaç Ünal, T., Hallaç Türk, F., Yıldırım, A. N., Polat, M., and Yıldırım, F. (2008). Selection of superior Ber (*Ziziphus jujuba* L.) genotypes in civril region. *Tarım Bilimleri Dergisi*, *14*(1), 51-56.

El Amir, D., AbouZid, S. F., Hetta, M. H., Shahat, A. A., and El-Shanawany, M. A. (2014). Composition of the essential oil of the fruits of *Phyllanthus emblica* cultivated in Egypt. *Journal of Pharmaceutical, Chemical and Biological Sciences, 2*, 202–207.

El-Desouky, S. K., Ryu, S. Y., and Kim, Y. K. (2008). A new cytotoxic acylated apigenin glucoside from *Phyllanthus emblica* L. *Natural Product Research*, *22*(1), 91-95.

Environment, Forests & Climate Change Department, Government of Mizoram. (2024). Mizoram: Land of the hill people. Retrieved from https://forest.mizoram.gov.in/page/mizoram-forest-at-a-glance

Erkan, M., and Dogan, A. (2019). Harvesting of horticultural commodities. *In Postharvest Technology of Perishable Horticultural Commodities* (pp. 129-159). Woodhead Publishing.

Fatima, N., Hafizur, R. M., Hameed, A., Ahmed, S., Nisar, M., and Kabir, N. (2017). Ellagic acid in *Emblica officinalis* exerts anti-diabetic activity through the action on β-cells of pancreas. *European journal of nutrition, 56,* 591-601.

Fitriansyah, S. N., Aulifa, D. L., Febriani, Y., and Sapitri, E. (2018). Correlation of total phenolic, flavonoid and carotenoid content of *Phyllanthus emblica* extract from Bandung with DPPH scavenging activities. *Pharmacognosy Journal*, *10*(3), 447-452.

Food Crumbles. (2018, May 28). The texture of fruit and vegetables – On turgor and plant cells. *Food Crumbles*. https://www.foodcrumbles.com/the-texture-of-fruit-vegetables-on-turgor-and-plant-cells/

Forest Survey of India. (2021) Ministry of Environment, Forest and Climate Change, Kaulagarh Road, P.O. IPE, Dehradun – 248195, Uttarakhand, India. https://fsi.nic.in/forest-report-2021-details

Galasheva, A. M., Makarkina, M. A., and Vetrova, O. A. (2023). Ascorbic acid content in summer apple tree varieties fruit depending on rootstock and meteorological conditions of vegetable. *Vestnik of the Russian Agricultural Science*, *5*, 47-51.

Gangappa, N. D., Singh, C., Verma, M. K., Thakre, M., Sevanthi, A. M., Singh, R., Srivastav, M., Raghunandan, k., Anusha C., Yadav, V, Nagaraja, A. (2022). Assessing the genetic diversity of guava germplasm characterized by morpho-biochemical traits. *Frontiers in Nutrition*, *9*, 1017680.

Gao, F-C., Yan, H-D., Gao, Y., Huang, Y., Li, M., Song, G.-L., Ren, Y-M., Li, J-H., Jiang, Y-X., Tang, Y-J., Wang, Y-X., Liu, T., Fan, G-Y., Wang, Z-G., Guo, R-F., Meng, F-H., Han, F-X., Jiao, S-J., and Li, G-Y. (2022). Interpretation of genotype-environment-sowing date/plant density interaction in sorghum [*Sorghum bicolor* (L.) Moench] in early mature regions of China. *Frontiers in Plant Science*, *13*, 1008198. https://doi.org/10.3389/fpls.2022.1008198

Gharibi, H., Moghadam, A. L., Alizadeh, M., and Baghdadi, G. (2023). Comparative analysis of morphological and biochemical properties of some Mulberry (*Morus* spp.) genotypes. *Journal of Applied and Natural Science*, *15*(4), 1421-1433.

Ghosh, D., and Parida, P. (2015). Medicinal plants of Assam, India: a mini review. *International Journal of Pharmacology and Pharmaceutical Sciences*, *2*(6), 5-10.

Ghosh, S. N., Roy, S., and Bera, B. (2013). Study on performance of aonla cultivars in laterite soil of West Bengal. *Journal of Crop and Weed*, *9*(2), 36-38.

Gocher, M., Gochar, R., Rawat, S. S., and Rana, D. K. (2020). Qualitative and quantities evaluation of *Phyllanthus emblica* L. fruits under valley condition of Garhwal Himalaya. *Journal of Pharmacognosy and Phytochemistry*, *9*(3), 1295-1299.

Godara, R. K., Sharma, R. K., Goyal, R. K., and Jitender Kumar, J. K. (2004). Physicochemical composition of different cultivars of aonla as influenced by time of harvesting. *Indian Journal of Hill Farming*, *17*(1/2), 56-58.

Golechha, M., Bhatia, J., and Arya, D. S. (2012). Studies on effects of *Emblica officinalis* (Amla) on oxidative stress and cholinergic function in scopolamine induced amnesia in mice. *Journal of Environmental Biology, 33(1),* 95.

Government of Tripura. (2024). *Geographical profile*. Tripura State Portal. Retrieved December 3, 2024, from https://tripura.gov.in/geographical-profile

Goyal, R. K., Kingsly, A. R. P., Kumar, P., and Walia, H. (2007). Physical and mechanical properties of aonla fruits. *Journal of food Engineering*, *82*(4), 595-599.

Güleryüz, M., Bolat, I. and Pirlak, L. (1998). Selection of Table cornelian cherry (Cornus mas L.) types in çoruh valley', Turkish Journal of Agriculture and Forestry, *22*(4), 357–364.

Halim, B., Syahputra, R. A., Adenin, I., Lubis, H. P., Mendrofa, F., Lie, S., and Nugraha, S. E. (2022). Determination of phytochemical constituent, antioxidant activity, total phenol and total flavonoid of extract ethanol *Phyllanthus emblica* fruit. *Pharmacognosy Journal*, *14*(1).

Harahap, F. S., Atifah, Y., and Ginting, N. (2020). Comparison of the chemical compounds of Malacca bark and Malacca fruit (*Phyllanthus emblica*) with gas chromatography-mass spectrometer (GC-MS). *Journal of Physics, 1477*(7), 072011.

Hazarika, B. N., Deka, B. C., Choudhury, S., and Sarma, B. (2009). Studies on variability in physico-chemical characters of different aonla accessions from Jorhat region of Assam. *Indian Journal of Horticulture*, 66(2), 190-192.

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.

Hendricks, D. G. (1998). Mineral analysis. In S. N. Suzanne (Ed.), Food Analysis (pp. 151-154). Maryland: Aspen Publications.

Hernández, L. H., Santos, F. A. D., Palomino, E. C., Tambarussi, E. V., and Moraes, C. B. (2020). Genetic variation of trees of *Caryocar brasiliense* for fruit morphometric traits. *Floresta e Ambiente*, *28*(2), e20180097.

Hilton, P. J., and Palmer-Jones, R. (1973). Relationship between the flavanol composition of fresh tea shoots and the theaflavin content of manufactured tea. *Journal of the Science of Food and Agriculture*, *24*, 813-818.

Hovenden, M. J., and Vander Schoor, J. K. (2004). Nature vs nurture in the leaf morphology of Southern beech, *Nothofagus cunninghamii* (Nothofagaceae). *New Phytologist*, *161*(2), 585-594.

Hssaini, L., Hanine, H., Razouk, R., Ennahli, S., Mekaoui, A., Guirrou, I., and Charafi, J. (2020). Diversity screening of fig (*Ficus carica* L.) germplasm through integration of morpho-agronomic and biochemical traits. *International Journal of Fruit Science*, *20*(4), 939-958.

Ikram, E. H. K., Eng, K. H., Jalil, A. M. M., Ismail, A., Idris, S., Azlan, A., and Mokhtar, R. A. M. (2009). Antioxidant capacity and total phenolic content of Malaysian underutilized fruits. *Journal of food Composition and Analysis*, *22*(5), 388-393.

Ingale, V. M., More, H. G., and Kad, V. P. (2016). Determination of engineering properties of aonla (*Phyllanthus emblica* L or *Emblica officinalis* G) fruits. *Journal of Krishi Vigyan*, *4*(2), 12-15.

Institute of Medicine (US) Panel on Micronutrients. (2001). *Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc.* National Academies Press. https://doi.org/10.17226/10026.

Iqbal, M., Bakshi, P., Wali, V. K., Kumar, R., Bhat, D., and Jasrotia, A. (2016). Efficacy of organic and inorganic mulching materials on weed count, growth, and yield of aonla (*Emblica officinalis*) cv. NA 7. *Indian journal of Agricultural sciences*, *86*(4), 545-549.

Ivanova, I., Serdyuk, M., Tymoshchuk, T., Havryliuk, O., and Tonkha, V. (2022). Dynamics of the average fruit weight and the ratio of kernels to pulp in cherry fruits grown in the southern steppe zone of Ukraine. *Редакційна колегія*, *13*(3), 27-37.

Jaćimović, V., Božović, D., Ercisli, S., Bosančić, B., and Necas, T. (2020). Sustainable Cornelian cherry production in Montenegro: Importance of local genetic resources. *Sustainability*, *12*(20), 8651.

Jain, A., and Garg, N. (2017). Therapeutic and Medicinal uses of Amalaki: A Review. *World J Pharm Res, 6*(02), 512-524.

Jain, S. K., and Khurdiya, D. S. (2004). Vitamin C enrichment of fruit juice based ready-to-serve beverages through blending of Indian gooseberry (*Emblica officinalis* Gaertn.) juice. *Plant Foods for human nutrition*, *59*, 63-66.

Jaisankar, I., Subramani, T., Singh, A. K., Gautam, R. K., Velmurugan, A., Rajeshkannan, T., and Parisa, D. (2016). Genetic Diversity among Jamun (*Syzygium cumini* L. Skeels) Accessions of Andaman and Nicobar Islands Revealed through Morpho-Biochemical and DNA markers. *Andaman Science Association*, *21*(1), 35-44.

Jaiswal, R., Singh, G., and Singh, A. K. (2007). Studies on physicochemical characteristics of aonla (*Emblica officinalis* Gaertn.) fruits. *Progressive Agriculture*, *7*(1 and 2), 90-92.

Jaiswal, V., and Jaiswal, R. K. (2022). A Drug Review of Amalaki (*Emblica officinalis*): A Traditional Indian Drug with Contemporary Applications. *Journal of Pharmaceutical Negative Results*, 4833-4845.

Jhaumeer Laulloo, S., Bhowon, M. G., Chua, L. S., and Gaungoo, H. (2018). Phytochemical screening and antioxidant properties of *Phyllanthus emblica* from Mauritius. *Chemistry of Natural Compounds*, *54*, 50-55.

Justin Thenmozhi, A., Dhivyabharathi, M., William Raja, T. R., Manivasagam, T., and Essa, M. M. (2016). Tannoid principles of *Emblica officinalis* renovate cognitive deficits and attenuate amyloid pathologies against aluminum chloride induced rat model of Alzheimer's disease. *Nutritional neuroscience, 19(6)*, 269-278.

Kaack, K. V. (2017). Improvement of quality characteristics of cherry fruit juice processed using fruits from 'Stevnsbær' clone 23 (*Prunus cerasus* L.). *International Journal of Forestry and Horticulture (IJFH)*, 3(1), 1-10.

Kader, A. A. (2002). Postharvest Technology of Horticultural Crops (Vol. 3311). University of California Agriculture and Natural Resources.

Kaim, J. C., and Bisht, V. K. (2017). Evaluation of physico-chemical characteristics of fruits of different cultivars of aonla (*Emblica officinalis* Gaertn) grown in Uttarakhand, Western Himalaya. *Asian Journal of Agriculture and Allied Sciences*, *1*(1), 1-6.

Kalekar, S. A., Munshi, R. P., Bhalerao, S. S., and Thatte, U. M. (2013). Insulin sensitizing effect of 3 Indian medicinal plants: An: in vitro: study. *Indian journal of pharmacology, 45(1),* 30-33.

Kapoor, B., Sharma, M., Sharma, R., Zadokar, A., Thakur, A., Sharma, P., Kumar, S., Rozar, K. P., Kumar, K. S., Hegde, N., and Pandey, D. (2023). De novo transcriptome profiling and development of novel secondary metabolites based genic SSRs in medicinal plant *Phyllanthus emblica* L. (Aonla). *Scientific Reports, 13*(1), Article 17319.

Khan, K. H. (2009). Roles of *Emblica officinalis* in medicine: A review. *Botany Research International, 2*(4), 218-228.

Koczorski, P., Furtado, B. U., Gołębiewski, M., Hulisz, P., Baum, C., Weih, M., and Hrynkiewicz, K. (2021). The effects of host plant genotype and environmental conditions on fungal community composition and phosphorus solubilization in willow short rotation coppice. *Frontiers in Plant Science*, *12*, 647709.

Krishna, H., Singh, D., Singh, R. S., Kumar, L., Sharma, B. D., and Saroj, P. L. (2020). Morphological and antioxidant characteristics of mulberry (*Morus* spp.) genotypes. *Journal of the Saudi Society of Agricultural Sciences*, *19*(2), 136-145.

Krishnaveni, M., & Mirunalini, S. (2012). Chemopreventive efficacy of *Phyllanthus emblica* L.(amla) fruit extract on 7, 12-dimethylbenz (a) anthracene induced oral carcinogenesis–A dose–response study. *Environmental toxicology and pharmacology*, *34(3),* 801-810

Kruczek, A. (2005). Effect of row fertilization with different kinds of fertilizers on the maize yield. *Acta Scientiarum Polonorum, Agricultura*, *4*(2), 37-46.

Kubola, J., Siriamornpun, S., and Meeso, N. (2011). Phytochemicals, vitamin C and sugar content of Thai wild fruits. *Food chemistry*, *126*(3), 972-981.

Kubola, J., Siriamornpun, S., and Meeso, N. (2011). Phytochemicals, vitamin C and sugar content of Thai wild fruits. *Food chemistry*, *126*(3), 972-981.

Kuhkheil, A., Badi, H. N., Mehrafarin, A., and Abdossi, V. (2020). Phytochemical and morpho-physiological variations in sea buckthorn (*Hippophae rhamnoides* L.) populations of Taleghan region in Iran. *Journal of Medicinal Plants*, *19*(76), 21-35.

Kulkarani, P., Pandey, H., Sharma, A. K., and Joshi, D. C. (2017). Physicochemical properties of aonla fruit and juice. *Chemical Science Review and Letters*, *6*(22), 1343-1347.

Kumar, A., P, N., Kumar, M., Jose, A., Tomer, V., Oz, E., and Oz, F. (2023). Major phytochemicals: Recent advances in health benefits and extraction method. *Molecules, 28*(2), 887.

Kumar, A., Singh, A., and Dora, J. (2012a). Essential perspectives for *Emblica officinalis*. *International Journal of Pharmaceutical and Chemical Sciences, 1*(1), 11-18.

Kumar, A., Singh, P., Kumar, B., Kumar, K. G., Shankar, U., and Gupta, P. K. (2021a). Morphological studies of underutilized fruits. *Plant Archives*, *21*(2), 715-718.

Kumar, E. V., Srivenkataramana, T., and Sundararaj, N. (1985). Branch sampling for estimating the number of fruit on a tree. *Journal of the American Society for Horticultural Science 110*(3):451 - 454.

Kumar, K. P. S., Bhowmik, D., Dutta, A., Yadav, A. P., Paswan, S., Srivastava, S., and Deb, L. (2012b). Recent trends in potential traditional Indian herbs *Emblica officinalis* and its medicinal importance. *Journal of Pharmacognosy and Phytochemistry, 1*(1), 24-32.

Kumar, M., Arya, R. K., Kumar, M., Gaur, R. K., and Sharma, S. (2021b). Evaluation of Aonla Varieties Under Semi-Arid Conditions of Haryana. *Ekin Journal of Crop Breeding and Genetics*, *7*(2), 139-144.

Kumar, P., and Khatkar, B. S. (2015). Physico-chemical properties and nutritional composition of aonla (*Emblica officinalis*) varieties. *International Food Research Journal*, *22*(6), 2358.

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.

Kumar, R., Singh, R., and Kumar, P. (2014). Performance of aonla (*Emblica officinalis*) cultivars for growth, yield, and quality in semi-arid condition. *Current Horticulture, 2*(2), 44-46.

Kumar, R., Syamal, M. M., Dwivedi, S. V., Anand, R. K., and Vishwanath, V. (2013). Studies on variability in physico-chemical properties of aonla (*Emblica officinalis* Gaertn) genotypes. *Asian Journal of Horticulture*, *8*(2), 706-708.

Kumar, S., Chithiraichelvan, R., and Karunakaran, G. (2011). Performance of aonla cultivars for yield and physico-chemical properties under Coorg conditions. *Indian Journal of Horticulture*, *68*(02), 268-269.

Kumar, V. N., and Vibha, A. K. (2013). A Comparative study of heavy metals in *Emblica officinalis*, *Phyllanthus emblica* and *Azadirachta indica*. *Int Res J Biological Sci*, *2*(8), 16-19.

Kumaran, A., and Karunakaran, R. J. (2006). Nitric oxide radical scavenging active components from *Phyllanthus emblica* L. *Plant Foods for Human Nutrition,* 61(1), 1–5.

Kumari, P., and Khatkar, B. S. (2018). Nutritional composition and drying kinetics of aonla fruits. *Journal of food science and technology*, *55*, 3135-3143.

Kumari, R., Sinha, N., Sharma, S., and Dhiman, K. (2024). Biochemical characterization and antioxidant potential of *Phyllanthus emblica* L. *International Journal of Advanced Biochemistry Research*, *8*(5), 901-906.

Lee, C. Y., Peng, W. H., Cheng, H. Y., Chen, F. N., Lai, M. T., and Chiu, T. H. (2006). Hepatoprotective effect of *Phyllanthus* in Taiwan on acute liver damage induced by carbon tetrachloride. *The American Journal of Chinese Medicine, 34(03),* 471-482.

Lee, S. K., and Kader, A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology, *20*(3), 207-220.

Li, D., Lu, X., Qian, D., Wang, P., Tang, D., Zhong, Y., Shang, Y., Guo, H., Wang, Z., Zhu, G., and Zhang, C. (2023). Dissected Leaf 1 encodes an MYB transcription factor that controls leaf morphology in potato. *Theoretical and Applied Genetics*, *136*(9), 183.

Li, Y., Zhang, Y., Liao, P. C., Wang, T., Wang, X., Ueno, S., and Du, F. K. (2021). Genetic, geographic, and climatic factors jointly shape leaf morphology of an alpine oak, *Quercus aquifolioides* Rehder and EH Wilson. *Annals of Forest Science*, *78*, 1-18.

Liu, X., Cui, C., Zhao, M., Wang, J., Luo, W., Yang, B., and Jiang, Y. (2008). Identification of phenolics in the fruit of emblica (*Phyllanthus emblica* L.) and their antioxidant activities. *Food chemistry*, *109*(4), 909-915.

Longvah, T., Anantan, I., Bhaskarachary, K., Venkaiah, K., and Longvah, T. (2017). *Indian food composition tables* (pp. 2-58). Hyderabad: National Institute of Nutrition, Indian Council of Medical Research, 2-58

López-Colin, G. A., Valdivia, C. E., Morales-Paredes, C., Sade, S., and Rau, J. R. (2018). Phenotypic similarity between fruits of *Gevuina avellana* (Proteaceae) and wasp-induced galls of *Nothofagus dombeyi* (Nothofagaceae) does not protect fruits from predation by rodents. *Acta Botanica Brasilica*, *32*(4), 624-630.

Lozano, J. E. (2006). Chemical composition of fruits and its technological importance. *In Fruit Manufacturing: Scientific Basis, Engineering Properties, and Deteriorative Reactions of Technological Importance* (pp. 133-161). Springer, Boston, MA.

Luna, R.K. (2005) Plantation Trees (pp 335), International Book Distributors, Dehra Dun.

Luqman, S., and Kumar, R. (2012). Correlation between scavenging property and antioxidant activity in the extracts of *Emblica officinalis* Gaertn., syn. *Phyllanthus emblica* L. Fruit. *Annals of Phytomedicine*, *1*(1), 54-61.

Mahata, S., Pandey, A., Shukla, S., Tyagi, A., Husain, S. A., Das, B. C., and Bharti, A. C. (2013). Anticancer activity of *Phyllanthus emblica* Linn.(Indian gooseberry): inhibition of transcription factor AP-1 and HPV gene expression in cervical cancer cells. *Nutrition and cancer, 65(sup1),* 88-97.

Maholiya, B. K., Prasad, H., Thakur, M., Gupta, A. K., and Solanki, S. P. S. (2015). Comparative performance of Aonla (*Emblica officinalis* G.) cultivars under parbhani condition. *International Journal of Bioresource Stress Management*, *6*, 778-780.

Maity, A., Gaikwad, N., Babu, K. D., More, A. K., and Sarkar, A. (2019). Physico-chemical and nutritional characteristics of main pomegranate (*Punica granatum* L.) cultivars grown in Deccan Plateau of India. *Agrochimica*, *63(2),* 105–121.

Majeed, M., Majeed, S., Mundkur, L., Nagabhushanam, K., Arumugam, S., Beede, K., and Ali, F. (2020). Standardized *Emblica officinalis* fruit extract inhibited the activities of α-amylase, α-glucosidase, and dipeptidyl peptidase-4 and displayed antioxidant potential. *Journal of the Science of Food and Agriculture, 100(2),* 509-516.

Majumder, D. A. N., Hassan, L., Rahim, M. A., and Kabir, M. A. (2013). Genetic diversity in mango (*Mangifera indica* L.) through multivariate analysis. *Bangladesh Journal of Agricultural Research, 38(2),* 343-353.

Mandliya, S., Majumdar, J., Misra, S., Pattnaik, M., and Mishra, H. N. (2023). Evaluation of dry microwave and hot water blanching on physicochemical, textural, functional, and organoleptic properties of Indian gooseberry (*Phyllanthus emblica*). *Journal of Food Measurement and Characterization, 17*, 2881–2891.

Manning, K. (1996). Soft fruits. In G. B. Seymour, J. E. Taylor, and G. A. Tucker (Eds.), Biochemistry of Fruit Ripening (pp. 347-377). Chapman and Hall, London.

Manzoor, M., Hussain, S. B., Anjum, M. A., Naseer, M., Ahmad, R., and Ziogas, V. (2023). Effects of harvest time on the fruit quality of Kinnow and Feutrell's early mandarins (*Citrus reticulata* Blanco). *Agronomy*, *13*(3), 802.

Mathew, M., and Subramanian, S. (2014). In vitro screening for anti-cholinesterase and antioxidant activity of methanolic extracts of ayurvedic medicinal plants used for cognitive disorders. PloS one, 9(1), e86804.

Matos-Filho, C. H. A., Carvalho-Junior, J. E. V. D., Costa, G. D. N., Costa, M. F., Nunes, J. A. R., Lopes, Â. C. D. A., and Ferreira-Gomes, R. L. (2023). Estimation of the extent of phenotypic diversity among cashew (*Anacardium occ*identale L.) genotypes based on agro-morphological and physicochemical traits. *Plant Genetic Resources: Characterization and Utilization, 1*(1), 1–9.

Maurya, A. K., Pratap, B., Sonkar, A., Tiwari, S., Yadav, G., Pratap, R., Patel, B., and Kumar, P. (2024). Evaluation of different varieties and genotypes of aonla (*Emblica officinalis* Gaertn.) under sodic soil condition of eastern Uttar Pradesh, India. *International Journal of Environment and Climate Change*, *14*(2), 100-105.

Mawalagedera, S. M. U. P., and Sooriyapathirana, S. D. S. S. (2014). Morphological characterization of drupes reveals a higher diversity of *Phyllanthus emblica* germplasm in Anuradhapura, Kandy and Kurunegala Districts of Sri Lanka. *Ceylon Journal of Science (Bio. Sci.), 43*(1), 125-135.

Meghwal, P. R., and Azam, M. M. (2004). Performance of some aonla cultivars in arid region of Rajasthan. *Indian Journal of Horticulture*, *61*, 87-88.

Mehrotra, S., Jamwal, R., Shyam, R., Meena, D. K., Mishra, K., Patra, R., and Nandi, S. P. (2011). Anti-Helicobacter pylori and antioxidant properties of *Emblica officinalis* pulp extract: A potential source for therapeutic use against gastric ulcer. *Journal of Medicinal Plants Research, 5(12),* 2577-2583.

Mengist, M. F., et al. (2022). Dissecting the genetic basis of bioactive metabolites and fruit quality traits in blueberries (*Vaccinium corymbosum* L.). *Frontiers in Plant Science*, *13*, 964656.

Ministry of Environment, Forest and Climate Change (2017). *About Meghalaya*. National Biodiversity Authority. Retrieved December 3, 2024, from https://megbiodiversity.nic.in/about-meghalaya

Mirheidari, F., Khadivi, A., Moradi, Y., and Paryan, S. (2022a). Identification of the promising accessions of spistan (*Cordia myxa* Roxb.) using morphological and fruit-related traits. *Food Science and Nutrition, 10*(12), 4168-4177.

Mirheidari, F., Khadivi, A., Saeidifar, A., and Moradi, Y. (2022b). Selection of superior genotypes of Indian jujube (*Ziziphus mauritiana* Lamk.) as revealed by fruit-related traits. *Food Science and Nutrition*, *10*(3), 903-913.

Modi, R., Sahota, P., and Pandove, G. (2023). Lactic acid fermentation of Amla-Indian gooseberry blend: Enhancing antioxidants and developing a novel bio-intervention. *Journal of Food Measurement and Characterization*, 1–13.

Mondal, T., Chattopadhyay, S., Mandi, G., Alam, M., Bauri, F. K., and Kundu, U. (2023). Survey and selection of superior rose apple (*Syzygium jambos* L.) genotypes from West Bengal. *Environment and Ecology, 41*(2B), 1247—1249.

Morton, J. F. (1960). The emblic (*Phyllanthus emblica* L.). *Economic Botany, 14*(2), 119–128.

Motalab, M., Mumtaz, B., Mohajan, S., Saha, B. K., and Jahan, S. (2022). Heavy metals, trace elements, minerals and ascorbic acid content of occasionally consumed eight indigenous fruits in Bangladesh. *Food Research*, *6*(5), 403-411.

Muthuraman, A., Sood, S., and Singla, S. K. (2011). The antiinflammatory potential of phenolic compounds from *Emblica officinalis* L. in rat. *Inflammopharmacology, 19,* 327-334.

Mythilypriya, R., Shanthi, P., and Sachdanandam, P. (2007). Analgesic, antipyretic and Ulcerogenic properties of an indigenous formulation–Kalpaamruthaa. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives, 21(6),* 574-578.

Naik, G. H., Priyadarsini, K. I., Bhagirathi, R. G., Mishra, B., Mishra, K. P., Banavalikar, M. M., and Mohan, H. (2005). In vitro antioxidant studies and free radical reactions of triphala, an ayurvedic formulation and its constituents. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, *19*(7), 582-586.

Nain, P., Saini, V., Sharma, S. (2012) In-vitro antibacterial and antioxidant activity of *Emblica officinalis* leaves extract. *International Journal of Pharmacy and Pharmaceutical Sciences, 4(1)*, 385–389

Naithani, C. D., Rawat, J. M. S., Singh, B., Khanduri, V. P., and Riyal, M. K. (2020). Determination of physico-chemical properties of aonla (*Emblica officinalis* Gaerth) fruits among different populations in Garhwal Himalaya. *International Journal of Fruit Science*, *20*(3), S1579-S1589.

National Horticulture Board. (2022, March). *First advance estimates of area and production of horticulture crops (2021-22)* [PDF]. Press Information Bureau. https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/mar/doc202232832101.pdf

Niang, M., Diouf, M., Samba, S. A. N., Ndoye, O., Cissé, N., and Van Damme, P. (2015). Difference in germination rate of baobab (*Adansonia digitata* L.) provenances contrasting in their seed morphometrics when pretreated with concentrated sulfuric acid. *African Journal of Agricultural Research*, *10*(12), 1412-1420.

Nigam, R., Tiwari, C., and Soni, R. (2021). Physico-chemical characterization and Phytochemical Analysis of Leaves of Rejuvnative Herb, *Emblica officinalis*. *Journal of Innovation in Applied Research*, *4*(1).

Niinemets, Ü. (2014). Cohort-specific tuning of foliage physiology to interacting stresses in evergreens. *Tree Physiology*, *34*(12), 1301-1304.

Nimse, S. B., and More, D. R. (2018). Evaluation of physical and nutritional properties of Aonla. *Journal of Pharmacognosy and Phytochemistry*, *7*(2), 3733-3735.

Nisha, P., Singhal, R. S., and Pandit, A. B. (2004). A study on degradation kinetics of ascorbic acid in amla (*Phyllanthus emblica* L.) during cooking. *International Journal of Food Sciences and Nutrition, 55*(5), 415–422.

Nóbrega, D. D. S., Mendes, A. C. N., Peixoto, J. R., Vilela, M. S., Faleiro, F. G., Alencar, E. R., Carmona, R. and Sousa, R. M. D. D. (2021). Fruit quality of wild, sweet, and yellow passion fruit genotypes in Distrito Federal, Brazil. *Bioscience Journal*, *37*, e37064.

Okanume, O. E., Ahmad, M. Z., and Agaba, O. A. (2019). Morphological and leaf epidermal features of some Phyllanthus species in Jos, Nigeria. *Annales of West University of Timisoara. Series of Biology*, *22*(1), 47-56.

Orabi, M. A., Hasan, A. H., AbouZid, S. F., El Amir, D., Hetta, M. H., Awadh, A. A. A., ... and El-Shanawany, M. A. (2023). Nutritional, Antioxidant, Antimicrobial, and Anticholinesterase Properties of *Phyllanthus emblica*: A Study Supported by Spectroscopic and Computational Investigations. *Metabolites*, *13*(9), 1013.

Pachuau, L., and Dutta, R. S. (2020). *Wild edible fruits of Northeast India: medicinal values and traditional practices*. Herbal Medicine in India: Indigenous Knowledge, Practice, Innovation and its Value, 437-450.

Pal, S., Ramamurthy, A., Rath, S., Mahajon, B. (2017). Healing Role of Guduchi [*Tinospora cordifolia* (Willd.) Miers] and Amalaki (*Emblica officinalis* Gaertn.) Capsules in Premature Aging Due to Stress: A Comparative Open Clinical Trial. *European Journal of Medicinal Plants*, *21,* 1–13.

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.

Pandey, D., Pandey, G., Pandey, A., and Dube, A. (2016). Field evaluation of Indian gooseberry (*Emblica officinalis*) accessions for yield, fruit quality and antioxidant potential. *The Indian Journal of Agricultural Sciences*, *86*(11), 1495-1498.

Pandey, D., Pandey, G., Shukla, S. K., and Pathak, R. K. (2008). *Indian gooseberry*. In K. V. Peter & Z. Abraham (Eds.), Biodiversity in horticultural crops (Vol. 1, pp. 252–283). Daya Publishing House.

Pandey, D., Shukla, S. K., and Kumar, A. (2008). Variability in aonla (*Emblica officinalis* Gaertn.) accessions collected from Panna forests of Madhya Pradesh. *Indian Journal of Agroforestry*, *10*(1), 73-77.

Pandey, G., Pandey, D., Tripathi, M., Singh, A., and Mishra, M. (2016). Studies on bio-chemical profiling of Indian gooseberry (*Emblica officinalis*) for genetic diversity. *Journal of Environmental Biology*, *37*(2), 179-184.

Panse, V.G. and Sukhatme, P.V. (1985) Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication, 87-89.

Pareek, S., and Kitinoja, L. (2011). Aonla (*Emblica officinalis* Gaertn.). In E. M. Yahia (Ed.), *Postharvest Biology and Technology of Tropical and Subtropical Fruits* (pp. 65-97). Cambridge: Woodhead Publishing. https://doi.org/10.1533/9780857092762.65

Parveen, K., and Khatkar, B. S. (2015). Physico-chemical properties and nutritional composition of aonla (*Emblica officinalis*) varieties. *International Food Research Journal*, *22*(6), 2358.

Patel, D. A., Patel, H. C., Sarvaiya, S. N., and Masu, M. M. (2009). Physico-chemical status of different genotypes and hybrids of aonla. Asian Journal of Horticulture, *4*(2), 461-463.

Patel, S. S., and Goyal, R. K. (2011). *Emblica officinalis* Gaertn.: A comprehensive review on phytochemistry, pharmacology, and ethnomedicinal uses. *Research Journal of Medicinal Plant*, 1-11.

Pathak, R. K. (2003). *Status report on genetic resources of Indian gooseberry-aonla (Emblica officinalis Gaertn.) in South and Southeast Asia*. APO Publication.

Pathak, R. K., Om, H., and Dwivedi, R. (1989). Collection, maintenance of evaluation of aonla (*Emblica officinalis* Gaertn.) germplasm. *Indian Journal of Plant Genetic Resources, 2*, 84–86.

Pathak, R. K., Singh, S., and Saroj, P. L. (2006). Aonla (*Emblica officinalis Gaertn.*). In P. L. Saroj and O. P. Awasthi (Eds.), *Advances in arid horticulture* (pp. 1-20). International Book Distributing Company.

Perianayagam, J. B., Sharma, S. K., Joseph, A., and Christina, A. J. M. (2004). Evaluation of anti-pyretic and analgesic activity of *Emblica officinalis* Gaertn. *Journal of ethnopharmacology*, *95(1),* 83-85.

Poltanov, E. A., Shikov, A. N., Dorman, H. D., Pozharitskaya, O. N., Makarov, V. G., Tikhonov, V. P., and Hiltunen, R. (2009). Chemical and antioxidant evaluation of Indian gooseberry (*Emblica officinalis* Gaertn. syn. *Phyllanthus emblica* L.) supplements. *Phytotherapy Research, 23*(9), 1309–1315.

Powell, B., Ickowitz, A., McMullin, S., Jamnadass, R., Padoch, C., Pinedo-Vasquez, M., and Sunderland, T. (2013). *The role of forests, trees, and wild biodiversity for improved nutrition: Sensitivity of food and agriculture systems.* Expert background paper for the International Conference on Nutrition 2. FAO.

POWO. (2024). *Plants of the World Online*. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; http://www.plantsoftheworldonline.org/ Retrieved March 8, 2024.

Prakash, N., Roy, S. S., Sharma, P. K., and Ngachan, S. V. (2012). *Developing the potential of underutilized horticultural crops of hill regions.* Today and Tomorrow's Printers and Publishers.

Prasad, S. K., Kumar, R., Debnath, A., Sharma, N. (2024). Morpho-biochemical diversity in tree tomato (*Solanum betaceum* Cav.) genotypes grown under different altitudinal locations of north eastern Himalayas of India. *Indian Journal of Traditional Knowledge (IJTK)*, *23*(1), 25-34.

Rabbani, M. A., Jan, S. A., Siddiqui, S. U., Ghafoor, A., and Ahmad, Z. (2019). Morpho-biochemical characterization of amla (*Phyllanthus emblica* L.) and tamarind (*Tamarindus indica* L.) germplasm from Pakistan. *Genetika*, *51*(2), 539-549.

Raghu, S. V., Rao, S., Kini, V., Kudva, A. K., George, T., and Baliga, M. S. (2023). Fruits and their phytochemicals in mitigating the ill effects of ionizing radiation: Review on the existing scientific evidence and way forward. *Food and Function, 14*(3), 1290-1319.

Rai, M., Gupta, P. N., and Pathak, R. K. (1993). Collecting genetic diversity of aonla (*Phyllanthus emblica* L.) germplasm from Uttar Pradesh. *Indian Journal of Plant Genetic Resources, 6*(2), 117-123.

Rajalakshmi, S., Vijayakumar, S., and Praseetha, P. K. (2019). Neuroprotective behaviour of *Phyllanthus emblica* (L) on human neural cell lineage (PC12) against glutamate-induced cytotoxicity. *Gene Reports, 17,* 100545.

Raju, C. A., Begum, S. S., Kalpana, B., and Sathish, A. (2023). Processing and nutritional evaluation of amla (*Phyllanthus emblica*) pomace. *Asian Journal of Dairy and Food Research.* 1-6.

Ram Chandra, R. C., Rakesh Srivastava, R. S., Sheo Govind, S. G., Hore, D. K., and Singh, A. S. (1998). Collection of genetic diversity of aonla (*Emblica officinalis* L.) from Garo Hills of Meghalaya. *Indian Journal of Hill Farming*, *11*(1-2), 116-123.

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, T. P., Sakaguchi, N., Juneja, L. R., Wada, E., and Yokozawa, T. (2005). Aonla (*Emblica officinalis* Gaertn.) extracts reduce oxidative stress in streptozotocin-induced diabetic rats. *Journal of Medicinal Food, 8*(3), 362–368.

Rose, K., Wan, C., Thomas, A., Seeram, N. P., and Ma, H. (2018). Phenolic compounds isolated and identified from amla (*Phyllanthus emblica*) juice powder and their antioxidant and neuroprotective activities. *Natural Product Communications, 13(10),* 1934578X1801301019.

Rovira-Clavé, X., Jiang, S., Bai, Y., Zhu, B., Barlow, G., Bhate, S., Coskum, A. F., Han, G., Ho, C. M. K., Hitzman, C., Chen, S. Y., Bava, F. A., and Nolan, G. P. (2021). Subcellular localization of biomolecules and drug distribution by high-definition ion beam imaging. *Nature Communications, 12*(1), 4628.

Sabir, S. M., Shah, R. H., and Shah, A. H. (2017). Total phenolic and ascorbic acid contents and antioxidant activities of twelve different ecotypes of *Phyllanthus emblica* from Pakistan. *Chiang Mai J. Sci*, *44*, 904-911.

Saeed, S., and Tariq, P. (2007). Antibacterial activities of *Emblica officinalis* and *Coriandrum sativum* against Gram negative urinary pathogens. *Pakistan journal of pharmaceutical sciences, 20(1),* 32-35.

Sahu, S. (2013). Evaluation of Physico-chemical Characteristics of Aonla Fruits (*Emblica officinalis* Gaertn.) as a Marketing Strategies. *Indian Horticulture Journal*, *3*(1and 2), 26-27.

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

Sajib, M. A. M., Hoque, M. M., Yeasmin, S., and Khatun, M. H. A. (2014). Minerals and heavy metals concentration in selected tropical fruits of Bangladesh. International Food Research Journal, *21*(5), 1731

Saleem, A., Akhtar, M. F., Sharif, A., Akhtar, B., Siddique, R., Ashraf, G. M., and Alharthy, S. A. (2022). Anticancer, cardio-protective and anti-inflammatory potential of natural-sources-derived phenolic acids. Molecules, *27*(21), 7286.

Sapkota, B. K., Khadayat, K., Sharma, K., Raut, B. K., Aryal, D., Thapa, B. B., and Parajuli, N. (2022). Phytochemical analysis and antioxidant and antidiabetic activities of extracts from *Bergenia ciliata*, *Mimosa pudica*, and *Phyllanthus emblica*. *Advances in Pharmacological and Pharmaceutical Sciences*, *2022*(1), 4929824.

Scartezzini, P., and Speroni, E. (2000). Review on some plants of Indian traditional medicine with antioxidant activity. *Journal of Ethnopharmacology, 71*(1–2), 23–43.

Serdar, U. (1999) 'Selection of chestnuts (c. Sativa mill.) in sinop vicinity', Acta Horticulturae, 494: 327–332. http/doi.10.17660/ActaHortic.1999.494.50.

Shaik, N. H., Rao, D. B., Vardhan, S. V., and Babu, Y. N. (2016). Determination of Physical Properties of Aonla Fruit (*Embilica officinalis*). *The Andhra Agriculture Journal*, *63*(3), 688-693.

Shalini, B., and Sharma, J. D. (2015). Beneficial effects of *Emblica officinalis* on fluoride-induced toxicity on brain biochemical indexes and learning-memory in rats. Toxicology international, 22(1), 35.

Shanmugasundaram, K. R., Seethapathy, P. G., and Shanmugasundaram, E. R. (1983). Anna Pavala Sindhooram–an antiatherosclerotic Indian drug. *Journal of Ethnopharmacology, 7*, 247-265.

Sharma, D., and Gupta, R. (2023). Physico-chemical characteristics of wild amla (*Emblica officinalis*) and indigenous medicinal plants from Himalayan region. *Himachal Journal of Agricultural Research*, *49*(2), 232-237.

Shastri, B. N. (Ed.). (1952). *Raw materials* (Vol. III). Council of Scientific and Industrial Research.

Shukla, A. K., and Dhandar, D. G. (2003). Genetic diversity of aonla in hill ecosystem of Himachal Pradesh. Paper presented in *National Symposium on Agroforestry and Sustainable Production*, 7–9 November 2003 at IGFRI, Jhansi.

Shukla, A. K., Samadia, D. K., Shukla, A. K., and Dhandar, D. G. (2005). Genetic resources of aonla (*Emblica officinalis* Gaertn.). *Indian Journal of Plant Genetic Resources, 18*(2), 188–193.

Shukla, A. K., Singh, D., and Shukla, A. K. (2009). Performance of Indian gooseberry (*Emblica officinalis*) cultivars under arid region of India. *The Indian Journal of Agricultural Sciences*, *79*(11), 849-852.

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, S., and Makwana, P. (2015). Characterization of aonla (*Emblica officinalis*) varieties under zero irrigation semi-arid conditions. *The Indian Journal of Agricultural Sciences*, *85*(10), 1365-1369.

Singh, A. K., Singh, S., Joshi, H. K., and Makwana, P. (2014). Characterization of *Morinda tomentosa* genotypes under rainfed conditions of western India. *Indian Journal of Agricultural Sciences*, *84*(11), 1407-1414.

Singh, A. K., Singh, S., Singh, R. S., and Joshi, H. K. (2012). Morphological variability of bael varieties under rainfed conditions of hot semi-arid environment of western India. *Indian Journal of Arid Horticulture*, *6*(1-2), 35-37.

Singh, E., Sharma, S., Pareek, A., Dwivedi, J., Yadav, S., and Sharma, S. (2011). Phytochemistry, traditional uses and cancer chemo preventive activity of amla (*Phyllanthus emblica*): The sustainer. *Journal of Applied Pharmaceutical Science, 2*(1), 176-183.

Singh, G., and Singh, S. (2021). Extent of variability in fruit morphological characters of local mango germplasm. *Sustainability, Agri, Food and Environmental Research, 9*(3), 425-434.

Singh, N., Kumar, M., and Sharma, J. (2022). Characterization of aonla (*Phyllanthus emblica* Linn.) germplasm under semi-arid condition of Haryana. *Pharma Innovation Journal*, *11*, 2341-2345.

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*, 1778-1782.

Singh, N., Kumar, M., and Sharma, J. R. (2022). Health promoting compounds in Aonla (*Phyllanthus emblica* Linn.) genotypes growing under Indian semi-arid conditions. *The Pharma Innovation Journal*, *11*(2), 2341-2345.

Singh, P., Sharma, A., Jasrotia, A., Salgotra, R. K., Sharma, M., Gupta, V. (2024). Diversity in morpho-pomological attributes and biochemical profiling of bael (*Aegle marmelos* (L.) Correa) genotypes of North-Western India. *Heliyon*, *10*(4), e26525

Singh, S. K., Meghwal, P. R., and Pathak, R. (2015). Molecular characterization of commercial varieties of *Phyllanthus emblica* using RAPD and nuclear rDNA SNPs. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, *85*, 971-978.

Singh, S., Kumar, M., Sharma, J. R., and Baloda, S. (2017). Performance of aonla cultivars for growth, yield and physic-chemical attributes under semi-arid conditions. *Journal of Agriculture and Technology*, *4*(1), 20-22.

Singh, S., Singh, A. K., and Joshi, H. K. (2006). Standardization of maturity indices in Indian gooseberry (Emblica afficitlalis) under semi-arid conditions of Gujarat. *The Indian Journal of Agricultural Sciences*, *76*(10).

Singh, V., Thakur, A., and Jawandha, S. K. (2015). Changes in physical and biochemical attributes of fruit during growth, development, and maturation of aonla. *HortFlora Research Spectrum*, *4*, 308-312.

Singh, V., Verma, S., Yadav, A., and Gopal, R. (2016). Studies of physicochemical characteristics of various cultivars of aonla (*Emblica officinalis* Gaertn.) under semi-arid conditions of eastern Uttar Pradesh. *International Journal of Plant Sciences*, *11*(2), 237-239.

Srikumar, R., N.J. Parthasarathy, E.M. Shankar S. Manikandan, R. Vijayakumar, R. Thangaraj, K. Vijayananth, D.R. Sheela and U.A. Rao, 2007 Evaluation of the growth inhibitory activities of Triphala against common bacterial isolates from HIV infected patients. *Phytotherapy Research., 21(5),* 476-80.

Srinivasan, P., Vijayakumar, S., Kothandaraman, S., and Palani, M. (2018). Anti-diabetic activity of quercetin extracted from *Phyllanthus emblica* L. fruit: In silico and in vivo approaches. *Journal of pharmaceutical analysis, 8(2),* 109-118.

Subhadrabandhu, S. (2001). *Under-utilized tropical fruits of Thailand*. RAP Publication (FAO).

Suja, R. S., Nair, A. M. C., Sujith, S., Preethy, J., and Deepa, A. K. (2009). Evaluation of immunomodulatory potential of *Emblica officinalis* fruit pulp extract in mice. I*ndian Journal of Animal Research 43*(2), 103-6.

Sultana, S., Ahmed, S., and Jahangir, T. (2008). *Emblica officinalis* and hepatocarcinogenesis: a chemopreventive study in Wistar rats. *Journal of ethnopharmacology*, *118*(1), 1-6.

Sumalatha, D. (2013). Antioxidant and antitumor activity of *Phyllanthus emblica* in colon cancer cell lines. *International Journal of Current Microbiology and Applied Sciences, 2*, 189–195.

Sumitra, M., Manikandan, P., Gayathri, V. S., Mahendran, P., and Suguna, L. (2009). *Emblica officinalis* exerts wound healing action through up-regulation of collagen and extracellular signal-regulated kinases (ERK1/2). *Wound Repair and Regeneration,* 17(1), 99-107.

Suriyavathana, M., and Subha, P. (2011). Proximate analysis on biochemical study of Phyllanthus acidus, *Phyllanthus emblica* and Citrus limon. *International Journal of Pharmacy and Life Sciences*, *2*(6), 801-804.

Szotowa, W., Wachnik, Z., and Weker, H. (1996). Nutrition of healthy children. Warsaw: PZWL Publishers.

Taiz, L., and Zeiger, E. (2010). Plant Physiology (4th ed.). Sinauer Associates, MA, USA.

Tase, V., and Jamir, T. (2024). Assessment of Physico-Chemical Characteristics and Phytochemical Screening of Some Wild Edible Fruits from Kohima, Nagaland. *J. Mater. Environ. Sci., 15(7), 1070*, *1080*.

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

Titirică, I., Roman, I. A., Nicola, C., Sturzeanu, M., Iurea, E., Botu, M., and Sestras, A. F. (2023). The main morphological characteristics and chemical components of fruits and the possibilities of their improvement in raspberry breeding. *Horticulturae, 9*(1), 50.

Tripathi, S. K., Kumar, S., and Bisoi, P. K. (2020). Studies on supplementation of natural ascorbic acid in dried Aonla (*Emblica officinalis* Gaertn.) powder. International Journal of Current Microbiology and Applied Sciences, *9*, 578-583.

Troup, R. S. (1921). *The silviculture of Indian trees* (Vol. 3, pp. 830-833). Clarendon Press.

Ud Din, S., Jaskani, M. J., Naqvi, S. A., Awan, F. S. (2020). Diversity and divergence in domesticated and wild jamun (*Syzygium cumini*) genotypes of Pakistan. *Scientia Horticulturae*, *273*, 109617.

Udupa KN, Ayurveda for Promotion of Health, Journal of Ayurveda, 3, 1985.

Unander, D. W., Webster, G. L., and Blumberg, B. S. (1990). Records of usage or assays in *Phyllanthus* (Euphorbiaceae). I. Subgenera *Isocladus, Kirganelia, Cicca,* and *Emblica*. *Journal of Ethnopharmacology, 30*, 233-264.

USDA (US Department of Agriculture) US Department of Health and Human Services. Dietary Guidelines for Americans. Washington, DC: USDA, (2005). http://www.health.gov/dietaryguidelines/dga2005/document/default.htm.

Vasudevan, M., and Parle, M. (2007). Effect of anwala churna (*Emblica officinalis* g aertn.): An ayurvedic preparation on memory deficit rats. *Yakugaku Zasshi*, *127*(10), 1701-1707.

Vattakaven, T., George, R., Balasubramanian, D., Réjou-Méchain, M., Muthusankar, G., Ramesh, B., and Prabhakar, R. (2016). India Biodiversity Portal: An integrated, interactive and participatory biodiversity informatics platform. *Biodiversity Data Journal, 4*, e10279. https://doi.org/10.3897/BDJ.4.e10279

Wali, V. K., Bakshi, P., Jasrotia, A., Bhushan, B., and Bakshi, M. (2015). *Aonla.* Directorate of Extension, SKUAST-Jammu, 1–30.

Wang, L., Cheng, Y., Ma, Q., Mu, Y., Huang, Z., Xia, Q., Zhang, Q., and Nian, H. (2019). QTL fine-mapping of soybean (*Glycine max* L.) leaf type associated traits in two RILs populations. *BMC Genomics*, *20*, 1-15.

Wang, L., Li, J., Zhao, J., and He, C. (2015). Evolutionary developmental genetics of fruit morphological variation within the Solanaceae. *Frontiers in Plant Science*, *6*, 248.

Wang, M., Wei, H., and Jeong, B. R. (2021). Lighting direction affects leaf morphology, stomatal characteristics, and physiology of head lettuce (*Lactuca sativa* L.). *International Journal of Molecular Sciences*, *22*(6), 3157.

Wiart, C. (2013). Note on the relevance of *Emblica officinalis* Gaertn. for the treatment and prevention of cancer. *European Journal of Cancer Prevention*, 22(2), 198.

Williams, R. J., and Spencer, J. (2004). Rice-Evans C. Flavonoids: Antioxidants or signaling molecules. *Free Radical Biology and Medicine, 36*, 838–849.

Wu, M., Cai, J., Fang, Z., Li, S., Huang, Z., Tang, Z., Luo, Q., and Chen, H. (2022). The composition and anti-aging activities of polyphenol extract from *Phyllanthus emblica* L. fruit. *Nutrients,* 14(4), 857.

Xie, T., Wang, W. P., Mao, Z. F., Qu, Z. Z., Luan, S. Q., Jia, L. J., and Kan, M. C. (2012). Effects of epigallocatechin-3-gallate on pentylenetetrazole-induced kindling, cognitive impairment and oxidative stress in rats. *Neuroscience Letters*, *516*(2), 237-241.

Yadav, S., Verma, M., and Rose, N. M. (2021). Assessment of total phenolic content and antimicrobial activity of plants leaves extract. *Journal of Pharmacognosy and Phytochemistry*, *10*(1), 819-823.

Yang, X. Q., He, L., Yuan, J. M., Xu, Z. P., Kong, W. X., and Lei, X. (2021). Study on correlation between effective components and mineral element content in *Phyllanthus emblica*, *33*(7), 38-47.

Ye, M., Zhu, X., Gao, P., Jiang, L., and Wu, R. (2020). Identification of quantitative trait loci for altitude adaptation of tree leaf shape with *Populus szechuanica* in the Qinghai-Tibetan Plateau. *Frontiers in Plant Science*, *11*, 632.

Younis, A. S. M., Al-Naggar, A. M. M., Bakry, B. A., and Nassar, S. M. A. (2020). Maximizing maize grain, protein, oil and starch yields by using high plant density and stress tolerant genotype. *Asian Journal of Plant Sciences*, *20*(1), 91-101.

Zeng, W., and Wang, S. (2001). Antioxidant activity and phenolic composition in selected herbs. Journal of Agricultural and Food Chemistry, *49*(10), 5165-5170.

Zeng, Z., Lv, W., Jing, Y., Chen, Z., Song, L., Liu, T., and Yu, R. (2017). Structural characterization and biological activities of a novel polysaccharide from *Phyllanthus emblica. Drug discoveries & therapeutics*, *11*(2), 54-63.

Zhang, L. Z., Zhao, W. H., Guo, Y. J., Tu, G. Z., Lin, S., and Xin, L. G. (2003). Studies on chemical constituents in fruits of Tibetan medicine *Phyllanthus emblica*. *Zhongguo Zhong Yao Za Zhi, 28*(10), 940–943.

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List of Publication

1. **Rozar, K. P.,** Kumar, S., Sharma, R., Hegde, N., Kumar, K. S., & Kumari, N. (2024). Variability in Morpho-physicochemical Traits and Selection of Superior Genotypes of Aonla (*Phyllanthus emblica* L.) from Northeast India. Indian Journal of Plant Genetic Resources, 37(03), 460-466.
2. **Rozar, K. P.,** Kumar, S., Sharma, R., Sharma, S. B., Nongrum, M. M., & Jopir, J. (2024). Comparison of Phenolic Content, Flavonoid Content and Antioxidant Activities of *Phyllanthus emblica* L. From North-East, India. *Indian Journal of Ecology*, *51*(4), 732-737.
3. **Rozar, K. P**., Kumar, S., Sharma, R., Hegde, N., Kumar, K. S., Sahoo, U. K., Kumari, N., and Devi, S. (2024). Influence of seed source on fruit morphometric characters and nutritional content of *Phyllanthus emblica* L. in the Indo-Burma biodiversity hotspot. *Ecological Frontiers*.
4. Kapoor, B., Sharma, M., Sharma, R., Zadokar, A., Thakur, A., Sharma, P., Kumar, S., **Rozar, K. P**., Kumar, K. S., Hegde, N., & Pandey, D. (2023). De novo transcriptome profiling and development of novel secondary metabolites based genic SSRs in medicinal plant *Phyllanthus emblica* L. (Aonla). *Scientific Reports, 13*(1), Article 17319. https://doi.org/10.1038/s41598-023-43851-6
5. Sharma, S. B., Kumar, S., **Rozar, K. P**., & Nongrum, M. M. (2024). Effect of fallow period on soil seed bank runoff and regeneration of successional forests. *Vegetos*, 1-9.
6. Kumar, S., Sharma, S. B., Nongrum, M. M., Singh, T. P., Kumari, N., & **Rozar, K. P.** (2020). Effect of pre-sowing treatments on the germination of five legume species and their tolerance to desiccation. *Indian Journal of Ecology*, *47*(1), 102-108.
7. Jopir, J., Upadhyaya, K., Lalhmangaihzuali, B., & **Rozar, K. P.** (2023). Assessment of some leguminous weeds as potential green manure crops under Mizoram, North East India. *Legume Research*, *46*(12), 1686-1691.

Presentation (Conference/Seminar/Workshop)

1. Variability in Physio-Chemical traits of Aonla (*Phyllanthus emblica* L.) Genotypes from Meghalaya of India" Presented at national seminar on Utilization and conservation of plant resources for sustainable development organized by Biodiversity research centre (BRC), Department of Environmental Science, Mizoram University on 1st to 2nd June, 2023 held at SES and NRM, Mizoram university.
2. "Determination of physic-chemical properties of aonla (*Phyllanthus emblica* L.) Fruits among different populations in parts of North-East India" presented at national Seminar on conservation of biodiversity Organized by Biotech kisan Hub (Funded by DBT, New Delhi) NEHU, Tura campus, Meghalaya on 2nd and 3rd September 2022.
3. "Effect of pre-treatment on germination of *Phyllanthus emblica* L. seeds" presented at the International conference on Biodiversity, biogeochemistry and ecosystem sustainability in changing environment, Mizoram University, Aizawl, 14th to 16th June, 2023.

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	**: K PUNG ROZAR**
DEGREE	**: DOCTOR OF PHILOSOPHY**
DEPARTMENT	**: FORESTRY**
TITLE OF THESIS	**: Morpho-Chemical Characterization Of *Phyllanthus Emblica* L. Growing In Wild Conditions In The Selected Regions Of North-East India**
DATE OF ADMISSION	**: 28/08/2018**

APPROVAL OF RESEARCH PROPOSAL

1. DRC	**: 22/03/2019**
2. BOS	**: 18/04/2019**
3. SCHOOL BOARD	**: 26/04/2019**
MZU REGISTRATION NUMBER	**: 1600467**
Ph.D REGISTRATION	**: MZU/Ph.D./1232 of 28/08/2018**
EXTENSION (IF ANY)	**: 2 years No. 16-2/MZU (Acad) 24/14-2 Dated 3/July/2024**

HEAD

DEPARTMENT OF FORESTRY

ABSTRACT

MORPHO-CHEMICAL CHARACTERIZATION OF PHYLLANTHUS EMBLICA L. GROWING IN WILD CONDITIONS IN THE SELECTED REGIONS OF NORTH-EAST INDIA

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

K PUNG ROZAR

MZU REGISTRATION No.: 1600467

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DEPARTMENT OF FORESTRY

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

DECEMBER, 2024

MORPHO-CHEMICAL CHARACTERIZATION OF PHYLLANTHUS EMBLICA L. GROWING IN WILD CONDITIONS IN THE SELECTED REGIONS OF NORTH-EAST INDIA

BY K PUNG ROZAR

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Supervisor

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Submitted

In partial fulfillment of the requirement of the degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl.

ABSTRACT

Fruits have been central to India's agriculture for millennia, contributing significantly to its economy. Among them, aonla (Indian gooseberry), scientifically termed *Phyllanthus emblica* L or *Emblica officinalis*, holds special importance due to its nutritional, medicinal, and cultural relevance. Rich in vitamin C and known for its healing properties, aonla has been traditionally used in Ayurvedic remedies like Trifala and Chavanprash. Beyond its fruit, various parts of the aonla plant, including leaves, bark, and seeds, serve diverse purposes. Its therapeutic applications address ailments like anemia, indigestion, and respiratory issues, while its adaptability and high productivity make it a promising crop for modern agriculture. Aonla's historical usage, dating back over 3,500 years, and its integration into traditional Indian medicine underscore its enduring value in health and wellness.

Aonla is deeply embedded in India's culture and mythology, symbolizing purity and longevity. Its mythological origins, linked to the tears of Brahma, highlight its sacred status in Indian traditions. The fruit is celebrated across diverse medicinal systems, including Ayurveda, Unani, and Tibetan medicine, where all plant parts—roots, leaves, flowers, and seeds are utilized for their therapeutic benefits. Cultivation of aonla thrives across India, with major production in states like Uttar Pradesh and Madhya Pradesh. Its resilience to varied climates and soils, from dry and alkaline lands to degraded forest areas, positions it as a vital crop for sustainable agriculture in marginal regions. Additionally, its growing commercial demand underscores its economic and industrial potential, particularly in health, cosmetics, and herbal products.

The genetic diversity of aonla is a critical asset for its cultivation and conservation. Found across diverse agro-climatic regions in India, from the Vindhyan hills to the northeastern and Himalayan regions, aonla demonstrates significant variability in fruit size, yield, and ripening time. Studies using molecular markers have revealed extensive genetic diversity, essential for breeding programs and adaptation to different environments. This diversity, shaped by natural selection,

enables aonla to exhibit unique traits suited to various regions, supporting its wide-ranging applications. As a subtropical plant, its robust nature and adaptability to drought, poor soils, and extreme temperatures further enhance its importance in promoting agricultural sustainability and supporting rural livelihoods.

Nutritionally, amla provides essential carbohydrates, proteins, minerals, and amino acids, making it valuable for human health. Traditionally, it has been employed to treat ailments such as diarrhea, inflammation, and jaundice and is a key ingredient in the herbal blend Triphala. Its pharmacological benefits include anti-aging, anti-cancer, anti-diabetic, antimicrobial, and cardio-protective effects, along with memory-enhancing and wound-healing capabilities. These attributes position amla as a versatile therapeutic agent in managing chronic diseases and promoting overall wellness.

The present investigation titled "Morpho-chemical characterization of *Phyllanthus emblica* L. Growing in wild conditions in the selected regions of north-east India" was conducted during 2020-2023 at Mizoram University, Tanhril, Aizawl, Mizoram (23º44'22"N, 92º 39' 54" E and 950 meters above sea level) with the following objectives**:**

1. To study morphometric variations of *Phyllanthus emblica* L. trees growing in the wild conditions of NE India

1. To study the physical and bio-chemical characteristics of the fruits of *Phyllanthus emblica* growing in different localities of NE India

The study investigates the morpho-chemical characterization of wild *Phyllanthus emblica* (Indian gooseberry) accessions in North East India, a region within the ecologically rich Indo-Burma biodiversity hotspot. While considerable research exists on cultivated forms of this fruit, limited information is available on the physico-chemical properties and genetic diversity of its wild counterparts. This knowledge gap hinders the full utilization of its potential benefits in health, nutrition, and rural economies. The research explores the morphological and biochemical variations among accessions, focusing on traits such as fruit size, shape, leaf structure, vitamin C content, tannins, and polyphenols. By studying the influence of diverse environmental conditions on these accessions, the research hypothesizes significant variations in their characteristics, attributed to high genetic diversity across agro-climatic zones.

Findings from this study are expected to provide critical insights for breeding programs aimed at enhancing desirable traits such as nutritional value. Moreover, the research seeks to identify high-yield, commercially viable accessions to benefit rural communities by promoting the cultivation and commercialization of wild *Phyllanthus emblica*. Such efforts could contribute to local economies and align with national goals of enhancing food security and health through indigenous crop utilization.

From a conservation perspective, the study aims to document unique genetic traits of wild accessions, supporting strategies for the preservation of this valuable species. It emphasizes the dual socio-economic and ecological significance of *Phyllanthus emblica*, advocating for its role in promoting rural livelihoods, biodiversity conservation, and resilience to climate challenges. These findings are poised to facilitate the sustainable exploitation of this indigenous fruit in nutraceutical, pharmaceutical, and agricultural applications, ensuring its enduring contribution to health, nutrition, and economic growth.

Results

The morphological characteristics of aonla (*Phyllanthus emblica*) accessions collected from North East India (Meghalaya, Mizoram, and Tripura states) were examined, revealing significant diversity in tree height, girth, shape, foliage density, leaf morphology, and surface features. Tree height was observed to range from 4.5 m to 13.4 m, with the tallest accessions exceeding those reported in other regions of India. Girth measurements were recorded between 20 cm and 132 cm, indicating potential implications for fruit production. A spreading tree shape was most commonly observed (45.0%), followed by semi-spreading (37.7%), with drooping and erects shapes being less frequent. Sparse foliage was noted in 69.4% of accessions, while dense foliage was associated with specific tree shapes. Variation in leaf morphology was documented, with shapes including oblong, oval, and elliptical, and lengths predominantly between 1.2 and 1.4 cm. An acute leaf apex was identified in 63.3% of accessions, while the majority of leaves (95%) exhibited glabrous surfaces. The observed diversity highlights the influence of genetic and environmental factors and provides valuable insights for breeding and conservation efforts.

The fruit shapes were predominantly flattened round (53.33%), round (38.33%), and triangular (8.33%), aligning with previous research on aonla cultivars. Fruit color exhibited a yellow-green spectrum, with one accession displaying an orange-red hue. Most accessions (75%) had smooth fruit surfaces, with rough and moderately rough textures observed in smaller proportions. Stalk thickness was evenly distributed between thick (43.3%) and thin (56.7%) categories. Stone shapes varied widely, with round being the most common, followed by oval, oval-round, and triangular forms. Harvest maturity ranged from early to late, with late-maturing accessions (65%) being the most prevalent.

The physical and agronomic traits of Indian gooseberry (*Phyllanthus emblica*) evaluated across accessions from Meghalaya, Mizoram, and Tripura, showed significant variability. Fruit length was recorded between 12.77 mm and 24.72 mm, while diameters ranged from 14.67 mm to 28.04 mm. The largest average fruit size and weight (6.44 g) were observed in Meghalaya, followed by Tripura and Mizoram. Moisture content was found to range from 76.93% to 85.91%, while dry matter content varied from 14.09% to 23.07%, with Meghalaya displaying the highest variability. Stone weight was measured as lowest in MZR15 (0.33 g) and highest in MZR16 (1.54 g), influencing pulp-to-stone ratios, which peaked at 13.01 (MGL20). Pulp weight ranged from 1.66 g (MZR2) to 11.14 g (MGL20), with pulp percentage reaching up to 92.91%. Yield analysis indicated an average production of 63.62 kg/tree, with the highest yields recorded in Mizoram accessions.

Significant variations were observed among accessions in parameters such as total soluble solids (TSS), titratable acidity, ascorbic acid, sugars (total, reducing, and non-reducing), and phenolic content. TSS ranged from 7.5° Brix in MGL5 to 18° Brix in MGL2, with the highest average recorded in Mizoram (12.29° Brix). Titratable acidity varied from 1.65% in MGL17 to 4.90% in MGL19, with consistent averages (~2.96%) across states. Ascorbic acid content ranged significantly from 180 mg/100 g in MGL15 to 1392.5 mg/100 g in MZR10, with Tripura recording the highest average (751.67 mg/100 g). Total sugar content varied from 3.898% in TRP16 to 13.056% in MZR14, with Mizoram exhibiting the highest average

(8.31%). Reducing sugars ranged from 2.47% to 9.10%, with the highest value observed in MZR14, while non-reducing sugars peaked at 5.71% in MZR16. Phenolic content, a key antioxidant marker, ranged from 687.7 mg/100 g in MGL13 to 3201.4 mg/100 g in MGL16, with Tripura showing the highest average phenol concentration (1599.26 mg/100 g).

The mineral content analyzed across various accessions, revealed significant variability in calcium, magnesium, iron, potassium, and phosphorus levels. The highest calcium content was observed in accession MZR12 from Mizoram (74.53 mg/100g), while the lowest was recorded in MZR15 (9.6 mg/100g). Magnesium levels ranged from 13.6 mg/100g (MGL5) to 27.58 mg/100g (TRP7), with Meghalaya accessions showing the highest average levels. Iron content varied widely, with MZR12 exhibiting the maximum (8.43 mg/100g) and TRP12 the minimum (0.73 mg/100g). Potassium levels ranged from 0.62% (CPG-1) to 2.09% (CPG-6), with state-wise averages showing minor differences. Phosphorus content was found to range between 0.053% (NKL1) and 1.307% (TRP5), with Mizoram accessions displaying the highest median.

In the present study, correlation, principal component analysis (PCA), and cluster analysis were applied to assess diverse morphological and physio-chemical traits in aonla accessions. Significant correlations were identified, such as a negative association between elevation and pulp-related traits, while latitude positively influenced fruit dimensions. Total soluble solids (TSS) correlated positively with titratable acidity (TA) and dry matter content, while phenol and rainfall showed an inverse relationship.

PCA revealed 13 principal components accounting for 77.35% of total variance. The first component highlighted traits related to fruit size, while the second emphasized bio-chemical traits. Cluster analysis grouped accessions into two main clusters, with subgroups based on geographic and trait-based diversity.

Based on an assessment of various physical and biochemical characteristics, including fresh weight, pulp-to-stone ratio, yield, Total Soluble Solids (TSS), ascorbic acid content, total sugar, phenol, and protein content the promising aonla fruit accessions was selected. The data revealed that several accessions demonstrated high total weighted scores, with MZR20 leading at 862, followed by MGL17 at 766, MZR19 at 754, TRP20 at 736, and MZR18 at 730. These accessions showed strong overall qualities across most traits, making them ideal candidates for further evaluation and commercial use. High fresh weight scores were observed in MGL6, MGL17, and TRP6, while MGL20 and TRP2 excelled in pulp-to-stone ratio and yield. Accessions like MZR19, MZR18, and MGL16 were distinguished by higher nutrient content, particularly in ascorbic acid, phenols, and protein. Balanced performance was seen in accessions such as MZR4 and TRP3, which exhibited moderate to high scores across all categories

Conclusion

The study highlights significant variability in morphological and biochemical traits of aonla across Meghalaya, Mizoram, and Tripura. Variations were observed in tree shape, foliage density, fruit dimensions, dry matter content, pulp percentage, and yield. While geographical factors like location and elevation influenced certain traits, others remained genetically determined. Wild aonla fruits from the northeast demonstrated unique characteristics, such as higher ascorbic acid and phenol content, compared to commercial cultivars. These traits underscore their pharmaceutical potential and exceptional antioxidant properties. Principal Component Analysis identified 13 components explaining 77.35% of variance in fruit traits, with size being most influential. Five elite accessions (MZR20, MGL17, MZR19, TRP20, and MZR18) were identified for their superior attributes, including fresh weight, yield, and nutrient content. The diversity observed in the present study offers opportunities for developing improved aonla varieties, emphasizing the Northeast's genetic reservoir as a valuable resource for breeding programs.