

**EVALUATION OF *Annona muricata* L. GENOTYPES FOR GROWTH, YIELD
AND QUALITY ATTRIBUTES**

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SHIVAMOGGA**

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**KELADI SHIVAPPA NAYAKA
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**DEPARTMENT OF FRUIT SCIENCE
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CERTIFICATE

This is to certify that the thesis entitled '**EVALUTION OF *Annona muricata* L. GENOTYPES FOR GROWTH, YIELD AND QUALITY ATTRIBUTES**' submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (HORTICULTURE) in FRUIT SCIENCE** to the College of Horticulture, Mudigere. Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga is a bonafide record of research work carried out by **Lathamani, M. K., ID NO. MH2TBA0288** (lathamanimk1999@gmail.com) during the period of study in this university under my guidance and supervision and no part of this thesis has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

**Mudigere
November, 2023**



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Reflecting on cherished moments.....

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Evaluation of *Annona muricata* L. Genotypes for Growth, Yield and Quality Attributes

(Lathamani, M. K.)

ABSTRACT

Annona muricata L. (Lakshmanphal) is an underutilized fruit crop which is gaining importance due to its potential health benefits. An experiment was conducted to evaluate the *Annona muricata* L. genotypes for growth, yield and quality attributes, during 2022-23 at Muddinakoppa village of Shivamogga district. Analysis of variance showed significant differences concerning growth, yield and quality attributes. The genotype PKN-25 recorded maximum fruit length (29.10 cm), fruit width (16.40 cm), fruit weight (2352.92 g), fruit volume (2262.46 cc) and pulp weight (1624.40 g). The highest number of fruits per tree (34) and highest fruit yield per tree (80.00 kg/tree) were recorded in PKN-25 followed by PKN-20 with 33 fruits per tree and 75.97 kg/tree. The highest values for fruit quality parameters like TSS (PKN-24: 18.23 °B), titratable acidity (PKN-39: 1.25 %), reducing sugars (PKN-03: 8.87 %), non-reducing sugars (PKN-20: 3.79 %), total sugar (PKN-24: 11.97%), TSS: Acid (PKN-24: 24.64), sugar: acid (PKN-24: 16.18), ascorbic acid (PKN-02: 22.68 mg/100g fruit pulp), antioxidant activity (PKN-03: 70.13 %) and total phenolic content (PKN-02, PKN-24: 126.48 mg GAE/ g dry weight) were also recorded during investigation. High level of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) coupled with high heritability along with high genetic advance as per cent of mean (GAM) were recorded for most of the traits studied, indicating a high level of variability within genotypes. All the characters have highly significant and positive correlation with the yield except number of seeds per fruit and titratable acidity. Diversity studies revealed that 34 genotypes of *Annona muricata* were grouped into six clusters. The fruit yield per tree contributed more towards total genetic divergence followed by titratable acidity and antioxidant activity. The PKN-25 and PKN-20 found to be superior for fruit and yield parameters whereas, PKN-24 and PKN-03 found to be superior in terms of quality attributes.

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**ಅನ್ನೋನಾ ಮುರಿಕಾಟಾ ಎಲ್. ದ ಬೆಳವಣಿಗೆ, ಇಳುವರಿ ಮತ್ತು ಗುಣಮಟ್ಟದ ಗುಣಲಕ್ಷಣಗಳಿಗಾಗಿ ವಂಶವಾಹಿ ರೂಪಗಳ
ಮೌಲ್ಯಮಾಪನ**

(ಲತಾಮಣಿ, ಎಂ. ಕೆ.)

ಸಾರಾಂಶ

ಅನ್ನೋನಾ ಮುರಿಕಾಟಾ ಎಲ್. (ಲಕ್ಷಣ ಫಲ) ಹೆಚ್ಚು ಬಳಕೆಯಾಗದ ಹಣ್ಣಿನ ಬೆಳೆಯಾಗಿದ್ದು ಅದರ ಆರೋಗ್ಯ ಪ್ರಯೋಜನಗಳಿಂದಾಗಿ ಪ್ರಾಮುಖ್ಯತೆಯನ್ನು ಪಡೆದಿರುತ್ತದೆ. 2022-23ರಲ್ಲಿ ಶಿವಮೊಗ್ಗ ಜಿಲ್ಲೆಯ ಮುದ್ದಿನಕೊಪ್ಪ ಗ್ರಾಮದಲ್ಲಿ ಬೆಳವಣಿಗೆ, ಇಳುವರಿ ಮತ್ತು ಗುಣಮಟ್ಟದ ಗುಣಲಕ್ಷಣಗಳಿಗಾಗಿ ಅನ್ನೋನಾ ಮುರಿಕಾಟಾದ ವಂಶವಾಹಿ ರೂಪಗಳನ್ನು ಮೌಲ್ಯಮಾಪನ ಮಾಡಲು ಪ್ರಯೋಗವನ್ನು ನಡೆಸಲಾಯಿತು. ಎಲ್ಲ ವಂಶವಾಹಿ ರೂಪಗಳಲ್ಲಿ ಬೆಳವಣಿಗೆ, ಇಳುವರಿ ಮತ್ತು ಗುಣಮಟ್ಟದ ಗುಣಲಕ್ಷಣಗಳಿಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸಗಳು ಕಂಡುಬಂದಿರುತ್ತದೆ. ವಂಶವಾಹಿ ರೂಪ ಪಿಕೆಎನ್-25 ಗರಿಷ್ಠ ಹಣ್ಣಿನ ಉದ್ದ (29.10 ಸೆಂ. ಮೀ.), ಹಣ್ಣಿನ ಅಗಲ (16.40 ಸೆಂ. ಮೀ.), ಹಣ್ಣಿನ ತೂಕ (2352.92 ಗ್ರಾಂ) ಹಣ್ಣಿನ ಪ್ರಮಾಣ (2262.46 ಸಿಸಿ) ಮತ್ತು ತಿರುಳಿನ ತೂಕ (1624.40 ಗ್ರಾಂ) ವನ್ನು ದಾಖಲಿಸಿದೆ. ಪ್ರತಿ ಮರಕ್ಕೆ ಅತ್ಯಧಿಕ ಸಂಖ್ಯೆಯ ಹಣ್ಣುಗಳು (34) ಮತ್ತು ಪ್ರತಿ ಮರಕ್ಕೆ ಹೆಚ್ಚಿನ ಹಣ್ಣಿನ ಇಳುವರಿಯನ್ನು (80.00 ಕೆಜಿ ಪ್ರತಿ ಮರ) ಪಿಕೆಎನ್-25 ರಲ್ಲಿ ದಾಖಲಿಸಲಾಗಿದೆ ನಂತರ ಪಿಕೆಎನ್-20 ವಂಶವಾಹಿ ರೂಪ ಪ್ರತಿ ಮರಕ್ಕೆ 33 ಹಣ್ಣುಗಳು ಮತ್ತು 75.97 ಕೆಜಿ ಇಳುವರಿಯನ್ನು ಹೊಂದಿದೆ. ಹೆಚ್ಚಿನ ಮೌಲ್ಯಗಳು ಟಿಎಸ್‌ಎಸ್ (ಪಿಕೆಎನ್-24:18.23 ಬ್ರಿಕ್ಸ್), ಟೈಟ್ರೇಟೆಬಲ್ ಆಮ್ಲೀಯತೆ (ಪಿಕೆಎನ್-39: ಶೇ. 1.25), ಕಡಿಮೆಯಾಗುವ ಸಕ್ಕರೆ ಪ್ರಮಾಣ (ಪಿಕೆಎನ್-03: ಶೇ. 8.87), ಕಡಿಮೆಯಾಗದ ಸಕ್ಕರೆ ಪ್ರಮಾಣ (ಪಿಕೆಎನ್-20: ಶೇ. 3.79) ಒಟ್ಟು ಸಕ್ಕರೆ (ಪಿಕೆಎನ್-24: ಶೇ. 11.97), ಟಿಎಸ್‌ಎಸ್: ಆಮ್ಲ (ಪಿಕೆಎನ್-24:24.64), ಒಟ್ಟು ಸಕ್ಕರೆ: ಆಮ್ಲ (ಪಿಕೆಎನ್-24:16.18) ಆಸ್ಕೋರ್ಬಿಕ್ ಆಮ್ಲ (ಪಿಕೆಎನ್-03:22.68 ಮಿ. ಗ್ರಾಂ ಪ್ರತಿ 100 ಗ್ರಾಂ ಹಣ್ಣಿನ ತಿರುಳು), ಆಂಟಿಆಕ್ಸಿಡೆಂಟ್ ಚಟುವಟಿಕೆ (ಪಿಕೆಎನ್-03: ಶೇ. 70.3) ಮತ್ತು ಒಟ್ಟು ಪೀನಾಲ್ ಅಂಶ (ಪಿಕೆಎನ್-02, ಪಿಕೆಎನ್-24:126.48 ಮಿ. ಗ್ರಾಂ ಜಿಎಇ ಪ್ರತಿ ಒಣ ತೂಕ) ಹಣ್ಣಿನ ಗುಣಮಟ್ಟದ ನಿಯತಂಕಗಳಿಗೆ ತನಿಖೆಯ ಸಮಯದಲ್ಲಿ ದಾಖಲಾಗಿದೆ. ಹೆಚ್ಚಿನ ಮಟ್ಟದ ವಂಶವಾಹಿ ರೂಪಗಳ ಗುಣಾಂಕದ ವ್ಯತ್ಯಾಸ (ಜಿಸಿಎ), ರೂಪರೇಖೆಯ ಗುಣಾಂಕದ ವ್ಯತ್ಯಾಸ (ಪಿಸಿಎ) ಮತ್ತು ಅಧಿಕ ಅನುವಂಶಿಕತೆ ಜೊತೆಗೆ ಹೆಚ್ಚು ಅನುವಂಶಿಕ ಮುಂಗಡದ ಸರಾಸರಿಯು ಅಧ್ಯಯನ ಮಾಡಿದ ಹೆಚ್ಚಿನ ಗುಣಲಕ್ಷಣಗಳಿಗೆ ದಾಖಲಿಸಲಾಗಿದೆ. ಪ್ರತಿಹಣ್ಣಿನ ಬೀಜಗಳ ಸಂಖ್ಯೆ ಮತ್ತು ಟೈಟ್ರೇಟೆಬಲ್ ಆಮ್ಲೀಯತೆಯನ್ನು ಹೊರತುಪಡಿಸಿ ಎಲ್ಲಾ ಪಾತ್ರಗಳು ಇಳುವರಿಯೊಂದಿಗೆ ಹೆಚ್ಚು ಮಹತ್ವದ ಮತ್ತು ಸಕಾರಾತ್ಮಕ ಸಂಬಂಧವನ್ನು ಹೊಂದಿದೆ. ವೈವಿಧ್ಯತೆಯ ಅಧ್ಯಯನದಲ್ಲಿ ಅನ್ನೋನಾ ಮುರಿಕಾಟಾದ 34 ವಂಶವಾಹಿ ರೂಪಗಳನ್ನು ಆರು ಗುಂಪುಗಳಾಗಿ ವರ್ಗೀಕರಿಸಲಾಗಿದೆ. ಒಟ್ಟು ಅನುವಂಶಿಕ ವ್ಯತ್ಯಾಸದಲ್ಲಿ ಪ್ರತಿ ಮರದ ಹಣ್ಣಿನ ಇಳುವರಿಯು ಹೆಚ್ಚಿನ ಕೊಡುಗೆ ನೀಡಿದ್ದು ನಂತರದಲ್ಲಿ ಟೈಟ್ರೇಟೆಬಲ್ ಆಮ್ಲೀಯತೆ ಮತ್ತು ಆಂಟಿಆಕ್ಸಿಡೆಂಟ್ ಗುಣಗಳು ಕಂಡುಬಂದಿದೆ. ಪಿಕೆಎನ್-25 ಮತ್ತು ಪಿಕೆಎನ್-20 ಹಣ್ಣು ಮತ್ತು ಇಳುವರಿ ನಿಯತಂಕಗಳಿಗೆ ಉತ್ತಮವಾಗಿದೆ ಎಂದು ಕಂಡು ಬಂದಿದೆ ಹಾಗೂ ಪಿಕೆಎನ್-24 ಮತ್ತು ಪಿಕೆಎನ್-03 ಹಣ್ಣಿನ ಗುಣಮಟ್ಟದ ಗುಣಲಕ್ಷಣಗಳ ವಿಷಯದಲ್ಲಿ ಉತ್ತಮವೆಂದು ಕಂಡುಬಂದಿದೆ.

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INTRODUCTION

I INTRODUCTION

Annona muricata L. is an evergreen tree species belongs to the family Annonaceae which bears the largest fruit among the family and having a chromosome number of $2n = 2x = 14$. It is native to Central America and is called by different names like soursop, graviola, sirsak, guanabana *etc.* There is a growing interest in *Annona muricata* due to its potential health benefits, including its use in traditional medicine for its alleged anticancer properties. Efforts are made to raise awareness, improve post-harvest handling and to develop value added products can help to promote the utilization of this crop as a nutritious and potentially valuable fruit crop.

It is widely grown crop of South America and it is distributed throughout tropical and subtropical parts of the world, including India, Malaysia and Nigeria. In India, it was introduced along with other fruits of this family in the eighteenth and nineteenth centuries (Morton, 1987). It grows on a limited scale in the southern subtropical regions of India, including Tamil Nadu, Karnataka, Andhra Pradesh and Kerala.

Annona muricata is an evergreen, slender, low branching and bushy tree which grow up to a height of 3 to 6 m. The leaves are obviate to elliptic with hermaphrodite flowers that bear in small clusters or solitary. The fruits are dark green and prickly on the outer surface. They are ovoid and can be up to 30 centimetres long, with a moderately firm texture. Their flesh is juicy, acidic, whitish in colour with an aroma similar to pineapple. The flavour of the fruit has been described as a combination of strawberry and apple with sour lime flavour. Fruit weight varies from 0.5 kg to 1.5 kg which is largely depend on the extent of pollination and fertilization.

The fruit is derived from the fusion of many fruitlets (aggregate of berries) and the fruit pulp consists of white fibrous juicy segments. Numerous black or dark brown seeds are embedded in a firm fleshy, acid-sweet with whitish pulp. Fruit contains protein (1 g), fat (0.3 g), dietary fibre (3.3 g), sugars (13.54 g), thiamine (6 %), riboflavin (4 %), niacin (6 %), folate (4 %), ascorbic acid (25 %), phosphorous (4 %), iron (5 %), calcium and zinc (1 %), respectively (Food value per 100 g of edible portion). This high nutrient profile fruit acts as an immune booster, blood pressure stabilizer, blood sugar regulator, potential evil of osteoporosis *etc.* The presence of acetogenins in the fruit made it as a natural cancer medicine (Badrie and Schauss, 2010).

More than 200 phytochemicals have been identified in this plant, mainly acetogenins, alkaloids and phenols. These phytochemicals have shown pharmacological activities such as antimicrobial, antioxidant, insecticide, larvicidal, selective cytotoxicity to tumoral cells, anxiolytic, anti-stress, anti-ulceric, wound

healing, anti-jaundice, hepato-protective, hypoglycemic, immune-modulatory and antimalarial characters (Khilari and Narayan, 2022).

Annona muricata is a low-altitude tree that thrives in a hot and humid environment. It is primarily grown at elevation below 900 metres above sea level. On the other hand, good productive orchards can be found up to 1100 metres above sea level. It adapts well to humid tropical climates. However, drought, partial shade and poor soil conditions are tolerable, but this crop cannot tolerate water stagnation which leads to floral abscission and root rot in plants. The ideal temperature for growth and development is 21 to 30°C. It is quite susceptible to drastic temperature changes, especially if it dips below freezing. A temperature of less than 12° C, high temperatures and low humidity effects pollination and fruit development. It can be cultivated in a various soil types, but it prefers sandy loam soil (Patel and Patel, 2016).

Morphological characterization of the genetic resources of *A. muricata* has been of transcendental importance to register particular traits and to differentiate their taxonomic, phenotypic and genetic through qualitative and quantitative attributes that are highly heritable and observable, as well as expressible in most of the environments. The systematic characterization has allowed to reveal the variation within the collections and select the most elite genotypes for their cultivation (Padmini *et al.*, 2013).

The knowledge of genetic variability is of great importance for crop improvement programme. Greater the variability in a population, greater the chances of effective selection for desirable types. In fact, most of the present day commercial varieties of are chance selection from natural seedlings. Assessment of genetic variability, nature and magnitude of characters association for quality, yield and yield attributing traits made easy for the success of any crop improvement programme.

Correlation co-efficient analysis measures the mutual relationship between various plant characters to determines the component characters on which selection can be made for the improvement in yield. Correlation provides information on the nature and extent of the relationship between pairs of characters. Hence, when the breeder applies selection for a particular character, not only it improves that trait, but also other characters and it will provide a reliable measure of genetic association between them which is helpful in breeding programmes.

Divergence analysis is a tool to measure the relative contribution of different components on diversity acting both at intra and inter-cluster level which helps in the identification of selected parameters to be used as criteria for yield and quality improvement (Mahalanobis, 1936).

Identification of suitable genotype is necessary for promoting its productivity, production and quality of the fruits under tropical conditions. In order to identify distinct characters of various *A. muricata* genotypes, the morphological characters are also equally important to the fruit characters. On the basis of yield and quality performance of different germplasm, the suitable varieties or genotype may be selected for further stability studies. This will also help the growers in selection of suitable genotype for commercial cultivation to get higher yield and good quality fruits.

Annona muricata is not as widely cultivated on a commercial scale compared to other major fruit crops. This limited cultivation means there is untapped potential for expanding production and meeting increasing demand. It is a relatively low-maintenance crop, making it an attractive option for sustainable agriculture in regions with limited resources or water scarcity. Promoting the cultivation of underutilized fruits can contribute to biodiversity conservation efforts by diversifying horticultural landscapes and reducing reliance on a small number of commercially dominant crops. Therefore, it is very much necessary to identify the elite genotypes from the existing orchard at Muddinakoppa, Shivamogga(D). Keeping the above points in the view, the present study was planned with the following objectives.

Objectives of Investigation:

1. To characterize the *Annona muricata* L. genotypes for morphological attributes.
2. To assess the yield and fruit quality parameters of *A. muricata* L. genotypes.
3. To study genetic variability of *A. muricata* L. genotypes for yield and yield attributes.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

The present study was conducted on “Evaluation of *Annona muricata* L. genotypes for growth, yield and quality attributes”. The research literature on performance of *A. muricata* is notably scarce. Hence, literature regarding other relative fruit crops on variability in morphological, fruit yield and physicochemical parameters in recent years has been included in this chapter. The available, relevant literature related to various aspects of the present investigation has been reviewed and presented under the following heads:

- 2.1. Morphological traits of the tree
- 2.2. Morphological traits of the tree foliage
- 2.3 Fruit and yield parameters
- 2.4 Bio-chemical parameters
- 2.5 Genetic variability studies
- 2.6 Correlation studies
- 2.7 Path co-efficient analysis
- 2.8 Genetic divergence studies

2.1. Morphological traits of the tree

Dasilva *et al.* (1999) identified that the soursop accession Moxoto-20.2 recorded the highest plant height (3.80 m) and the lowest (2.90 m) was in Moxoto-16.3.

Mathakar (2005) conducted a study on 24 custard apple hybrids at Mahatma Phule Krishi Vidyapeeth, Rahuri and found that tree height ranged from 1.98 to 3.23 m.

Kumar *et al.* (2008) reported that considerable variation observed among the bael trees grown in Western Uttar Pradesh. The height of seedling-origin trees varied from 10 m to 19.33 m. The bael accession BT-2 grown in Mohrka village was found with dwarf nature and the seedling origin tree of genotype BT-10 grown in Ghunghrawali village was the tallest one.

Kumar *et al.* (2010) evaluated different mandarin, sweet orange and rootstock species under mid-hill conditions in Arunachal Pradesh. They recorded the maximum plant height in Mediterranean orange followed by Zigardio mandarin. In contrast, the minimum plant height was recorded in Wilking orange.

Rao and Subramanyam (2011) evaluated 35 germplasm of custard apple for scarce rainfall zone for their growth and yield. The highest plant height of 3.2 m was

recorded in Phythota-3 followed by MMR-9 (2.91 m), while the lowest plant height was recorded in NLD-1 (2.1 m). Highest stem girth was recorded (37.00 cm) in Atemoya x Washington followed by MMR-8 (35.2 cm), while lowest stem girth was recorded in JGL-6 (26.1 cm).

Saraswathy *et al.* (2010) conducted a study on the evaluation of sapota genotypes collected from different parts of India. The highest tree height (11.20 m) was recorded by the hybrid CO-1 followed by the variety Cricket Ball (10.98 m).

The study was carried out by Selvan *et al.* (2010) for morphological characterization of newly evolved mango hybrids. Hybrids of cross Amrapali x Sensation produced large to medium sized trees, while hybrids of Amrapali x Lal Sundri cross produced dwarf statured trees.

Shukla *et al.* (2010) studied the performance of different commercial varieties of aonla under hot arid condition viz., Krishna, Kanchan Chakaiya, NA-6 NA-7, NA-10 and Anand-1. The plant height was maximum in NA-7 (3.46 m) and minimum in Anand-1 (2.1m). The maximum plant girth was recorded in NA-6 (125 cm).

Singh *et al.* (2015) evaluated different aonla varieties for their vegetative characters. Among the cultivars, growth habit was varied viz., upright spreading, tall upright, tall spreading, tall drooping and tall semi- spreading.

Tripathi *et al.* (2016) observed that the popular cultivars of aonla in north India produced lesser vegetative growth as compared to cultivar BSR-1 under the humid conditions of western ghats. The plant height was recorded maximum (6.32 m) in BSR-1 and minimum (3.71 m) in Chakaiya.

Abhilash *et al.* (2018) evaluated the elite strains of acid lime for the growth and yield parameters. The maximum tree height (4.62 m) was recorded in KLS-24 and it was significantly superior to other genotypes.

Chandrashekar *et al.* (2018) evaluated 35 genotypes of jackfruit under the coffee ecosystem of lower Pulncy hills. Erect growth habit was found to be more frequent (54.28 %) followed by semi-erect (42.85 %) and 2.85 per cent of genotypes were observed with irregular growth habit.

Rajadurai *et al.* (2022) reported that, the variety Arka Sahan showed increased tree height (6.28 m), followed by Raydurg (3.63 m) and mammoth (3.32 m) and reduced tree height was recorded in APK (Ca) 1 (2.98 m). The variety Mammoth recorded enhanced stem girth (85.67cm) followed by Arka Sahan (55.31 cm) and Raydurg (52.23 cm) and least stem girth was observed in APK (Ca) 1 (35.25 cm).

Pooja *et al.* (2022) evaluated morphological and yield traits of tamarind genotypes. Among sixteen genotypes studied, the longest tree height was recorded in K-9 (5.08 m) while, the shortest was recorded in K-10 (3.00 m) and the maximum stem girth was recorded in K-9 (1.01 m) whereas, the minimum was recorded in S-7 (0.48 m).

2.2. Morphological traits of the tree foliage

Thakur and Singh (1967) reported leaf size for *Annon squamosa* 10.6 cm length and 4.1 cm breadth, *A. reticulata* 16.5 cm length and 15.0 cm breadth, *A. atemoya* 10.2 cm length and 4.0 cm breadth, *A. cherimola* 13.4 cm length and 7.5 cm breadth, respectively.

Mathakar (2005) reported leaf length from 9.00 cm to 21.03 cm, while leaf breadth ranged from 3.68 to 11.11 cm in custard apple, respectively.

Gitonga *et al.* (2008) conducted research on assessment of phenotypic diversity of macadamia (*Macadamia* spp.) germplasm in Kenya using leaf and fruit morphology. The analysis of variance revealed significant differences in leaf length, leaf width, petiole length and leaf marginal serrations.

Jadhav (2008) found that the leaf length and breadth in 24 hybrids of custard apple varied from 11.53 cm to 17.09 cm and 3.18 cm to 8.51 cm, respectively.

Algabal *et al.* (2012) conducted a study on tamarind genotypes and reported that among 36 genotypes studied, the leaf colour ranged from light green to dark green.

George *et al.* (2013) evaluated 100 avocado accessions and significant variations were observed among the accessions with respect to leaf shape; roundish (32 %), lanceolate (28 %), obovate (5 %), oval (3 %) and oblong-lanceolate (32 %), leaf colour; green (10 %), dark green (43 %) and light green (10 %), leaf margins; undulate (47 %), entire (53 %), leaf base shapes; acute (72 %) and obtuse (28 %), pubescence on leaves; sparse (23 %) and dense (5 %).

Singh *et al.* (2015) studied different aonla varieties for their vegetative characters. Among cultivars, leaf characters were varied viz., the leaflet colour (green to pale yellowish green), shape (oblong, oval oblong and elliptical), apex (obtuse and acute) also varied among the cultivars. The size of leaves in terms of length and breadth ranged between 1.25 cm to 1.47 cm and 0.23 cm to 0.37 cm, respectively.

Nkansah *et al.* (2017) found significant variation in the leaf shape, leaf colour, leaf margin and leaf base shape of one hundred avocado accessions. The five leaf shapes were observed among the accessions these are, roundish (32 %), lanceolate (28 %), obovate (5 %), oval (3 %) and oblong lanceolate (32 %). The per cent distribution

of leaf colour was 48, 43, and 10 per cent for green, dark green and light green, respectively. The two leaf margins were observed among the accessions, undulated (48 %) and entire (53 %). Two leaf base shapes were observed acute (78 %) and obtuse (28 %).

Abraham *et al.* (2018) observed significant variations concerning leaf shape; ovate shaped seeds (3.77 %), narrowly obovate (9.43 %), obovate (1.89 %), oval (32.08 %), rounded (11.32 %), lanceolate (5.66 %), oblong lanceolate (35.85 %) and leaf apex shape; very acute (3.7 %), acute (49 %), obtuse (34 %) and very obtuse (13.2 %).

Sawitri *et al.* (2019) studied ten durian accessions and observed variations in leaf shapes, leaf colour, leaf base shapes and leaf apex shapes. The 30 per cent of accessions had oblong shaped leaves, 40 per cent were elliptic and 10 per cent were oval shape and oblong by 20 per cent. The leaf apex shape consisted of 50 per cent long acuminate and 50 per cent acuminate. The leaf colour indicated dark green and green colour by 70 per cent and 30 per cent, respectively.

Handique *et al.* (2022) conducted studies on the morphological characterization of custard apple grown in Assam. The leaves of custard apple collected from different locations in Assam show a lanceolate leaf blade shape with entire leaf margin, acuminate apex and acute base. The colour of the leaves varies from light green to dark green. The leaf length of custard apple leaves collected from different places ranges from 16.73 cm to 24.27 cm, leaf breadth ranges from 2.83 cm to 4.63 cm with petiole length ranged from 0.90 cm to 1.53 cm.

Jagruthi *et al.* (2022) evaluated eighteen *Annona* genotypes of two species for leaves and fruit morphological attributes. For morphological traits, the genotype Mammoth noted with lanceolate leaf shape, obtuse leaf base and acuminate leaf apex, Washington and Island Gem had elliptic leaf shape and rounded leaf base and apex.

2.3 Fruit and yield parameters

Thakur and Singh (1967) reported that custard apple possesses average length and diameter of 7.8 cm and 7.4 cm, respectively, with an average weight of 203.5 g and volume of 163 cc, respectively.

Mangave (1982) reported that the average weight of individual fruit of custard apple varies from 108.15 to 322.41g, respectively.

Shete *et al.* (1991) screened seedling selections in the custard apple under Rahuri conditions and the number of seeds per fruit was observed to be 22 to 72. They reported that the number of fruits in *Annona squamosa* seedlings ranged from 27 to 49 per tree, whereas the average yield per tree varied from 4.26 kg to 8.70 kg, respectively.

Agustin (1999) observed that the pulp weight per fruit of the Corte's Selection was 622.88 g and average skin weight of the Mexican cherimoya cultivar was 139.18 g.

Dasilva *et al.* (1999) evaluated *A. muricata* germplasm in Brazil and they revealed that average fruit weight ranged from 369 g to 839 g. The pulp per cent varied from 54.7 per cent to 89 per cent and seed per cent varied from 1.4 per cent to 5.1 per cent.

Mathakar (2005) conducted a study on twenty-four custard apple hybrid and found that the fruit physical characters *viz.*, fruit length (4.1 to 13.8 cm), fruit breadth (3.2 to 11.8 cm) and fruit weight (187.7 to 672.5 g) varies, respectively. The pulp weight per fruit ranged from 88.8 to 496.4 g. The number of seeds per fruit varied from 25 to 56 and they observed that the seed weight per fruit ranged from 13.2 to 33.3 g with mean seed weight of 24.4 g. They found that number of fruits per tree ranged from 14 to 61, whereas yield varied from 7.2 kg to 15.1 kg per tree.

Patel *et al.* (2005) carried out experiment to find out the existing natural variability among the jamun seedling trees. The genotypes, RNC-26 and RNC-11 were found promising for physico-chemical characters. Highest pulp content (97.71%) was recorded in V-8 followed by V-6 (95.84 %) and V-7 (93.81%) genotypes collected from Varanasi region. Thin seed with almost negligible seed weight (0.12 g) was observed in V-8 followed by V-6 (0.16 g) and V-7 (0.31 g).

Dikshit *et al.* (2008) conducted a study on physical characterization of the fruits which revealed variation in average fruit weight (90.8-375 g), number of seeds per fruit (21.2-73), weight of pulp per fruit (44.4-188 g) and fruit-pulp ratio (37-54.2), respectively. They observed that seed weight per fruit ranged from 8.3-30.9 g.

Rao and Subramanyam (2009) reported that the highest fruit weight (30.7 g) in aonla cultivar NA-10 followed by Kanchan (30.2 g) whereas, it was lowest (16.18 g) in Chakaiya. The fruit volume of aonla cultivars ranged from 1.01 to 1.51 cc, it was maximum (1.51 cc) in NA-6 and minimum (1.01 cc) in Kanchan.

Rao and Subramanyam (2011) evaluated thirty-five germplasm of custard apple for their growth and yield. Highest fruit weight per tree was recorded (278.9 g) in Atemoya X Balanagar followed by Y. Palli – 12 (270.6 g), while lowest fruit weight was recorded in MMR-10 (138.9 g), respectively. They found maximum seed weight in Balanagar SR (22.6 g), while minimum seed weight was recorded in JGL-2 (4.00 g), respectively. The fruit yield was recorded highest (15.7 kg) in Ramaphal followed by MMR-10 (15 kg), while lowest fruit yield was recorded in NLD-10 (2.8 kg).

Prakash *et al.* (2010) observed wide range of variability in the physico-chemical composition of jamun genotypes. The Selection 1 was observed most promising for fruit weight (14.55g), minimum seed weight (1.73g) and higher pulp per cent (90.05).

Saraswathy *et al.* (2010) conducted study on evaluation of sapota genotypes collected from different parts of India. PKM-1 had more number of fruits/tree (1690); Cricket Ball registered the highest mean fruit weight of 135 g. The highest yield of 139 kg/tree was recorded by PKM-4 followed by Virudhunagar local which recorded an yield of 135.75 kg/tree.

Shukla *et al.* (2010) studied the performance of different commercial varieties of aonla was assessed under hot arid condition *viz.*, Krishna, Kanchan Chakaiya, NA-6 NA-7, NA-10 and Anand-1. Maximum fruit size was observed in Krishna (3.92 x 4.60cm) and minimum in Kanchan (3.31 x 3.80cm). However, fruit weight varied from 30.16 to 48.3g depending on cultivar and it was maximum in Krishna (48.3g) and minimum in Kanchan (30.16g). total pulp weight was maximum in Krishna (45.6g) and minimum in Kanchan (28.77g).

Ghojage *et al.* (2011) conducted study to assess the variability of quality characters of jamun genotypes from seedling trees. Among the physical parameters, the fruit weight ranged between 13.45 g in genotype KJS-4 to 5.27 g in genotype KJS-24. The genotype KJS-4 and KJS-9 had the highest pulp weight (11.47 g) and highest pulp content (87.35%) respectively, while the genotype KJS-15 had lowest pulp weight (3.56 g) and pulp content (60.23%). The fruit with minimum seed weight was recorded in the genotype KJS-9 (1.34 g), while the highest seed weight was recorded in the genotype KJS-2 (2.08 g).

Girwani *et al.* (2011) reported that maximum fruit weight (250 g) was recorded in Hybrid-1 (Atemoya X Balanagar) followed by Hybrid-6 (Red sithaphal X Atemoya) (225 g) and Hybrid-4 (British guinea X Atemoya) (220 g). Among all the hybrids, Maximum number of fruits per tree (94) was recorded in Hybrid- 1 followed by Hybrid-6. while the seed content per fruit was also minimum (20) in this hybrid.

Kinley and Chinawat (2011) studied 30 accessions which were selected from six districts in the major mandarin-growing regions in Bhutan for morphological characteristics. The accessions from Dagana had the highest fruit weight with 107.2 g followed by Samtse, Zhemgang, Sarpang, Trongsa and Tsirang with fruit weights of 96.1, 93.3, 87.6, 78.9 and 58.3 g, respectively.

Bayram *et al.* (2012) evaluated 13 avocado cultivars. The highest fruit pulp ratio, fruit number per tree (587), mean yield (79.4 kg/tree), fruit weight (313 g), fruit length and fruit width (81 mm) were found in Fuerte. While, lowest values of these parameters were noticed in Hass (64.5 %), Reed (74), seed (22.5 kg/tree), Fuerte (300 g) and seed (81mm), respectively.

Bhatnagar *et al.* (2012) collected 182 custard apple fruit sample from seven districts of Rajasthan and observed that pulp weight and seed weight per fruit varied from 21.50 g to 47.00 g and 9.75 to 26.02 g, respectively.

Hashmi and Pawar (2012) reported that the average fruit weight of custard apple fruits, collected from different locations was 160.45 g.

Keles *et al.* (2014) revealed that average fruit weight, kernel weight and kernel ratio in walnut were ranged from 8.93 to 13.92 g, 4.62 to 7.36 g and 47.80 to 58.98 per cent among twenty promising walnut genotypes, respectively. Measurements of fruit dimensions showed that the average fruit length and width were found between 42.80–29.97 mm and 25.73–34.77 mm, respectively.

Prakash (2014) carried out survey to identify the elite genotypes among the natural population. Individual fruit weight ranged from 85.64 to 131.60 g, fruit length (5.52 to 7.42 cm), fruit breadth (5.17 to 5.99) cm and seed weight (34.60 to 56.0 g/fruit).

Alcasid *et al.* (2015) studied the morphological traits of different mango accessions from different regions in the Philippines. The diversity of seed weight was observed among the mango accessions. The seed weight ranged from 12.79-82.75 g with a mean of 28.78g.

Bakane *et al.* (2015) randomly selected fifty fruit sample of Balanagar variety. Fresh fruit weight and size of the custard apple varied in the range of 114.8 to 231.64 g and 58.92 to 74.15 mm, respectively.

Kumar (2015) evaluated custard apple genotypes for recipe standardization and found that, among the four genotypes the number of seeds per fruit varies from 29.7 (IGCA-38) to 52.9 (IGCA-18), respectively.

Saitwal *et al.* (2015) collected 101 genotypes of custard apple from Western Maharashtra; twenty-two genotypes were found superior for physico-chemical characteristics. On the basis of two-year data (2011 and 2012); the highest fruit pulp per cent was found in Island Gem (61.72) and SG-8 (60.46).

Shyamamma *et al.* (2016) explored thirty jackfruit genotypes in Southern India. Significant variation was found in jackfruit weight (500 g to 14.66 kg). The highest fruit weight of 14.66 kg was recorded in Mottam Varika. The highest fruit length of 72.33 cm was recorded in clone HMT.

Ismadi *et al.* (2019) observed variations in fruit length, fruit width and fruit weight of avocado. The fruit length was ranged between 7.25-12.45 cm with an average length of 10.80 cm. The fruit had a width of 7.45-10.57 cm with an average of 9.12 cm. The fruit weight between 374-590 g with an average weight of 471.85 g.

Vijay *et al.* (2017) studied morphological, qualitative and quantitative characteristics of sixteen genotypes of jamun. The study revealed that there was a wide variation among the accessions. JJ-5 was the most promising genotype among the 16 accessions for average fruit weight (55.40 g), fruit length (27.78 mm), fruit width (22.01 mm), pulp weight (31.60 g) and seed weight (14.70g).

Yadav *et al.* (2017) were made extensive survey for determining variability for physical and biochemical traits and find out the elite custard apple genotypes. Result of study reveal that custard apple genotypes showed wide type of variability with respect to fruit weight (110.45 – 335.37 g), fruit length (45.32–84.12 mm), fruit breadth (55.28–95.92 mm), pulp weight (50.75–205.87 g), no. of seed/fruit (18–63) and seed weight (7.27–26.12 g).

Chandel *et al.* (2018) were evaluated 18 genotypes of custard apple for yield parameters and physical aspects. The results revealed a great variability for yield and quality traits. The fruit physical characters *viz.*, fruit length (7.53 to 11.76 cm), fruit breadth (7.14 to 10.98 cm), fruit weight (155.86 to 365.78 g), pericarp weight (75.85 to 162.58 g), pulp weight (60.44 to 180.56 g), number of seeds per fruit (48.33 to 20.00) and seed weight (15.00 to 23.00 g) showed significant variation.

Priyanka *et al.* (2018) conducted study in red laterite zone of West Bengal with the view to find out suitable custard apple cultivars. Island Gem gave significantly highest yield (10.7 kg/ plant) followed by Balanagar (6.1 kg/plant). Maximum fruit weight (162.0g) was recorded from Arka Sahan followed by Balanagar (128.0 g).

Krishna *et al.* (2018) were collected thirteen different avocado genotypes for evaluating the fruit characteristics. The genotypes PAKAV002 and PAKAV010 had the average fruit weight ranging (307.1 g and 346.8 g), maximum of pulp to fruit ratio 62.34 per cent and 56.97 per cent. Similarly, genotypes PAKAV010 (11.425%), PAKAV013 (11.96%) and PAKAV002 (14.47%) had low seed weight to the total fruit weight which is regarded important factor for avocado selection and evaluation.

Kumar *et al.* (2018) carried out investigation on fruit morphology and quality parameter studies of global custard apple germplasms. The fruit shape ranged from round to cordate, fruit weight varied from 98.8 to 170.1 gm, fruit length varied from 5.47 to 7.0 cm, fruit width varied from 5.57 to 7.13 cm, fruit volume varied from 77 to 178 cm³ and pulp to seed ratio ranged from 3.69 to 32.87.

Usha *et al.* (2018) were carried out an experiment to evaluate the macadamia genotypes for morphological and yield contributing traits. Significant differences were also observed among the genotypes for fruit cluster length, number of fruits per cluster, nut weight, nut diameter, shell weight, pericarp weight. Significantly higher number of nuts per cluster (7.53), kernel weight (3.17 g) and nut yield per tree (16.16 kg) were recorded in genotype G-5.

Yashwant *et al.* (2018) studied the morphological and fruit quality traits of custard apple germplasms. The fruit shape ranged from round to cordate, fruit weight varied from 98.8 to 170.1 g, fruit length varied from 5.47 to 7.0 cm, fruit width varied from 5.57 to 7.13 cm, fruit volume varied from 77 to 178 cm³ and pulp to seed ratio ranged from 3.69 to 32.87.

Idate *et al.* (2019) undertaken survey in the area of Purander Tashil of Pune district. Ten elite selections were made, which were evaluated with check cultivar Balanagar. It was observed that cv. Phule Purandar (JWC 1) recorded maximum average fruit weight (366.17 g) and yield plant per plant (50.90 kg).

Nimisha *et al.* (2019) reported that, the phenomenon of irregular bearing is more dominant in perennial fruit crops. The alternate bearing is observed in most of the fruit crops like apple, mango, citrus, pecan nut and pistachio nut.

Meghana *et al.* (2020) evaluated twenty-five local selections of custard apple with Balanagar variety as check for yield characters along with various physical characteristics of fruit. It was observed that selection CLS-9 recorded maximum number of fruits per plant (34.00) and fruit yield (4.36 kg/plant). Physical parameters viz. fruit length (8.49 cm), fruit breadth (8.44 cm), fruit volume (170.50 ml), fresh weight of the fruit (198.42 g) and ripe weight of the fruit (176.10 g) was recorded maximum in selection CLS-16 than the check variety Balanagar. However, maximum pulp weight, pulp per cent and pulp-peel ratio was noticed in selection CLS-18 (75.32 g, 46.84% and 1.56 respectively). Minimum number of seeds per fruit (14.17) and seed weight (3.81g) was recorded in selection CLS-1.

Amulya *et al.* (2022) evaluated 356 trees of bael for growth, fruit characters and showed considerable variations. Among 356 trees, SB-353 was found superior with respect to fruit characters viz., length (13 cm), volume (310 cm³), weight (68.03 g), pulp weigh (202.40 g) and higher pulp: seed (10.22).

Arshad *et al.* (2022) carried out evaluation study on jamun genotypes. There were fourteen genotypes and the results indicated that genotype Dhupdal showed maximum fruit length (3.47 cm), fruit breadth (2.47cm), fruit size (8.57 cm²), seed length (2.44 cm), the genotype GKVK-1 showed highest seed breadth (1.10 cm), fresh seed weight (2.71 gm), dry seed weight (1.81 gm), the genotype Bahadoli registered maximum fruit weight (15.44 gm), pulp weight (13.23 gm), pulp content (89.18%) and pulp-seed ratio (8.24%) was found highest in the genotype AJG-85.

Handique *et al.* (2022) conducted studies on morphological characterization of custard apple grown in Assam. The fruits of North Lakhimpur recorded maximum length (8.90 cm) and diameter (8.63 cm) while the fruits of Guwahati recorded minimum length and diameter of 6.10 cm and 5.80 cm, respectively. Again, the fruit

weight ranges from 145.00 g to 443.33 g and volume ranges from 114.67 to 385.00 cc. The total seed number per fruit ranges from 30.33 to 82.33 while the weight of ten seeds was found to be 1.14 g to 2.03 g.

Pooja *et al.* (2022) carried out evaluation of morphological and yield traits of tamarind genotypes. All the morphological and yield traits showed significant difference among the selected genotypes indicating the presence of adequate variations. The analysis of variance revealed significant difference with respect to pod traits, pod yield per tree (K-9: 12.80 kg), number of pods per tree (NTI-52: 989.07) and pulp per cent (K-9: 48.87).

Rajadurai *et al.* (2022) conducted study in black vertisol region of southern part of Tamil Nadu with the view to find out suitable custard apple cultivars for the region. Among the five custard apple varieties evaluated, Arka Sahan recorded the enhanced individual fruit weight (214.12g), less number of seeds per fruit (8.88) and pulp weight (60.76g). The variety Raydurg showed less rind weight of 41.89 g per fruit. The variety Balanagar recorded the increased number of fruits per tree (250.36), yield/tree (22.79kg) and yield (6.15 tonnes/ha) followed by APK 1 showed number of fruits per tree (204.45), yield per tree (21.20 kg) and yield (5.72 tonnes/ha).

Ashrafi *et al.* (2023) studied morphological diversity in 103 wild pomegranates in the northeastern area of Iran was studied using 46 traits related to trees, flowers, and fruits. The results showed that the fruit weight ranged from 17.93 to 99.9 g with an average of 48.92 g, the total aril weight ranged from 0.54 g to 64.78 g with an average of 24.25 g, and the weight of 100 arils was between 4.89 and 46.21 with an average of 13.79.

Rakesh *et al.* (2023) reported that, alternate bearing habit is found in most of fruit crops like common olive, mango, apple, litchi, pistachio nut, avocado, citrus, pecan nut, plum and date palm.

2.4 Bio-chemical parameters

Liu (2000) observed the performance of African Pride cultivar of custard apple in China. The total sugar content was found to be 18.3 per cent.

Mathakar (2005) found the variation of TSS and acidity among twenty-four custard apple hybrids from 16.0 to 27.0 °Brix, 0.19 to 0.26 per cent and TSS-acidity ratio 70.2 to 163.2. He observed that the total sugar, reducing sugar and non-reducing sugar content in 24 hybrids of custard apple ranged from 14.75 to 24.35 per cent, 12.10 to 22.45 per cent and 1.65 to 2.95 per cent, respectively.

Prakash *et al.* (2010) observed wide range of variability in the physico-chemical composition of jamun fruit among investigated genotypes. The Selection-1 was observed most promising for higher total soluble solid (21.23%) and total sugar (20.24%).

Rao and Subramanyam (2011) evaluated thirty-five germplasm of custard apple and found maximum TSS in NLD-8 (25.9 °Brix), while minimum TSS observed in Bangalore (14.1 °Brix), respectively.

Shukla *et al.* (2010) studied the performance of different commercial varieties of aonla was assessed under hot arid condition viz., Krishna, Kanchan Chakaiya, NA-6 NA-7, NA-10 and Anand-1. There were significant variation with regards to yield, vitamin-c, juice content, TSS, dry matter and acidity in different cultivars.

Ghojage *et al.* (2011) conducted study to assess the variability of quality characters among best selected jamun genotypes from seedling trees. Among the chemical parameters the maximum TSS was recorded in the genotype KJS-3 (21.2 %), while strain KJS-29 recorded minimum TSS (21.2 %). The genotype KJS-17 registered the highest value for total sugar (18.43 %) while the lowest value in KJS-22 (8.24 %).

Girwani *et al.* (2011) conducted study on evaluation of custard apple hybrids for fruit yield and quality attributing characters. The TSS ranged from 22- 28°B and was found to be maximum in Hybrid -2 (Sithphal X Pondapple).

Kinley and Chinawat (2011) studied 30 accessions, which were selected from six districts in the major mandarin-growing regions in Bhutan for morphological characteristics. The highest TSS were found in the accessions from Trongsa (12.9 °Brix) followed by Zhemgang (12.1 °Brix), Dagana (11.2 °Brix), Sarpang (10.9 °Brix), Tsirang (10.6 °Brix) and Samtse (10.3 °Brix).

Hashmi and Pawar (2012) observed the collected custard apple fruits from different locations, possessing TSS 24.3°Brix, and acidity 0.23 to 0.28 per cent, whereas ascorbic acid content varies from 15.9 to 20.8 mg per 100 g of fruit pulp, respectively.

Prakash (2014) carried out survey to identify the elite genotypes among the natural population. Total soluble solids varied from 11.0 to 15.5 °B, titratable acidity 5.26 to 6.80 per cent and total sugars from 9.32 to 13.86 per cent.

Kumar (2015) conducted a study to evaluate custard apple genotypes for recipe standardization and he found that, among the four genotypes the ascorbic acid content varied from 34.16 to 38.36 mg per 100 g pulp, respectively.

Radunic *et al.* (2015) conducted experiment to evaluate physical and chemical properties of eight pomegranate accessions. Variables that define sweet taste, such as low total acidity (TA; 0.37– 0.59%), high total soluble solids content (TSS; 12.5– 15.0%) and their ratio (TSS/TA) were evaluated, and results generally aligned with sweetness classifications of the fruit. Pomegranate fruit had a high variability in total phenolic content (1985.6–2948.7 mg/L).

Santhoshkumar and Brindha (2015) screened the fresh leaves of soursop for its antioxidant and free radical scavenging potential. They observed that phenolics (104.43±0.013 mg/g), Vit C (1.98±0.011 mg/g) and total antioxidant capacity (TAC) with IC₅₀ values of 44.2474 µg/ml contents were found to be present.

Amanda *et al.* (2015) evaluated the soursop varieties Crioula, Lisa and Morada for the proximate composition, composition of fibers and components with antioxidant activity. The Lisa-M variety showed a higher level of phenolic compounds (284.25 mg gallic acid/100 g of soursop pulp), differing significantly ($p < 0.05$) from the Crioula- M soursop (154.67 mg gallic acid/100 g of soursop pulp).

Victoria *et al.* (2016) studied in vitro and in vivo antioxidant effects of *Annona muricata* seed extracts (n-hexane and ethanol extracts) using ascorbic acid as standard. Ethanol and n-hexane extracts at 100µg/ml and 20µg/ml, respectively, exhibited 49 per cent and 32 per cent inhibition of DPPH radical, respectively. Ascorbic acid (standard) exhibited upto 96.9 per cent inhibition of DPPH radical even at 20µg/ml.

Vijay *et al.* (2017) studied morphological, qualitative and quantitative characteristics of sixteen genotypes of jamun. The biochemical characteristics showed high variability among all the accessions of jamun. Maximum TSS was found in JJ-4 (21.25°Brix) and JJ-3 (19.85 °Brix). Acidity was highest (0.53%) in JJ-9 and ascorbic acid in JJ-15 (42.30 (mg/100 g).

Yadav *et al.* (2017) were made extensive survey for determining variability for physical and biochemical traits and find out the elite custard apple (*Annona squamosa* L.) genotypes. The chemical quality attributes varied significantly among different genotypes. TSS of pulp varied between 26.61–32.63 °Brix; acidity 0.20–0.30 per cent; ascorbic acid 18.25–38.24 mg; TSS/Acid ratio 88.70–174.72; total sugars 12.48–17.55 per cent.

Nag *et al.* (2018) evaluated 60 genotypes with the objectives of estimate the post-harvest and quality attributes traits. The highest value for quality parameters like total soluble solids (°brix), fruit yield per plant and pulp-seed ratio was observed in IGCA-21 genotype, total sugar per cent (IGCA-2), reducing sugar per cent (IGCA-3), non-reducing sugar per cent (IGCA-51), acidity per cent (IGCA-15), pulp ratio (IGCA-25) and peel per cent (IGCA-36).

Pooja *et al.* (2018) carried out investigation on evaluation and character association studies on yield and quality parameters of tamarind genotypes. The genotypes differed significantly with respect to total soluble solids (D-9: 22.76 °Brix), titrable acidity (S-8: 11.25%) and sugars content viz., reducing sugar (C-4: 34.06%), non-reducing sugar (D-9: 12.17%) and total sugar (C-4: 46.18%).

Priyanka *et al.* (2018) was conducted study in red laterite zone of West Bengal with the view to find out suitable custard apple cultivars for the zone. Significantly highest TSS was recorded from the cultivar Arka Sahan (24.8 °B) and minimum in Atemoya (11.4 °B). Acidity content in different cultivars was estimated from 0.11% (Balanagar) to 0.18% (Atemoya). Total sugar content was highest in Arka Sahan (22.4%) followed by Iceland Gem (19.3%).

Chandel *et al.* (2019) evaluated 18 genotypes of custard apple for physico-chemical aspects. The variation was observed for fruit chemical characters viz., TSS (20.19 to 25.22 °Brix), acidity (0.32 to 0.45%), ascorbic acid (32.4 to 37.8 mg/100 g pulp), total sugar (13.01 to 18.20%), reducing sugar (10.80 to 14.50%) and non-reducing sugar (2.10 to 3.70%).

Idate *et al.* (2019) undertaken survey in the area of Purander Tashil of Pune district. Ten elite selections were made, which were evaluated with check cultivar Balanagar. Quality attributes viz., TSS (23.56 °B), TSS: Acid ratio (71.40) and pulp (47.82 %) were found at its maximum in cv. Phule Purandar (JWC-1).

Hashim *et al.* (2020) evaluated antioxidant properties of soursop extracts by free radical scavenging activity against 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals comparing with standard ascorbic acid, quercetin, and catechin. Results indicated that methanolic extracts showed exceptionally higher radical scavenging activity compared with n-hexane crude extract with IC₅₀ 44.21 µg/mL and 302.41 µg/mL, respectively.

Gangappa *et al.* (2022) reported that Lucknow-49, Punjab Pink, *Psidium friedrichsthalianum*, and Shweta had the highest 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 µmol Trolox/g), respectively.

Rajadurai *et al.* (2022) conducted study in black vertisol region of Southern part of Tamil Nadu with the view to find out suitable custard apple cultivars for the region. Arka Sahan recorded significantly highest value for TSS (30.32 °Brix), followed by Balanagar (23.53 °Brix) and APK(Ca) 1 (23.10 °Brix). Minimum TSS content observed in Mammoth (20.67 °Brix). The TSS ranged from 20.67 to 30.32 °Brix among varieties.

2.5 Genetic variability

Genetic variability studies help the plant breeder to make an effective and efficient selection of genotypes from the available material which can be utilized for the further crop improvement programme. The success of any breeding programme mainly depends on the extent of genetic variability available in the population.

Genotypic coefficient of variation indicates the relative magnitude of genetic diversity present in the material and helps to compare the genetic variability of different characters.

The phenotype of any plant is influenced by the genotype, environment and the interaction between them. Further, the variation in segregating population is attributed by both heritable and non-heritable components and the variation in a pure line is by only environmental factors.

Heritability and genetic advance are the very important selection parameters. Heritability estimates provide the information on the degree of inheritance of characters from parent to progeny. Knowledge on the heritability of different characters in relation to their contribution towards yield is a pre-requisite for an efficient breeding programme. Genetic advance is another important genetic parameter for determining the amount of expected change that could occur due to selection.

Manohar *et al.* (1981) studied phenotypic and genotypic variability parameters in pomegranate. High genetic coefficient of variation was observed for per cent acidity, arils per fruit, fruit yield/tree. These characters also possessed high heritability as well as high genetic advance.

Mir *et al.* (2010) studied ten diverse genotypes of pomegranate grown in Karewa belts of Kashmir. The range of variability was high for plant height (cm), plant spread (cm), fruit weight (g), fruit volume (cm³) and number of seeds per fruit. Phenotypic coefficient of variation was higher than genotypic coefficient of variation for all the characters under test. High heritability and high magnitude of genetic advance was recorded for plant height (cm), fruit weight (g), number of seeds per fruit and fruit set per cent. Whereas, low heritability was recorded in ascorbic acid (mg/100ml) and number of fruits per plant.

Singh and Misra (2010) carried out genetic variability studies on eighteen bael genotypes. High values for GCV and PCV were observed for the fruit yield and fruit weight. High heritability along with high estimates of genetic advance (% of mean) was observed with fruit weight and fruit yield.

Singh *et al.* (2012) studied on morpho-chemical characters of anola which exhibited considerable genetic variability in fruit morphology. Highest phenotypic (9375.77) and genotypic (8773.12) variance was found in fruit weight. However, the lowest values (0.016 and 0.011) were found in fruit length and fruit diameter for genotypic and phenotypic variance, respectively. The heritability (broad sense) values were highest (0.99) for sugar content whereas, lowest (0.42) for fruit diameter. Genetic advance was found to be maximum (187850.27) for fruit weight and minimum (13.92) for fruit diameter. On the other hand, the highest genetic gain was for sugar (4655.58 %) and least (282.29 %) for moisture content in anola fruit crop.

Nayak *et al.* (2013) revealed that comparatively high degree of genotypic coefficients of variation (GCV) along with phenotypic coefficients of variation (PCV) was observed in quality traits like fruit weight and fruit volume of mango. High magnitude of broad-sense heritability was recorded in traits like fruit volume (0.82), ascorbic acid (0.83) and fruit length (0.70). Moderate degree of heritability was noted in traits, *viz.*, titratable acidity (0.58), fruit width (0.62), peel thickness (0.53) and total soluble solids (0.69). High heritability along with high genetic advance was estimated for fruit weight and fruit volume.

Rabha *et al.* (2013) studied on variability, heritability, genetic advance as per cent of mean in 32 citrus genotypes. The genotypes exhibited significant differences for all the characters under study. A wide range of variability in PCV and GCV was observed for fruit length, fruit breadth, fruit weight, rind weight, rind thickness, juice content, number of seed per fruit, seed weight, TSS, acidity, ascorbic acid, reducing sugar, total sugar and yield. High heritability and high genetic gain were observed for leaf lamina length, leaf lamina width, fruit length, fruit breadth, fruit weight, number of seeds per fruit, seed weight, TSS, acidity, ascorbic acid, reducing sugar, total sugar and yield.

Jambhale *et al.* (2014) were carried out study on the genetic variability, association among the yield component traits, their direct and indirect effects on the yield. High heritability with high genetic advance as per cent mean recorded for characters seeds per fruit (98.3, 148.75), pulp to seed ratio (79.70, 91.47), yield per plant (83.5, 37.64), fruit length (84.5, 34.04), fruits per plant (71.8, 24.18), fruit diameter and average fruit weight indicating that these traits are predominantly governed by additive gene action.

Gill and Navprem (2015) assessed the nature and genetic parameters to select superior genotypes of mango. The moderate estimates (>7.0%) of genotypic coefficient of variation (GCV) recorded for fruit yield/plant (11.70), fruit weight (7.18), pulp weight (8.73) and peel weight (9.69) signified the presence of adequate variation among the genotypes. Physical fruit attributes *viz.*, fruit yield/tree, fruit weight and pulp weight had substantially higher heritability coupled with high genetic advance and confirmed that these traits are under the control of additive gene action.

Gupta *et al.* (2015) were conducted experiment to estimate genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance (GA) from the data collected on 20 grape cultivars. The high estimates of GCV and PCV recorded for bunch weight, berry weight, bunch number and fruit yield per vine indicated the presence of adequate genetic variation among the genotypes and suitability of these traits for further improvement by selection. High heritability estimates coupled with high genetic

advances for these traits confirmed that these traits are under the control of additive gene action and phenotypic selection for their improvement will be effective.

Lal *et al.* (2016) studied genetic variability, correlation and path coefficient analysis for yield and yield contributing traits on 24 peach genotypes. Maximum variability recorded for TSS: acid ratio and fruit weight. However, low differences between the phenotypic and genotypic coefficients of variation indicated low environmental influence on the expression of these traits. High heritability coupled with high genetic advance was obtained with acidity, TSS: acid ratio, fruit weight and yield per plant.

Rao *et al.* (2016) studied on genetic variability in fifty genotypes of bael fruit. Results revealed that high values of GCV and PCV were observed for yield per tree, fruit pulp weight, fruit weight, seed weight, number of fruits per tree, ascorbic acid, skull weight, and reducing sugar. High heritability (in broad sense) along with high estimates of genetic advance (% of mean) was observed for almost all the characters *viz.*, yield per tree, fruit weight, fruit pulp weight, skull weight, seed weight per fruit, T.S.S., ascorbic acid and total sugar.

Marboh *et al.* (2018) observed wide range of variability for most characters studied. Phenotypic and genotypic coefficients of variation were high for pulp weight (32.86 and 31.11 %), seed weight (30.56 and 27.93 %) and fruit weight (22.65 and 21.17%), respectively. The heritability was more than 80 per cents for fruit yield (93.86%), fruit length (94.07 %), fruit weight (87.43 %), pulp weight (89.58%), pulp thickness (80.34 %), and seed weight (83.54 %).

Perveen *et al.* (2018) studied genetic variability in 23 diverse genotypes including four mutant lines of pomegranate revealed higher genetic variability for most of the biochemical and morphological traits studied. High magnitude of coefficient of variability (phenotypic and genotypic) was observed for fruit and aril traits characters like fruit weight, fruit volume and biochemical traits like titratable acidity, while low to moderate level of variation was observed in total soluble solids (TSS) and seed parameters like seed length and width. High heritability coupled with high magnitude of genetic advance was recorded for most of the characters *viz.* fruit weight, fruit volume and titratable acidity. Whereas, comparatively lower heritability accompanied by low genetic advance was exhibited by characters like TSS and fruit diameter.

Sridhar *et al.* (2018) carried out studies to assess the genetic variability, heritability and genetic advance for different characters in 16 diverse cultivars of mango. The high phenotypic coefficient of variation and genotypic coefficient of variation were observed for petiole length, fruit weight, pulp content, seed weight, reducing sugars, non-reducing sugars, titratable acidity, TSS: acid ratio, ascorbic acid

and yield. High heritability was recorded for majority of the characters viz., tree height (99.51), fruit diameter (94.53), fruit weight (91.81), fruit skin thickness (93.16), pulp content (99.07), seed weight (97.52), TSS (94.06), reducing sugars (93.61), ascorbic acid (94.88) and yield per plant (96.59).

Anita *et al.* (2019) conducted study to generate information on genetic variability using twelve custard apple genotypes. Higher phenotypic coefficient of variation is observed over genotypic coefficient of variation for all traits studied, indicating the performance of environment over genetic parameter. Higher GCV and PCV were observed for fruit weight, number of fruits per plant, yield per plant, total sugar and pulp weight. High heritability for stem girth, number of fruits per plant, pulp weight, fruit length, pulp: peel ratio and fruit width. High GAM was observed for yield per fruit, number of seeds per fruit and peel weight.

Gupta and Kour (2019) studied on genetic variability and heritability in guava, estimated the high GCV and PCV were recorded for fruit yield per plant, fruit weight, plant height, petiole size, acidity and number of seeds per fruit while low GCV and PCV were expressed by leaf length and fruit breadth. Heritability estimates revealed that all the characters under study ranged from 99.97 for leaf breadth to 61.99 for TSS. Genetic advance as per cent of mean varied from 15.13 (fruit breadth) to 70.73 (number of seeds per fruit). High heritability coupled with high genetic advance as per cent of mean was recorded for fruit yield, plant height, fruit weight, acidity and number of seeds per fruit.

Gangappa *et al.* (2022) conducted study on assessment of the genetic variability, diversity, and structure in a collection of 28 diverse germplasm lines of guava. The coefficient of variation values for the qualitative and quantitative traits varied from 23.5–72.36 to 1.39–58.62%, respectively.

2.6 Correlation studies

Inamdar (2000) observed that the fruit yield in jamun had significantly positive correlation with fruit volume, seed volume, fruit length, fruit breadth, seed length, pulp weight, pulp to seed ratio, pulp per cent, pulp thickness and fruit size, while it had negatively correlation with fruit weight and seed per cent, at Gilihosur in Karnataka.

Meena and Singh (2003) worked on correlation studies of twenty-four genotypes in pomegranate. The weight of the 100 arils, juice content, total soluble solids, total sugars and ascorbic acid content showed highly significant positive correlation with the average fruit weight and among themselves both at phenotypic and genotypic levels.

Mir *et al.* (2006) studied the association between different characters and magnitude of association of different characters with gross fruit yield (kg/plant) in ten cultivars of pomegranate including one local check. Data revealed that genotypic correlation coefficients were higher than their corresponding phenotypic ones for most of the characters, implying an inherent relationship among them. Fruit weight, fruit diameter, fruit volume, juice content, fruit set and number of fruits per plant exhibited highly significant positive correlation.

Sharma *et al.* (2006) assessed the character association among various quantitative traits of ten jackfruit genotypes in Faizabad. They observed that the genotypic correlation coefficients were higher than the phenotypic correlation coefficient in most of the characters. Fruit yield per tree showed significant and positive association at the phenotypic and genotypic level with fruit weight, which had highly significant positive association with fruit length, weight of bulbs with seed per fruit.

A study was undertaken by Islam *et al.* (2010) to analyze the correlation and path co-efficient for growth and fruit characters in twenty ber genotypes. Strong positive genotypic correlation was found between yield per plant and individual fruit weight (0.965), fruit length (0.737), fruit breadth (0.807) and pulp/stone ratio (0.574).

Saraswathy *et al.* (2010) evaluated of sapota genotypes collected from different parts of India. The studies revealed that there was a positive correlation between tree height and canopy spread. The attributes like number of fruits per tree and canopy spread had positive correlation with fruit yield per tree. The quality traits viz., total sugars and ascorbic acid content had negative correlation with fruit yield indicating that simultaneous improvement of yield and quality was not possible.

Vartika *et al.* (2012) carried out studies on correlation between different physico-chemical characters of fruits from the selected jamun genotypes. All genotypes showed highly significant positive correlation of pulp weight, fruit volume, pulp to seed ratio and titratable acidity with fruit weight. Seed per cent had highly significant but negative correlation with fruit weight.

Jambhale *et al.* (2014) studied genetic variability, association among the yield component traits, their direct and indirect effects on the yield. Yield per plant exhibited highly significant positive correlation with fruit cavity (0.88, 0.68), number of fruits per plant (0.87, 0.85), average fruit weight (0.77, 0.67) and pulp thickness (0.63, 0.54) at both genotypic and phenotypic levels respectively.

Gill and Navprem (2015) studied nature and genetic parameters to select superior genotypes of mango. Estimates of correlation co-efficient showed positive significant association of fruit yield per plant with fruit breadth (0.72) and fruit weight (0.66), while it was negatively associated with acidity (-0.076).

Krishna *et al.* (2017) revealed correlation studies in mango for different physical parameters. Among the physical parameters with the number of fruits per tree (0.756*) is positively correlated. Among the quality parameters the data showing that yield is positively correlate with total sugars (0.824*) and TSS: acidity ratio (0.853*) whereas negatively correlate with ascorbic acid (-0.939**).

Reeta (2017) reported that correlation studies in aonla, fruit weight shown significant positive correlation with fruit volume (0.996**), pulp thickness (0.932*), pulp weight (1.000**) and juice content (0.999**) but it was non significantly positive correlation with stone weight (0.357) and yield (0.73).

Pooja *et al.* (2018) carried out investigation on evaluation and character association studies on yield and quality parameters of tamarind genotypes. The results of correlation co-efficient analysis revealed that pod length (cm), pod width (cm), pod weight (g), pulp weight (g), titratable acidity, total sugar, total soluble solids and pH attributes shown positive association for higher yield.

Igbari *et al.* (2019) studied morphological characters of seven cultivars of mango collected from Ibadan Nigeria, which includes: leaf length and width, leaf apex, petiole length, fruit length and width, fruit colour and shape were assessed. The results of principal component analysis based on similarity matrix revealed correlation between leaf length and petiole length, fruit length, width and shape whereas fruit colour exhibited no correlation with any of the other parameters.

Gangappa *et al.* (2022) studied a total of 33 morpho-biochemical traits for assessment of the genetic variability, diversity, and structure in a collection of 28 diverse germplasm lines of guava. They reported that fruit weight was positively correlated with ascorbic acid content; however, titratable acidity was negatively correlated with fruit weight.

Jagruthi *et al.* (2022) studied eighteen annona genotypes related to growth, yield and fruit quality. The high magnitude of heritability and genetic advance as per cent mean was noted for most of the traits indicated presence of fixable genes and least influence of environment for inheritance. The results of the association analysis presented significant and positive association of fruit yield with growth and fruit morphology and fruit quality attributes at both genotypic and phenotypic levels.

Lal *et al.* (2022) studied forty peach genotypes for physico-chemical and yield attributes grown under temperate environment. Principal component analysis (PCA) revealed that first PC, which is the most important component, explained 39.8 per cent of total variation and was positively related to leaf length and leaf length: width ratio, leaf thickness, oil content (fresh and dry-weight basis), stone weight and yield.

2.7 Path co-efficient analysis

Path co-efficient analysis is a tool in genetic analysis for partitioning the association of the components on yield into direct and indirect effect of the characters through other components. The path co-efficient analysis was used to study the cause and effect relationship, diagrammatically.

Meena and Singh (2003) worked on path coefficient studies of twenty-four genotypes in pomegranate. The path coefficient analysis at genotypic level revealed that the total sugars had the maximum positive direct effect, while juice content showed the minimum positive indirect effect via seed content on average fruit weight. Whereas, the maximum negative direct effect on average fruit weight was noted for the seed content.

Mir *et al.* (2006) were carried experiment to find out association between different characters and magnitude of association of different characters with gross fruit yield (kg/plant) in ten cultivars of pomegranate including one local check. Among the characters studied, number of fruits per plant, fruit weight, fruit volume and fruit set recorded maximum positive direct effect towards gross fruit yield (kg/ plant) at both the levels.

Mir *et al.* (2009) conducted study to estimate the path coefficients of various qualitative and quantitative characters of 10 pomegranate cultivars. The genotypic path analysis showed that maximum direct effect was contributed by number of fruits per plant (0.772), which was followed by fruit volume (0.530) and fruit weight (0.271). Fruit diameter, plant height and juice content exhibited high negative direct effects (-0.895, -0.197 and -0.120, respectively). At the phenotypic level, the maximum positive effect came from number of fruits per plant (0.765), followed by fruit volume, fruit weight, rind thickness and rind weight. Fruit diameter revealed maximum direct negative effect (-0.750), followed by fruit set per cent, plant height and plant spread.

Majumder *et al.* (2012) studied sixty diverse genotypes direct and indirect effects through path coefficients analysis in mango as to estimate the contribution of most important characters towards yield. In genotypic path analysis, number of fruits per plant had the highest positive direct effect (0.899) on yield. Higher positive direct effects were also observed for the character fruit weight (0.324). Number of fruits per plant and fruit length showed negative direct effects towards yield.

Kumar *et al.* (2013) conducted an experiment on path analysis for nut and kernel characters of pecan nut. Path analysis revealed that nut yield efficiency (0.964) had highest positive direct effect on nut yield followed by kernel weight (0.226), kernel length (0.087), kernel height (0.039), fat content (0.035) and nut height (0.033). Kernel height (0.434) had a highest positive indirect effect on nut yield through nut yield

efficiency and protein content (-0.397) gave highest negative effect on nut yield via nut yield efficiency.

Jambhale *et al.* (2014) were carried out study on the genetic variability, association among the yield component traits, their direct and indirect effects on the yield. Number of fruits per plant had the highest direct effect (0.97) on yield per plant followed by average fruit weight (0.56), length of fruit (0.19) indicating importance of these characters and which can be strategically used to improve the yield of papaya.

Gill and Navprem (2015) estimated path analysis, which revealed that fruit weight (1.60) and fruit breadth (0.41) had moderately higher direct effects on fruit yield. Fruit weight showed indirect contribution via all the traits except fruit juice acid content signifying that fruit weight is the major contributor towards fruit yield per plant in mango.

Gupta *et al.* (2015) were conducted experiment to estimate correlations and path coefficients from the data collected on 20 grape cultivars. Fruit yield per vine showed significant positive association with bunch length, bunch width, bunch weight and bunch number while significant negative association of berry length, berry diameter and berry weight with acidity per cent indicated that improvement of these traits through selection will also improve quality of table grapes by reducing acidity. Number of bunches per vine had maximum direct effect on fruit yield per vine followed by bunch weight. Bunch length as well as bunch width contributed to fruit yield per vine indirectly via bunch weight.

Lal *et al.* (2016) studied on path coefficient analysis on peach, they revealed that fruit weight (0.9786) followed by TSS (0.299), fruit pulp thickness (0.211) and ascorbic acid (0.0028) influenced direct effect on fruit yield per tree. The direct effects of these traits on fruit yield were found positive and considerably high. Moreover, fruit length, fruit diameter had positive and higher indirect effect on fruit yield through fruit weight in peach.

Lal *et al.* (2017) conducted experiment to determine the genotypic and phenotypic correlation along with their direct and indirect effects through path coefficients analysis in mango. The result suggests that there were strong inherent relationship between the traits. The fruit weight ($r^2 = 0.236, 0.234$), fruit length ($r^2 = 0.371, 0.370$), fruit diameter ($r^2 = 0.393, 0.391$), fruit width (0.366, 0.361), titratable acidity ($r^2 = 0.273, 0.272$) and peel weight ($r^2 = 0.370, 0.365$) showed positive association with yield both at genotypic and phenotypic levels, respectively. At genotypic level, the highest positive direct effect was exhibited via fruit weight (5.74) followed by fruit diameter (0.259), titratable acidity (0.159), pulp: stone (0.143) and ascorbic acid (0.067) on yield.

Phenotypic path coefficient analysis on guava studied by Gupta and Kour (2019) revealed that positive direct effect on yield was exhibited by fruit length (1.950), acidity (0.328), leaf length (0.306), number of seeds per fruit (0.166) and very low magnitude with fruit weight (0.039), plant height (0.075) and petiole size (0.006) indicating good scope for improvement in fruit yield. Fruit length also showed indirect contribution *via* fruit weight (1.196) and fruit breadth (1.348).

Parmar *et al.* (2020) reported that the fruit weight had highest positive direct effect on fruit yield followed by number of fruits per tree. Positive direct effect on fruit yield was recorded for fruit length, chlorophyll content, acidity and plant height on sapota.

2.8 Genetic divergence

Ranjan *et al.* (2009) studied forty-two important cultivars for diversity in mango fruit characters. Using group constellation, cultivars were grouped into three distinct clusters. Cultivar with higher mean for weight of fruit and peel, fruit length, fruit width were grouped in cluster III and high pulp weight and TSS, weight were grouped in cluster II. Highest intra-cluster distance was observed in cluster I, while highest inter-cluster distance was between cluster I and II. Pulp weight contributed maximum towards the genetic divergence (34.03%) followed by peel weight (22.65%), TSS (10.22%) stone weight (7.90%) and width (5.46%).

Sharma *et al.* (2010) studied the nature and magnitude of genetic divergence of 216 bearing trees of persian walnut. All 216 walnut genotypes grouped into 10 clusters. Maximum mean nut weight, kernel weight and kernel per cent were recorded in clusters 2, 2 and 6 respectively, while the average minimum shell thickness was found in cluster 6. The genotypes of cluster 2 and 9 were found highly diverse from each other and will give better segregants after hybridization which can then be used as cultivar in the future.

Singh *et al.* (2011) studied nature and magnitude of genetic diversity was assessed in 170 wild raspberry genotypes based on eight quantitative characteristics. The non-hierarchical cluster analysis resulted in 12 clusters of genotypes. The cluster pattern did not exhibit any interrelation between geographical isolation and genetic diversity. Of the 170 genotypes, 31 fell in cluster XII, 27 in cluster V, 19 in cluster I, 17 in cluster IX, 16 in cluster VIII, 15 in cluster XI, 13 in cluster II, 12 in cluster VII, 10 in cluster III, six in cluster X, three in cluster VI and one genotype in cluster IV. Genotypes falling under clusters III, VI, VI can be used as parents in hybridization programmes for improving important traits like TSS, fruit weight and acidity respectively.

Jana *et al.* (2015) studied thirty-two guava cultivars for genetic divergence (Ward's minimum variance method) on the basis of growth and yield. Thirty-two germplasm were distributed into six clusters. Cluster II was largest having eleven genotypes and was nearest to cluster III (28.200) and farthest to cluster VI (82.786). The maximum inter cluster distance was between cluster IV and cluster VI (222.411). Cluster VI had high mean cluster value for fruit set per cent in rainy and winter seasons. Cluster V and cluster II had medium mean cluster value for the same character.

Igbari *et al.* (2019) studied morphological characters of seven cultivars of mango from Ibadan Nigeria, which includes: leaf length and width, leaf apex, petiole length, fruit length and width, fruit colour and shape were assessed. Cluster and dendrogram analysis based on farthest neighbour, mean character difference and constrained clustering strategy, revealed that mango cultivars are distinctively divided into two groups based on their fruit features: Cluster A comprises Julie, Edward, Palmer, and Kent whereas cluster B comprises Saigon, Madoe and Lipen.

Gangappa *et al.* (2022) studied a total of 33 morpho-biochemical traits for assessment of the genetic variability, diversity, and structure in a collection of 28 diverse germplasm lines of guava. The principal component analysis (PCA) was 84.2 per cent and 93.3 per cent for qualitative and quantitative traits, respectively. Furthermore, K-mean clustering was executed; the population was grouped into three clusters for both traits. Additionally, the dendrogram using agglomerative hierarchical clustering (AHC), where all the germplasm were grouped into four clusters, revealed that among the clusters, clusters III and IV were highly divergent.

Lal *et al.* (2022) studied forty peach genotypes for physico-chemical and yield attributes grown under temperate environment. The maximum standard deviation was observed for fruit weight, followed by firmness index, fruit width and least for fruit shape index and titratable acidity. The cluster analysis classified genotypes into two major groups. The first group possessed superior attributes in terms of highest fruit length, weight, width and diameter, while second group had maximum fruit weight, TSS, titratable acidity and highest yield.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The present investigation on “Evaluation of *Annona muricata* L. genotypes for growth, yield and quality attributes” was carried out in Muddinakoppa village of Shivamogga District during September, 2022 to July, 2023 with an objective to evaluate 50 different genotypes for different morphological and qualitative characters. The bio-chemical analysis of different characters was carried out at the College of Horticulture, Mudigere. The details of materials and method for investigation and statistical procedures followed are outlined in this chapter.

3.1 Geographical location and weather condition of the Experimental site

The place of collection of 50 genotypes was Kalpataru Nursery, Muddinakoppa, Shivamogga district which is located about 11 km from Shivamogga district. It is located between 13° 58' N latitude and 75° 29' E longitude with an elevation of 646 m above mean sea level. The meteorological data on monthly average maximum and minimum temperature, relative humidity and rainfall during the experimental period was presented in Appendix I.

3.2 Experimental details

The present investigation was carried out using 50 genotypes of *Annona muricata*. The experiment comprised of two sub experiments. The experiment no. 1 is based on morphological characterization of all 50 genotypes. Among 50 genotypes, 34 elite fruiting genotypes were subjected to experiment no 2. (Assessment of fruit and quality parameters) (Plate 1).

1. Location : Farmer’s Field, Muddinakoppa, Shivamogga Taluk.
2. Number of genotypes : 50 Genotypes (Seedling origin)
3. Age of the genotypes : 8 Years

3.3 Observation recorded:

Individual trees were taken for the purpose of recording observations on various parameters of growth, yield and quality. The mean value of the data was worked out for the purpose of statistical computation. The details of observation recorded for various parameters like tree, foliage, fruit and biochemical analysis in the experiment and their techniques adopted for recording the observations were described below.

3.4 Methods adopted for recording observations

3.4.1 Tree parameters

The selected plants were measured for tree height, stem girth and plant growth habit.

3.4.1.1 Tree height (m)

The tree height of the different genotypes measured using Ravi altimeter. It is a portable instrument for measuring the height of trees without the trigonometric tables and formulas required for determination of Abney's level. It consists of four scales viz, 20 m, 30 m, red scale for slope correction and per cent scale. For the measurement of tree 20 m scale is used. The observer must stand about 20 m of horizontal distance from tree to get height of the tree above the eye level directly. Since, the scales are in units, the height of the tree is indicated in the same unit in which the horizontal distance is taken. The height can be read through a longitudinal window in the metal case, which is covered by glass. The instrument has a pistol grip. A lever, on one side of instrument releases a button below the index finger and locks the movement of the pointer on the scales. While releasing the lever, the instrument is pointed to the tip of the tree through the eye-view and the target. The button is pressed when the eye, the target and the tip of the tree are in line. The button should be pressed when the movement of the pointer stops.

$$\text{Tree height (m)} = \text{Top reading} + \text{Base reading}$$

3.4.1.2 Stem girth (cm)

The girth of the tree trunk was measured by using a measuring tape and reading was expressed in terms of centimeters.

3.4.1.3 Growth habit

Tree growth habit was recorded visually based on guidelines by Protection of Plant Varieties and Farmer's Rights Authority (PPV & FRA) in custard apple. It was observed that there were two types of plant growth habits: erect and spreading.

3.4.2 Leaf characters

3.4.2.1 Leaf length (cm)

The leaf length was measured from the base of the petiole to the tip of the terminal leaflet by the standard measuring scale and expressed in centimeters and classified into short (<10 cm), medium (10-15 cm) and long (>15 cm).

3.4.2.2 Leaf breadth (cm)

The leaf breadth was measured at the widest part of the leaf by a standard measuring scale and expressed in centimeters.

3.4.2.3 Colour of matured leaf

Leaf colour of the genotypes were identified with the help of colour chart of Royal Horticultural Society and recorded.



Plate1. General view of the experimental plot

3.4.2.4 Leaf shape

The leaf shape was recorded visually based on guidelines by Protection of Plant Varieties and Farmer's Rights Authority (PPV & FRA) in custard apple. It was observed that there were four types of leaf shape: ovate, obovate, lanceolate and elliptic.

3.4.2.5 Leaf apex shape

The leaf apex shape was recorded visually based on guidelines by Protection of Plant Varieties and Farmer's Rights Authority (PPV & FRA) in custard apple. It was observed that there were 3 types of leaf apex shapes: acute, acuminate and rounded.

3.4.2.6 Leaf base shape

The leaf base shape was recorded visually based on guidelines by Protection of Plant Varieties and Farmer's Rights Authority (PPV & FRA) in custard apple. It was observed that there were three types of leaf apex shapes: acute, obtuse and rounded.

3.4.2.7 Leaf margin

The leaf margin was recorded visually means and classified as,

- a) Entire
- b) Undulate

3.4.2.8 Petiole length(cm)

The petiole length is measured by a standard measuring scale and expressed in centimeters and classified into short (<1.5 cm) and long (>1.5 cm).

3.4.2.9 Chlorophyll content(mg/g)

Chlorophyll content of leaf was analyzed by collecting the healthy, fully matured leaves from tree at peak growth stage. Chlorophyll 'a', Chlorophyll 'b' and total chlorophyll content of leaf tissue were determined by using dimethyl sulfoxide (DMSO) method as suggested by Shoaf and Lium (1976). Fresh leaf tissue (100 mg) was cut in to small pieces and incubated in 10 ml of dimethyl sulfoxide in dark for 24 hours. Later the absorbance of the extract was measured at 645 nm and 663 nm using DMSO as blank in spectrophotometer (Model- VISISCAN-167).

The chlorophyll 'a', chlorophyll 'b' and total chlorophyll, contents were calculated by using the formulae given below and expressed in mg per g fresh weight.

$$\text{Chlorophyll} - a = 12.7(A_{663}) - 2.69(A_{645}) \times \frac{V}{1000 \times W \times a}$$

$$\text{Chlorophyll} - b = 22.9(A_{645}) - 4.68(A_{663}) \times \frac{V}{1000 \times W \times a}$$

$$\text{Total chlorophyll} = 20.2 (A_{645}) + 8.02 (A_{663}) \times \frac{V}{1000 \times W \times a}$$

Where,

A= Absorbance at specific wave lengths (645 nm and 663 nm)

V= Final volume of the extract (10 ml)

W= Fresh weight of the sample (100 mg)

a = Path length of the light (1 cm)

3.4.3 Yield parameters

3.4.3.1 Fruit length (cm)

After harvest, length of the individual fruit was measured with help of a standard measuring scale and the mean was worked out and expressed in centimeters.

3.4.3.2 Fruit width (cm)

The width of the individual fruit was measured with the help of standard measuring scale and the mean was worked out and expressed in centimeters.

3.4.3.3 Fruit weight (g)

Fruit weight was recorded by weighing fresh fruit on electronic weighing balance and average fruit weight was calculated and represented in grams.

3.4.3.4 Fruit volume (cm³)

Volume of the fruits of various genotypes were recorded using water displacement method.

3.4.3.5 Pulp weight (g)

Pulp of the single fruit was extracted and weighed using an electronic weighing balance of different genotypes. The average was worked out and expressed in grams.

3.4.3.6 Pericarp thickness (mm)

The pericarp thickness of the individual fruit was measured with the help of a vernier scale and the mean was worked out and expressed in millimeters.

3.4.3.7 Number of seeds per fruit

Seeds extracted from the individual fresh fruit were counted and expressed in number.

3.4.3.8 Seed weight per fruit (g)

The seeds which were extracted from the individual fresh fruits were weighed in an electronic weighing balance and expressed in grams.

3.4.3.9 Number of fruits per plant

The number of fruits produced per tree were counted and recorded in numbers.

3.4.3.10 Fruit yield per tree (kg)

The fruit yield per tree was recorded at different intervals of harvest and expressed in kilograms.

3.4.3.11 Fruit yield per hectare (ton)

The fruit yield per tree was recorded randomly from the tress and it was expressed in yield (ton) per hectare.

3.4.4 Biochemical parameters

3.4.4.1 Total soluble solids (° Brix)

The Total Soluble Solids (TSS) in sample were recorded by using ATAGO digital refractometer ranges from 0 to 93 °Brix. Take sample and crushed with mortar and pestle a then extract the juice, this juice placed in refractometer that gives value in °Brix.

3.4.4.2 Titratable acidity (%)

The acidity content of different samples was estimated (Ranganna, 1986). A clear homogenized juice was taken in 100 ml conical flask. One to two drops of phenolphthalein indicator were added to it. Then the diluted sample was titrated against 0.1N sodium hydroxide solution taken in a burette. The end point of titration was indicated by a faint pink colour. Titration was continued till three current readings were obtained. Percentage of acidity was calculated by using the formulae with the obtained titrated values. The acidity percentage of the juice in terms of citric acid was calculated adopting the following formula and expressed in percentage (%).

$$\text{Titratable acidity (\%)} = \frac{\text{Titer value} \times \text{N of Alkali} \times \text{Eq. wt. of acid} \times \text{Volume Made up}}{\text{Weight of samples} \times \text{Aliquot taken for estimation} \times 1000}$$

Note: Meq of citric acid = 0.06404

3.4.4.3 Reducing sugars (%)

Reducing sugars present in the samples were estimated by DNSA (3,5-dinitrosalicylic acid) reagent method and are expressed in percentage. The clean and dried test tubes were taken to which 0.2, 0.4, 0.6, 0.8 and 1ml of prepared standard glucose was added. This was made up to 1ml using distilled water and 1ml of DNSA reagent was added. The test tubes were closed with aluminium foil and were kept in boiling water bath for minutes. The test tubes were cooled and 4 ml of distilled water was added. The test tubes were vortexed and O.D measured at 540 nm. Similarly test tubes with 0.25 ml of prepared sample were taken and volume made up to 1 ml of DNSA reagent was added to the test tubes. These test tubes were kept for 10 minutes and cooled test tubes and O.D was measured at 540 nm. The amount of reducing sugar present in the sample was calculated using standard graph (Ranganna, 1986).

$$\text{Reducing sugars (\%)} = \frac{\text{Glucose (mg) in sample from standard curve}}{\text{Aliquot taken for test (ml)}} \times \frac{\text{Vol. made (ml) after alcohol evaporation}}{\text{Vol. taken for alcohol evaporation (ml)}} \times \frac{\text{Vol. made (ml) after sample extraction}}{\text{Sample taken for extraction (mg)}} \times 100$$

3.4.4.4. Total sugars (%)

Total sugars present in the samples were estimated by Anthrone reagent method and are expressed in percentage. Sample aliquot (1.0 ml) was pipetted out at different concentrations (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 ml) of standard glucose solution in different test tubes and volume made up to 2.5 ml each with distilled water and all the tubes are kept in an ice bath, and 5 ml of anthrone reagent was added slowly and the contents were stirred gently with a glass rod. Then the contents were heated on boiling water bath exactly for 7.5 minutes and cooled immediately in ice bath. After cooling, the absorbance of the solutions was measured at 630 nm against the blank. Then the sugar content was calculated through standard glucose curve (Ranganna, 1986).

$$\text{Total sugars (\%)} = \frac{\text{Glucose (mg) in a sample from standard curve}}{\text{Aliquot taken (ml) for test}} \times \frac{\text{Vol. made after hydrolysis (ml)}}{\text{Vol. taken for alcohol hydrolysis (ml)}} \times \frac{\text{Vol. made after alcohol evaporation (ml)}}{\text{Vol. taken for evaporation (ml)}} \times \frac{\text{Vol. made after sample extraction (ml)}}{\text{sample taken for extraction (ml)}} \times 100$$

3.4.4.5 Non-reducing sugars (%)

Non-reducing sugars is estimated by subtracting the reducing sugar from total sugar content of the sample.

$$\text{Non-reducing sugars (\%)} = \text{Total sugars} - \text{Reducing sugars}$$

3.4.4.6 TSS: Acid

The ratio of total soluble solids and acidity content of the genotypes were calculated and recorded.

3.4.4.7 Sugar: Acid

The ratio of total sugars and acidity content of the genotypes were calculated and recorded.

3.4.4.8 Ascorbic acid (mg/100g)

Presence of amount of ascorbic acid in different genotypes was estimated based on the procedure discussed by Ranganna (1986). About 5 ml of sample filtrate was taken which is diluted with the 4 per cent oxalic acid and made up to 100 ml using distilled water. Pipette out 5 ml of the supernatant, for this add about 10 ml of 4 per cent oxalic acid and titrated against the dye.

Preparation of solutions:

- Four per cent Oxalic acid: About 4 g of oxalic acid was dissolved in little quantity of water and final volume made to 100 ml using distilled water.
- Standard stock solution: Dissolve 100 mg ascorbic acid in 100 ml of 4 per cent oxalic acid solution in standard flask (1 mg / ml).
- Working standard solution: Dilute about 10 ml of stock solution with 4 per cent oxalic acid. The concentration of working standard solution is 100 µg per ml.
- Dye solution: Dissolve about 50 mg of sodium salt of 2, 6-dichlorophenol indophenols in approximately 150 ml of hot distilled water containing about 42 mg of sodium bicarbonate. Later cool and dilute with distilled water to 200 ml. Store in a refrigerator and standardize every day.
- Standardization of dye: Take about 5 ml of working standard ascorbic acid solution and 10 ml of 4 per cent oxalic acid in a 25 ml conical flask. Fill a micro burette with dye. Later titrate the solution in the conical flask against the dye solution till the solution in the flask turns to pink which persists for 15 seconds. Determine the dye factor ie., mg of ascorbic acid per ml of the dye using formulae;

$$Dye\ factor = \frac{0.5}{Titre\ value}$$

$$Ascorbic\ acid\ (mg/100g) = \frac{Titre\ value \times Dye\ factor \times Vol.\ make\ up\ (ml)}{Aliquot\ taken\ for\ estimation \times Vol.\ of\ sample\ taken} \times 100$$

3.4.4.9 Antioxidant activity (%)

Scavenging activity (DPPH) assay

The free radical scavenging activities of the extracts were determined by using 2, 2- Diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging method. A fresh 0.002 per cent solution of DPPH was prepared in methanol and its absorbance was recorded at 515 nm. 50 µl of pure extracts was mixed with 3 ml solution of DPPH and allowed to stand in darkness for 15 minutes. The absorbance was again recorded at 515 nm. The control was prepared as above without sample solution, the scavenging activity was estimated based on the percentage of DPPH radical scavenged, and the scavenging effect (%) was calculated by the following equation (Maizura *et al.*, 2011).

Scavenging effect %

$$= \frac{(\text{Absorbance of control} - \text{Absorbance of sample})}{(\text{Absorbance of control})} \times 100$$

3.4.4.10 Total phenolic acid (mg GAE/g dry weight)

The total phenolic content of all plant extract was determined by using the Folin-ciocalteu reagent (Sadasivam and Manikam, 1991). One milliliter of extract solution was added to a flask containing 9 ml of distilled water. The extract solution was thoroughly mixed with 1 ml of Folin-ciocalteu's phenol reagent. After 5 min, 10ml of 7 per cent Na₂CO₃ was added. The mixture was further shaken and made up to 25 ml with the addition of 4ml of distilled water. Then, the absorbance was measured at 750 nm after 90 min of incubation at room temperature using a spectrophotometer. The total phenolic content was expressed as mg of gallic acid equivalents (mg GAE/g) dry matter.

$$\text{Polyphenolic content (mg GAE/g)} = c \frac{V}{m}$$

Where,

c = Concentrations of gallic acid obtained from calibration curve in mg/ml

V= Volume of extract in ml

m = Mass of extract in gram.

3.4.5 Statistical analysis

The statistical analysis was done by one sample Z-test for morphological characterization, whereas for fruit and quality parameters, fruits were replicated thrice by using a Randomized Complete Block Design (RCBD). The details of the statistical procedure adopted for analysis of the data recorded on *A. muricata* genotypes to get

an idea of the nature of variation, magnitude of variation, the association of characters and direct and indirect effects of characters on fruit yield are presented below.

3.4.5.1 Estimation of genetic variability parameters

The variability for different quantitative and qualitative traits in *A. muricata* was estimated as detailed below.

Variance due to genotype, phenotype, and environment were computed as follows.

- a. Genotypic variance (σ^2_g) = $\frac{\text{Treatment MSS} - \text{Error MSS}}{r}$
- b. Environmental variance (σ^2_e) = Error mean sum of squares
- c. Phenotypic variance (σ^2_p) = $\sigma^2_g + \sigma^2_e$

Where, 'r' is the number of replications.

3.4.5.2 Phenotypic and genotypic coefficient of variation

Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for all the characters were calculated according to the formula provided by Burton and Devane (1953).

- a. Phenotypic coefficient of variation (PCV %) = $\frac{\sigma^2_p}{\bar{X}} \times 100$
- b. Genotypic coefficient of variation (GCV %) = $\frac{\sigma^2_g}{\bar{X}} \times 100$

Where,

σ^2_p = Phenotypic variance

σ^2_g = Genotypic variance

$\bar{X}$ = Mean

PCV and GCV were classified as shown below following the method suggested by Robinson *et al.* (1949)

0-10 % = Low

>10-20 % = Moderate

>20 % = High

3.4.5.3 Heritability (h^2 broad sense)

Broad-sense heritability was estimated for all the traits using the following formula of Johnson *et al.* (1955).

$$h^2 (\%) = \frac{\sigma^2_g}{\sigma^2_p}$$

Where,

h^2 (b) = Heritability (broad sense) expressed in per cent

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

The heritability percentage was categorized as low, moderate and high as suggested by Robinson *et al.* (1949) and is given below.

0-30 % = Low

>30-60 % = Moderate

>60 % = High

3.4.5.4 Genetic advance (GA)

The extent of genetic advance was estimated by using the following formula of Johnson *et al.* (1955).

$$GA = h^2 \times K \times \sigma_p$$

Where,

h^2 = Heritability estimate

K = Selection differential at given intensity (which is equal to 2.06 at 5 per cent intensity of selection)

σ_p = Phenotypic standard deviation

3.4.5.5 Genetic advance as per cent over mean (GAM)

Genetic advance as per cent over mean was assessed by using the following formula.

$$\text{Genetic advance as per cent over mean} = \frac{GA}{\text{Grand Mean}} \times 100$$

Genetic advance as per cent over mean was grouped into low, moderate and high as given below as suggested by Johnson *et al.* (1955).

0 to 10 % = Low

>10 to 20 % = Moderate

>20 % = High

3.4.5.6 Correlation coefficient analysis

The correlation coefficient among all possible character combinations at phenotypic (rp) and genotypic (rg) level were estimated employing formula (Al-Jibouri *et al.*, 1958).

$$r_p(xy) = \frac{Cov_p(xy)}{\sqrt{\sigma_p^2(x) \times \sigma_p^2(y)}}$$

$$r_g(xy) = \frac{Cov_g(xy)}{\sqrt{\sigma_g^2(x) \times \sigma_g^2(y)}}$$

Where,

$r_p(xy)$ = Phenotypic correlation coefficient between characters 'x' and 'y'

$r_g(xy)$ = Genotypic correlation coefficient between characters 'x' and 'y'

$Cov_p(xy)$ = Phenotypic covariance of character 'x' and 'y'

$Cov_g(xy)$ = Genotypic covariance of character 'x' and 'y'

$\sigma_p^2(x)$ = Phenotypic variance of character 'x'

$\sigma_p^2(y)$ = Phenotypic variance of character 'y'

$\sigma_g^2(x)$ = Genotypic variance of character 'x'

$\sigma_g^2(y)$ = Genotypic variance of character 'y'

The test of significance for the association between characters was done by comparing table 'r' values at (n-2) error degrees of freedom for phenotypic and genotypic correlations with estimated values, respectively.

3.4.5.7 Path coefficient analysis

Path coefficient analysis was carried out in advanced breeding lines using the simple correlation coefficient to know the direct and indirect effects of the yield components as suggested by Wright (1921) and illustrated by Dewey and Lu (1959).

Path coefficients were obtained by solving simultaneous equations, which express the basic relationship between correlations and path coefficients.

The equations were as follows:

$$P_{01} + P_{01} r_{12} + \dots + P_{op} r_{1p} = r_{01}$$

$$P_{02} r_{12} + P_{02} + \dots + P_{op} r_{2p} = r_{02}$$

$$P_{02} R_{iop} + P_{02} r_{2p} + \dots + P_{op} = r_{op}$$

Where,

$P_{01}, P_{02}, \dots, P_{0p}$ = Direct path coefficients of variables 1, 2, ... P on the independent variable 0.

$r_{12}, r_{13}, r_{ip}, \dots, r_p$ (P-1) = Possible correlation coefficients between independent variables.

$r_{01}, r_{02}, \dots, r_{0p}$ = The correlation between dependent and independent variables.

3.4.7.8 Genetic diversity using D^2 statistical analysis

The genetic diversity among thirty-four genotypes of *Annona muricata* L. was assessed by using D^2 Mahalanobis statistics (Mahalanobis, 1936). The grouping of accessions was done using Tocher's method, as described by Rao (1952). The steps involved in the analysis are:

- a) Test of significance of difference by Wilk's static for aggregate traits.
- b) Transformation of correlated variables

In terms of variance and covariances, the D^2 value was obtained by,

$$D^2 = w_{ij} (x_{i1} - x_{i2}) (x_{j1} - x_{j2})$$

Where w_{ij} is the estimate of variance and covariance matrix.

Transformation was done by pivotal condensation method. Transformation of correlated variables into uncorrelated variables was done by substituting these values of x_1, x_2, x_3 and x_4 in the transformed equation and the corresponding transformed values y_1, y_2, y_3 and y_4 were obtained (original mean to transformed data).

- c) Computation of D^2 values

For each combination of population, the mean of deviation for the characters was computed and the D^2 was calculated as the sum of the squares of these deviations.

$$\text{i.e., } D^2 = \sum (y_{i1} - y_{i2})^2$$

Where, $i = 1, 2, 3, \dots, p$ characters.

- d) Test of significance of D^2 values

The significance of D^2 values for a pair of population was tested against the table values of χ^2 for p degree of freedom. Where p = Total number of characters

- e) Grouping into clusters

The method suggested by Tocher (Rao, 1952) was followed for cluster

formation. The genotypes were arranged in the order of their relative distance from each other. The values were arranged in ascending order of magnitude in each column. Two genotypes having smallest distance from each other were considered first to which a genotype having smallest average D^2 value from the first two genotypes was added. If at any stage, the average D^2 of a group appeared to be high from those already included, it was considered that the group does not fit with the former cluster and hence taken outside the first cluster and second cluster was formed. This process was continued and clusters were formed.

(i) Estimation of average intra cluster distances

The average of the distances of all possible combinations of genotypes included in a cluster was calculated.

(ii) Estimation of average inter cluster distances

This was calculated by measuring the distances between various combinations of clusters divided by the product of the number of genotypes in the concerned cluster combinations. The clusters were taken one by one and their distance from each other was calculated.

i.e., Average inter cluster distance between cluster i and j = $\frac{\sum D_{ij}^2}{n_i \times n_j}$

n_i = Number of genotypes in cluster i

n_j = Number of genotypes in cluster j

f) Contribution of individual characters towards divergence

In all the combinations, each character was ranked on the basis of $(y_{i1} - y_{i2})$. Rank one was given to the highest mean difference and the rank 'p' to the lowest mean difference where 'p' is the total number of characters. The number of times appearing first in ranking for each character was counted and the per cent contribution was calculated taking the total number of combinations as hundred.

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

The data pertaining with respect to 50 genotypes of *Annona muricata* L. on various morphological and bio-chemical characters revealed various interesting facts, which are described in this chapter using appropriate tables and figures under following headings.

- 4.1 Morphological traits of the tree
- 4.2 Morphological traits of the tree foliage
- 4.3 Fruit and yield parameters
- 4.4 Biochemical parameters
- 4.5 Genetic variability studies
- 4.6 Correlation studies
- 4.7 Path co-efficient analysis
- 4.8 Genetic divergence studies

Experiment No. 1. Morphological characterization of *Annona muricata* L. genotypes

4.1 Morphological traits of the tree

4.1.1 Tree height(m)

The data pertaining to tree height had showed greater difference during the experimental period, which is presented in Table 1. Tree height was found maximum within a range of 5.10-5.50 m in one genotype *i.e.*, PKN-03 (5.12 m) followed by 16 genotypes with a range of 4.60-5.00 m. The minimum tree height was observed within a range of 2.10-2.50 m in two genotypes *viz.*, PKN-22 (2.42 m) and PKN-44 (2.44 m).

4.1.2 Stem girth(cm)

The genotypes showed wide variation in stem girth (Table 2). The highest stem girth was recorded within a range of 66-70 cm in PKN-16 (70.00 cm) followed by PKN-20 (62.00 cm). The lowest stem girth was recorded within a range of 21-25 cm in two genotypes *viz.*, PKN-44 (22.80 cm) and PKN-22 (24.50 cm).

4.1.3 Growth habit

During experimental period, plant growth habit exhibited greater variation among the genotypes. Spreading growth habit was observed in maximum number of genotypes of 46. Whereas, erect growth habit was observed in only 4 genotypes *viz.*, PKN-14, PKN-09, PKN-34 and PKN-42 which is furnished in Table 3.

Table 1. Frequency distribution of tree height in different genotypes of *Annona muricata* L.

Tree height (m) (Range)	Frequency (Number of genotypes)
2.10 - 2.50	2
2.60 - 3.00	4
3.10 -3.50	5
3.60 -4.00	9
4.10 -4.50	14
4.60 -5.00	16
5.10 -5.50	1
Total	N = 50

Table 2. Frequency distribution of stem girth in different genotypes of *Annona muricata* L.

Stem girth (cm) (Range)	Frequency (Number of genotypes)
21-25	2
26-30	3
31-35	4
36-40	2
41-45	5
46-50	13
51-55	14
56-60	5
61-65	1
66-70	1
Total	N = 50

Table 3. Variation in growth habit of *Annona muricata* L. genotypes

Growth habit	
Spreading	Erect
46	4

4.2 Morphological traits of the tree foliage

4.2.1 Leaf length (cm)

Among the genotypes studied, leaf length showed significant difference which is illustrated in Table 4. Maximum leaf length was observed in PKN-05 (16.60 cm) followed by PKN-16 (16.57 cm) and minimum leaf length was observed in PKN-41 (10.63 cm).

4.2.2 Leaf breadth (cm)

Genotypes had shown a wide variation for leaf breadth which is presented in Table 4. Maximum leaf breadth was observed in PKN-20 (6.60 cm) followed by PKN-16 (6.43 cm) whereas, minimum value for leaf breadth was observed in PKN-22 (4.10 cm) which were significantly different from other genotypes.

4.2.3 Colour of matured leaf

The genotypes exhibited only green colour leaves in all the genotypes, no variation was observed which is furnished in Table 5.

4.2.4 Leaf shape

The genotypes produced different types of leaf shape during experimental period. Maximum genotypes (31) had shown lanceolate leaf shape and ovate leaf shape was observed in 19 genotypes which is represented in Table 5 (Plate 2).

4.2.5 Leaf apex shape

Representation of variation in leaf apex shape among *A. muricata* genotypes is illustrated in Table 5. Acuminate leaf apex shape was observed maximum in 39 genotypes whereas, rounded leaf apex shape was observed minimum in 11 genotypes (Plate 3).

4.2.6 Leaf base shape

The genotypes did not shown any variation in trait leaf base shape. All the genotypes had acute leaf base shape which is represented in Table 5.

4.2.7 Leaf margin

Variations in leaf margin (entire to undulate) among the genotypes was recorded. All the genotypes exhibited entire leaf margin (Table 5).

4.2.8 Petiole length (cm)

The data pertaining to petiole length showed a significant variation among the genotypes. Longer petiole length (0.9 cm) was observed in PKN-28 genotype whereas, shorter petiole length (0.5 cm) was observed in PKN-09, PKN-30, PKN-37 and PKN-43 genotypes (Table 6).

Table 4. Variation in leaf characters and chlorophyll content of *Annona muricata* L. genotypes

Sl. no.	Genotypes	Leaf length (cm)	Leaf breadth (cm)	Petiole length (cm)	Chlorophyll 'a' (mg/g)	Chlorophyll 'b' (mg/g)	Total-chlorophyll (mg/g)
01.	PKN-01	12.07	4.57	0.63	1.99	0.83	2.82
02.	PKN-02	14.80	5.40	0.73	1.87	0.79	2.66
03.	PKN-03	13.60	5.20	0.60	1.65	0.58	2.23
04.	PKN-04	14.50	5.33	0.80	1.74	0.65	2.39
05.	PKN-05	16.60	5.87	0.70	1.82	0.74	2.56
06.	PKN-06	15.00	5.50	0.80	1.62	0.58	2.20
07.	PKN-07	13.37	4.37	0.70	1.73	0.67	2.40
08.	PKN-08	12.43	4.13	0.60	1.89	0.73	2.62
09.	PKN-09	12.87	4.43	0.50	1.83	0.71	2.54
10.	PKN-10	13.40	4.50	0.60	1.65	0.59	2.24
11.	PKN-11	13.00	4.73	0.70	1.68	0.61	2.29
12.	PKN-12	10.73	6.00	0.70	1.79	0.68	2.47
13.	PKN-13	15.80	4.60	0.60	1.64	0.57	2.21
14.	PKN-14	13.70	5.77	0.70	1.98	0.83	2.81
15.	PKN-15	13.20	5.57	0.70	1.85	0.76	2.61
16.	PKN-16	16.57	6.43	0.60	1.79	0.66	2.45
17.	PKN-17	11.60	4.93	0.60	1.63	0.52	2.15
18.	PKN-18	11.77	4.67	0.60	1.73	0.61	2.34
19.	PKN-19	14.43	5.63	0.70	1.83	0.75	2.58
20.	PKN-20	16.20	6.60	0.70	1.61	0.59	2.20
21.	PKN-21	11.73	4.87	0.80	1.97	0.82	2.79
22.	PKN-22	10.70	4.10	0.53	1.24	0.35	1.59
23.	PKN-23	13.20	5.73	0.60	1.73	0.64	2.37
24.	PKN-24	13.70	5.60	0.70	1.83	0.76	2.59
25.	PKN-25	15.00	6.10	0.80	1.92	0.82	2.74
	SD	1.648	0.639	0.099	0.191	0.132	0.322
	CV	0.125	0.123	0.145	0.113	0.211	0.139

Continued.....



Ovate leaf



Lanceolate leaf

Plate 2. Variation in leaf shape of *Annona muricata* L. genotypes



Rounded leaf apex



Acuminate leaf apex

Plate 3. Variation in leaf apex shape of *Annona muricata* L. genotypes

Sl. no	Genotypes	Leaf length (cm)	Leaf breadth (cm)	Petiole length (cm)	Chlorophyll 'a' (mg/g)	Chlorophyll 'b' (mg/g)	Total-chlorophyll (mg/g)
26	PKN-26	11.40	4.53	0.80	1.98	0.81	2.79
27	PKN-27	14.90	5.63	0.70	1.86	0.78	2.64
28	PKN-28	14.00	5.77	0.90	1.73	0.62	2.35
29	PKN-29	13.07	4.97	0.60	1.87	0.73	2.60
30	PKN-30	13.97	4.77	0.50	1.69	0.59	2.28
31	PKN-31	14.20	5.57	0.80	1.71	0.62	2.33
32	PKN-32	12.60	4.67	0.80	1.79	0.69	2.48
33	PKN-33	12.17	5.00	0.70	1.82	0.72	2.54
34	PKN-34	14.53	5.93	0.70	1.68	0.58	2.26
35	PKN-35	13.70	5.53	0.80	1.72	0.65	2.37
36	PKN-36	12.70	4.87	0.60	1.69	0.61	2.30
37	PKN-37	15.50	6.03	0.50	1.71	0.68	2.39
38	PKN-38	11.30	4.51	0.70	1.21	0.32	1.53
39	PKN-39	14.30	5.53	0.80	1.62	0.56	2.18
40	PKN-40	11.70	4.80	0.57	1.25	0.33	1.58
41	PKN-41	10.63	5.10	0.53	1.28	0.36	1.64
42	PKN-42	14.20	5.30	0.80	1.57	0.49	2.06
43	PKN-43	14.20	5.67	0.50	1.61	0.54	2.15
44	PKN-44	11.20	3.30	0.70	1.20	0.31	1.51
45	PKN-45	10.77	5.40	0.80	1.73	0.65	2.38
46	PKN-46	11.40	5.50	0.70	1.54	0.49	2.03
47	PKN-47	11.03	4.70	0.70	1.58	0.52	2.10
48	PKN-48	10.80	5.20	0.80	1.62	0.61	2.23
49	PKN-49	11.53	4.90	0.70	1.59	0.58	2.17
50	PKN-50	11.27	5.40	0.60	1.62	0.65	2.27
	SD	1.648	0.639	0.099	0.191	0.132	0.322
	CV	0.125	0.123	0.145	0.113	0.211	0.139

*PKN- Prasanna Kalpataru Nursery

Table 5. Variation in leaf parameters of *Annona muricata* L. genotypes

Sl. no	Genotypes	Leaf shape	Leaf apex shape	Leaf base shape	Leaf margin	Colour of matured leaf
01.	PKN-01	Lanceolate	Acute	Acute	Entire	Green group
02.	PKN-02	Lanceolate	Acute	Acute	Entire	Green group
03.	PKN-03	Lanceolate	Acute	Acute	Entire	Green group
04.	PKN-04	Lanceolate	Rounded	Acute	Entire	Green group
05.	PKN-05	Lanceolate	Acute	Acute	Entire	Green group
06.	PKN-06	Lanceolate	Acute	Acute	Entire	Green group
07.	PKN-07	Lanceolate	Rounded	Acute	Entire	Green group
08.	PKN-08	Lanceolate	Acute	Acute	Entire	Green group
09.	PKN-09	Lanceolate	Acute	Acute	Entire	Green group
10.	PKN-10	Lanceolate	Acute	Acute	Entire	Green group
11.	PKN-11	Lanceolate	Rounded	Acute	Entire	Green group
12.	PKN-12	Lanceolate	Acute	Acute	Entire	Green group
13.	PKN-13	Lanceolate	Acute	Acute	Entire	Green group
14.	PKN-14	Ovate	Rounded	Acute	Entire	Green group
15.	PKN-15	Ovate	Acute	Acute	Entire	Green group
16.	PKN-16	Lanceolate	Acute	Acute	Entire	Green group
17.	PKN-17	Lanceolate	Acute	Acute	Entire	Green group
18.	PKN-18	Lanceolate	Acute	Acute	Entire	Green group
19.	PKN-19	Ovate	Acute	Acute	Entire	Green group
20.	PKN-20	Lanceolate	Acute	Acute	Entire	Green group
21.	PKN-21	Lanceolate	Acute	Acute	Entire	Green group
22.	PKN-22	Ovate	Acute	Acute	Entire	Green group
23.	PKN-23	Ovate	Rounded	Acute	Entire	Green group
24.	PKN-24	Ovate	Acute	Acute	Entire	Green group
25.	PKN-25	Lanceolate	Acute	Acute	Entire	Green group

Continued.....

Sl. no	Genotypes	Leaf shape	Leaf apex shape	Leaf base shape	Leaf margin	Colour of matured leaf
26.	PKN-26	Lanceolate	Acute	Acute	Entire	Green group
27.	PKN-27	Ovate	Acute	Acute	Entire	Green group
28.	PKN-28	Ovate	Acute	Acute	Entire	Green group
29.	PKN-29	Lanceolate	Acute	Acute	Entire	Green group
30.	PKN-30	Lanceolate	Rounded	Acute	Entire	Green group
31.	PKN-31	Ovate	Acute	Acute	Entire	Green group
32.	PKN-32	Lanceolate	Acute	Acute	Entire	Green group
33.	PKN-33	Lanceolate	Acute	Acute	Entire	Green group
34.	PKN-34	Ovate	Acute	Acute	Entire	Green group
35.	PKN-35	Lanceolate	Acute	Acute	Entire	Green group
36.	PKN-36	Lanceolate	Acute	Acute	Entire	Green group
37.	PKN-37	Ovate	Rounded	Acute	Entire	Green group
38.	PKN-38	Lanceolate	Acute	Acute	Entire	Green group
39.	PKN-39	Ovate	Acute	Acute	Entire	Green group
40.	PKN-40	Lanceolate	Acute	Acute	Entire	Green group
41.	PKN-41	Lanceolate	Acute	Acute	Entire	Green group
42.	PKN-42	Ovate	Rounded	Acute	Entire	Green group
43.	PKN-43	Ovate	Acute	Acute	Entire	Green group
44.	PKN-44	Ovate	Rounded	Acute	Entire	Green group
45.	PKN-45	Ovate	Rounded	Acute	Entire	Green group
46.	PKN-46	Ovate	Rounded	Acute	Entire	Green group
47.	PKN-47	Lanceolate	Acute	Acute	Entire	Green group
48.	PKN-48	Ovate	Acute	Acute	Entire	Green group
49.	PKN-49	Ovate	Acute	Acute	Entire	Green group
50.	PKN-50	Lanceolate	Acute	Acute	Entire	Green group

4.2.9 Chlorophyll content(mg/g)

4.2.9.1 Chlorophyll 'a' (mg/g)

The genotypes shown wide variation in chlorophyll 'a' content. The maximum value for chlorophyll 'a' was found in PKN-01 (1.99 mg/g) followed by PKN-14 (1.98 mg/g) and PKN-26 (1.98 mg/g) whereas, minimum value for chlorophyll 'a' content was found in PKN-44 (1.20 mg/g) (Table 4).

4.2.9.2 Chlorophyll 'b' (mg/g)

The greater variation was observed in chlorophyll 'b' content of the genotypes. The maximum chlorophyll 'b' was found in PKN-01 and PKN-14 (0.83 mg/g) followed by PKN-21 and PKN-25 (0.82 mg/g). However, minimum chlorophyll 'b' content was found in PKN-44 (0.31 mg/g) (Table 4).

4.2.9.3 Total chlorophyll (mg/g)

The genotypes shown wide range of variation in total chlorophyll content. The maximum value for total chlorophyll was found in PKN-01 (2.82 mg/g) followed by PKN-14 (2.81 mg/g), PKN-21 and PKN-26 (2.79 mg/g, respectively). The minimum value for total chlorophyll content was found in PKN-44 (1.51 mg/g) (Table 4).

Experiment No. 2. Assessment of fruit yield and biochemical parameters of *Annona muricata* L. genotypes

4.3 Fruit and yield parameters

Analysis of variance for different fruit and quality parameters is depicted in Table 6.

4.3.1 Fruit length (cm)

Fruit length of *Annona muricata* L. genotypes had shown significant variation which is enumerated in Table 7. Maximum length of fruit (29.10 cm) was observed in genotype PKN-25 which was statistically on par with PKN-20 (28.80 cm), PKN-30 (27.73 cm) and PKN-16 (26.47 cm). Whereas, minimum length of fruit was observed in genotype PKN-47 (13.60 cm) (Plate 4).

4.3.2 Fruit width (cm)

Significant difference in fruit width was recorded among the genotypes. Maximum fruit width was observed in genotype PKN-25 (16.40 cm) which was statistically on par with PKN-20 (15.90 cm). However, minimum was observed in genotype PKN-32 (10.07 cm) which is represented in Table 7 (Plate 5).

4.3.3 Fruit weight (g)

Fruit weight had shown significant variation and presented in Table 7. Maximum fruit weight was observed in PKN-25 (2352.92 g) which was statistically on par with PKN-20 (2302.14 g). However, minimum fruit weight was observed in PKN-37 (1035.34 g).

Table 6. Analysis of variance for yield and quality parameters of *Annona muricata* L. genotypes

Sl. No.	Source	Mean Sum of Squares (MSS)		
		Replication	Treatment	Error
	Degrees of freedom	2	33	66
1	Fruit length (cm)	1.731	60.605**	2.029
2	Fruit width (cm)	1.051	6.84**	0.67
3	Fruit weight (g)	1318.548	386357.687**	1818.974
4	Fruit volume (cc)	840.296	387604.698**	1577.568
5	Pericarp thickness (mm)	0.027	0.159**	0.018
6	Pulp weight (g)	5531.748	222775.255**	5238.989
7	Number of seeds per fruit	18.471	857.369**	67.501
8	Seed weight per fruit (g)	3.74	173.617**	13.669
9	TSS(°B)	0.494	1.222**	0.171
10	Titrateable acidity (%)	0	0.046**	0.001
11	Reducing sugars (%)	0.009	0.93**	0.045
12	Non-reducing sugars (%)	0.002	0.626**	0.004
13	Total sugars (%)	0.15	1.601**	0.067
14	TSS: Acid	0.155	28.929**	0.343
15	Sugar: Acid	0.124	15.276**	0.113
16	Ascorbic acid (mg/100 g)	0.266	11.19**	0.237
17	Antioxidant activity (%)	2.872	5.56*	3.44
18	Total phenolic content (mg GAE/100g dry weight)	7.062	55.767**	7.818

* Significant at 5 per cent

** Significant at 1 per cent

Table 7. Variation in fruit parameters of *Annona muricata* L. genotypes

Sl. no	Genotypes	Fruit length(cm)	Fruit width(cm)	Fruit weight(g)	Fruit volume(cc)
01.	PKN-01	18.00	12.50	1723.46	1469.37
02.	PKN-02	25.57	13.60	1937.88	1979.57
03.	PKN-03	25.60	13.40	1968.97	1753.98
04.	PKN-04	20.63	12.80	1794.25	1616.82
05.	PKN-05	22.57	13.03	1916.83	1852.27
06.	PKN-06	21.07	10.87	1885.26	1768.22
07.	PKN-07	19.40	10.50	1643.09	1547.96
08.	PKN-08	15.60	14.40	1540.22	1333.57
09.	PKN-09	19.43	12.40	1583.24	1341.44
10.	PKN-10	17.33	13.90	1364.25	1466.66
11.	PKN-11	18.80	13.20	1546.29	1553.72
12.	PKN-12	16.50	12.50	1577.59	1485.13
13.	PKN-13	18.20	13.00	1285.90	1098.12
14.	PKN-14	25.67	13.27	2106.85	1966.80
15.	PKN-15	20.90	12.07	1849.51	1816.54
16.	PKN-16	26.47	14.30	2241.04	2059.64
17.	PKN-17	15.80	12.30	1307.55	1174.81
18.	PKN-18	14.20	13.70	1310.17	1242.90
19.	PKN-20	28.80	15.90	2302.14	2251.72
20.	PKN-21	20.67	11.40	1787.63	1793.05
21.	PKN-23	18.80	11.60	1430.53	1689.90
22.	PKN-24	23.07	12.40	1961.29	1724.61
23.	PKN-25	29.10	16.40	2352.92	2262.46
24.	PKN-26	19.60	14.90	1751.49	1885.32
25.	PKN-27	14.67	12.27	1295.49	1301.62
26.	PKN-28	19.40	12.20	1628.21	1707.93
27.	PKN-29	16.40	12.77	1713.54	1782.88
28.	PKN-30	27.73	10.80	1116.65	996.67
29.	PKN-31	15.50	11.56	1204.29	1011.42
30.	PKN-32	15.57	10.07	1265.49	1258.30
31.	PKN-34	14.27	12.17	1246.91	1342.32
32.	PKN-37	15.50	10.36	1035.34	987.30
33.	PKN-39	15.80	13.80	1241.52	1022.24
34.	PKN-47	13.60	10.23	1094.94	1149.73
	S.Em±	0.82	0.47	24.62	22.93
	CD @ 5%	2.32	1.33	69.53	64.75



Ovoid fruit



Elongated fruit



Irregular fruit



Heart-shaped fruit

Plate 4. Variations observed in fruit shape of *Annona muricata* L. genotypes



Plate 5. Variation in fruit parameters of *Annona muricata* L. genotypes

4.3.4 Fruit volume (cc)

The result showed significant difference in fruit volume. Among the genotypes studied, fruit volume was observed highest in genotype PKN-25 (2262.46 cc) which was statistically on par with PKN-20 (2251.72 cc) and lowest was observed in genotype PKN-37 (987.30 cc) which is presented in Table 7.

4.3.5 Pulp weight (g)

Pulp weight had shown significant variation in the genotypes which is illustrated in Table 8. Higher pulp weight was observed in genotype PKN-25 (1624.40 g) followed by PKN-20 (1555.19 g) and PKN-16 (1553.06 g). The lowest pulp weight (572.30 g) was observed in genotype PKN-39.

4.3.6 Pericarp thickness (mm)

During experimental period, pericarp thickness was observed maximum in PKN-17 (3.10 mm) which was significantly on par with PKN-03, PKN-12, PKN-28 (3.00 mm, respectively) and PKN-21 (2.90 mm). However, minimum was observed in genotype PKN-26 (2.20 mm) and PKN-31 (2.20 mm). The variations in pericarp thickness among the genotypes is documented in Table 8.

4.3.7 Number of seeds per fruit

The data showed significant variation on number of seeds per fruit (Plate 6). Maximum number of seeds per fruit was produced in genotype PKN-34 (99.33) which was statistically on par with PKN-37 (96.33) and PKN-47 (86.67). Whereas, minimum number of seeds per fruit was observed in genotype PKN-25 (40.67) (Table 8).

4.3.8 Seed weight per fruit (g)

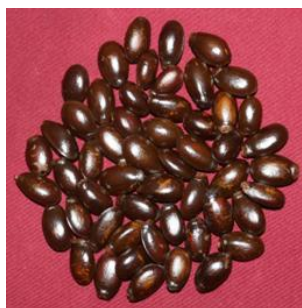
The genotypes showed significant difference on seed weight per fruit which is presented in Table 8. Maximum seed weight per fruit was observed in PKN-34 (44.70 g) which was statistically on par with PKN-37 (43.35) and PKN-47 (39.00). However, minimum seed weight per fruit was observed in PKN-25 (18.30 g).

4.3.9 Number of fruits per tree

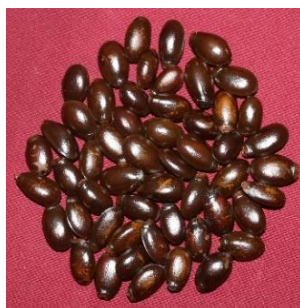
The number of fruits per tree showed significant differences during the experimental period. PKN-25 genotype produced highest number of fruits per tree (34), which was statistically on par with PKN-08, PKN-11, PKN-20, PKN-28, PKN-34 and PKN-47 (33). However, lowest number of fruits per tree was observed in PKN-27 (26) (Table 9).

Table 8. Variation in fruit and seed parameters of *Annona muricata* L. genotypes

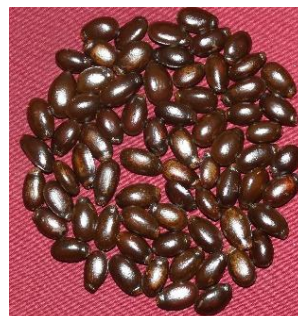
Sl. no	Genotypes	Pulp weight(g)	Pericarp thickness(mm)	No. of seeds/fruit	Seed weight/fruit (g)
01.	PKN-01	841.48	2.40	53.00	23.85
02.	PKN-02	979.89	2.50	47.33	21.30
03.	PKN-03	942.72	3.00	44.67	20.10
04.	PKN-04	934.87	2.60	52.00	23.40
05.	PKN-05	1334.98	2.40	45.33	20.40
06.	PKN-06	952.62	2.60	46.00	20.70
07.	PKN-07	1000.28	2.70	55.67	25.05
08.	PKN-08	953.21	2.40	64.33	28.95
09.	PKN-09	889.45	2.90	63.67	28.65
10.	PKN-10	845.12	2.40	67.00	30.15
11.	PKN-11	965.02	2.80	64.00	28.80
12.	PKN-12	814.27	3.00	74.33	33.45
13.	PKN-13	766.71	2.70	76.00	34.20
14.	PKN-14	1503.95	2.60	44.33	19.95
15.	PKN-15	985.18	2.70	45.33	20.40
16.	PKN-16	1553.06	2.60	44.67	20.10
17.	PKN-17	758.61	3.10	67.67	30.45
18.	PKN-18	725.21	2.40	76.33	34.35
19.	PKN-20	1555.19	2.80	41.00	18.45
20.	PKN-21	1258.74	2.90	52.67	23.70
21.	PKN-23	1043.76	2.80	78.33	35.25
22.	PKN-24	947.96	2.60	46.33	20.85
23.	PKN-25	1624.40	2.70	40.67	18.30
24.	PKN-26	986.74	2.20	52.67	23.70
25.	PKN-27	781.10	2.50	76.67	34.50
26.	PKN-28	912.42	3.00	55.33	24.90
27.	PKN-29	1128.91	2.50	54.00	24.30
28.	PKN-30	692.02	2.40	66.00	29.70
29.	PKN-31	688.15	2.20	85.67	38.55
30.	PKN-32	863.20	2.50	85.67	38.55
31.	PKN-34	797.25	2.80	99.33	44.70
32.	PKN-37	625.08	2.60	96.33	43.35
33.	PKN-39	572.30	2.80	83.00	37.35
34.	PKN-47	686.88	2.40	86.67	39.00
	S.Em±	11.5	0.08	4.74	2.13
	CD @ 5%	31.21	0.22	13.39	6.03



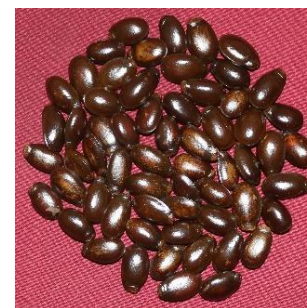
PKN-01



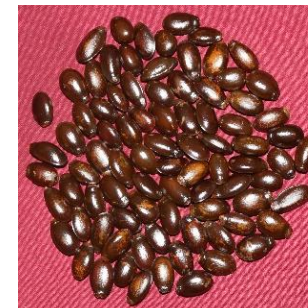
PKN-09



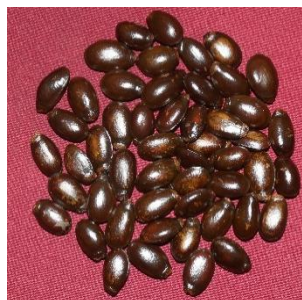
PKN-17



PKN-11



PKN-34



PKN-04



PKN-03



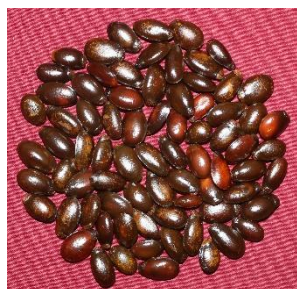
PKN-20



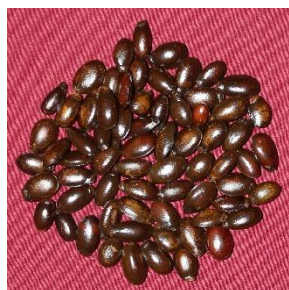
PKN-02



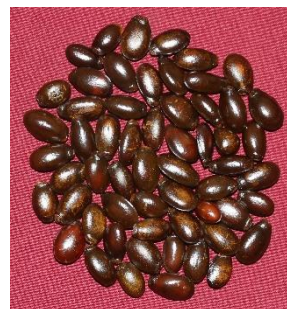
PKN-25



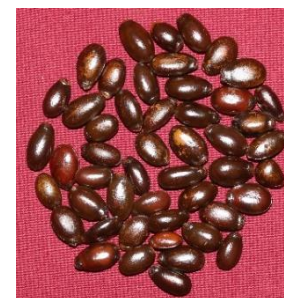
PKN-37



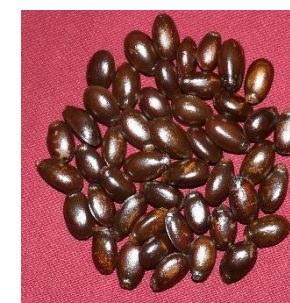
PKN-12



PKN-30



PKN-15



PKN-26

Plate 6. Variation in number of seeds per fruit of *Annona muricata* L. genotypes

4.3.10 Fruit yield per tree (kg)

Fruit yield per tree had shown significant difference among genotypes which is presented in Table 9. The results revealed that, significantly maximum fruit yield per tree was observed in PKN-25 (80.00 kg) and it was followed by PKN-20 (75.97 kg) whereas, minimum was observed in PKN-30 (31.27 kg).

4.3.11 Fruit yield (t/ha)

Significant differences were observed in genotypes with respect to fruit yield per hectare (Table 9). Among the genotypes studied, significantly higher yield/ha was recorded in PKN-25 (22.24 t/ha), which was followed by PKN-20 (21.12 t/ha). However, it was observed minimum in PKN-30 (8.69 t/ha).

4.4 Biochemical parameters

4.4.1 Total soluble solids (°B)

Significant differences were observed in total soluble solids among *A. muricata* genotypes which is furnished in Table 10. Highest total soluble solids were observed in PKN-24 (18.23 °B) which was statistically on par with PKN-26 (18.20 °B), PKN-05 (18.12 °B), PKN-03 (18.10 °B), PKN-06 (18.10 °B), PKN-15 (18.10 °B), PKN-16 (18.10 °B), PKN-02 (17.97 °B), PKN-14 (17.96 °B), PKN-20 (17.76 °B), PKN-04 (17.70 °B), PKN-07 (17.60 °B) and PKN-29 (17.60 °B). However, least was recorded in PKN-12 (16.30 °B).

4.4.2 Titratable acidity (%)

Significant variation was observed in titratable acidity content of fruits which is presented in Table 10. Titratable acidity was observed maximum in PKN-39 (1.25%) followed by PKN-32 (1.23%) and minimum titratable acidity was recorded in PKN-24 (0.74%).

4.4.3 Reducing sugars (%)

The *Annona muricata* L. genotypes had shown significant difference on reducing sugars in fruits. Highest content of reducing sugars were observed in PKN-03 (8.87 %) followed by PKN-29 (8.79 %) which was statistically on par with PKN-04 (8.61 %), PKN-13 (8.61 %) and PKN-28 (8.54 %) genotypes. Whereas, lowest content of reducing sugars were observed in PKN-47 (6.79 %) (Table 10).

4.4.4 Non-reducing sugars (%)

The non-reducing sugars content in fruits showed greater difference in genotypes. Highest content of non-reducing sugars were observed in PKN-20 (3.79 %) which was statistically on par PKN-15 (3.76 %) followed by PKN-02 (3.72 %) and lowest content was observed in PKN-29 (2.14 %) genotype (Table 10).

Table 9. Variation in yield parameters of different *Annona muricata* L. genotypes

Sl. no	Genotypes	Number of fruits per tree	Fruit yield/tree (kg)	Fruit yield/ha (Tonnes)
01.	PKN-01	30.00	51.70	14.37
02.	PKN-02	27.00	52.32	14.55
03.	PKN-03	28.00	55.13	15.33
04.	PKN-04	30.00	53.83	14.96
05.	PKN-05	27.00	51.75	14.39
06.	PKN-06	32.00	60.33	16.77
07.	PKN-07	32.00	52.58	14.62
08.	PKN-08	33.00	50.83	14.13
09.	PKN-09	32.00	50.66	14.08
10.	PKN-10	28.00	38.20	10.62
11.	PKN-11	33.00	51.03	14.19
12.	PKN-12	32.00	50.48	14.03
13.	PKN-13	27.00	34.72	9.65
14.	PKN-14	32.00	67.42	18.74
15.	PKN-15	29.00	53.64	14.91
16.	PKN-16	29.00	64.99	18.07
17.	PKN-17	27.00	35.30	9.81
18.	PKN-18	32.00	41.93	11.66
19.	PKN-20	33.00	75.97	21.12
20.	PKN-21	31.00	55.42	15.41
21.	PKN-23	26.00	37.19	10.34
22.	PKN-24	32.00	62.76	17.45
23.	PKN-25	34.00	80.00	22.24
24.	PKN-26	28.00	49.04	13.63
25.	PKN-27	26.00	33.68	9.36
26.	PKN-28	33.00	53.73	14.94
27.	PKN-29	32.00	54.83	15.24
28.	PKN-30	28.00	31.27	8.69
29.	PKN-31	31.00	37.33	10.38
30.	PKN-32	32.00	40.50	11.26
31.	PKN-34	33.00	41.15	11.44
32.	PKN-37	31.00	32.10	8.92
33.	PKN-39	32.00	39.73	11.04
34.	PKN-47	33.00	36.13	10.04
	SD	2.379	11.983	3.331
	CV	0.078	0.243	0.243

Table 10. Bio-chemical parameters of different *Annona muricata* L. genotypes

Sl. no	Genotypes	TSS(°B)	Titrateable acidity (%)	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)	TSS: acid	Sugar: acid
01.	PKN-01	16.80	0.99	7.61	3.02	10.63	16.97	10.74
02.	PKN-02	17.97	0.86	8.22	3.72	11.94	20.90	13.88
03.	PKN-03	18.10	0.78	8.87	2.74	11.61	23.21	14.88
04.	PKN-04	17.70	0.82	8.61	2.91	11.52	21.59	14.05
05.	PKN-05	18.12	0.77	8.48	2.87	11.35	23.53	14.74
06.	PKN-06	18.10	0.75	8.28	2.97	11.25	24.13	15.00
07.	PKN-07	17.60	0.92	8.11	2.82	10.93	19.13	11.88
08.	PKN-08	16.50	0.96	8.09	2.71	10.80	17.19	11.25
09.	PKN-09	17.30	0.87	7.91	3.05	10.96	19.89	12.60
10.	PKN-10	16.60	0.96	7.07	3.32	10.39	17.29	10.82
11.	PKN-11	16.50	0.92	8.43	2.39	10.82	17.93	11.76
12.	PKN-12	16.30	0.96	8.19	2.42	10.61	16.98	11.05
13.	PKN-13	17.20	0.85	8.61	2.22	10.83	20.24	12.74
14.	PKN-14	17.96	0.83	7.96	3.46	11.42	21.64	13.76
15.	PKN-15	18.10	0.75	8.14	3.76	11.90	24.13	15.87
16.	PKN-16	18.10	0.77	8.32	3.32	11.64	23.51	15.12
17.	PKN-17	16.81	0.97	8.23	2.75	10.98	17.33	11.32
18.	PKN-18	16.80	0.95	7.87	2.68	10.55	17.68	11.11
19.	PKN-20	17.76	0.85	7.56	3.79	11.35	20.89	13.35
20.	PKN-21	17.40	0.85	8.37	2.78	11.15	20.47	13.12
21.	PKN-23	16.80	0.94	7.46	2.18	9.64	17.87	10.26
22.	PKN-24	18.23	0.74	8.46	3.51	11.97	24.64	16.18
23.	PKN-25	17.43	0.76	8.12	3.12	11.24	22.93	14.79
24.	PKN-26	18.20	0.75	8.48	3.35	11.83	24.27	15.77
25.	PKN-27	16.40	1.09	7.48	2.89	10.37	15.05	9.51
26.	PKN-28	17.43	0.87	8.54	2.65	11.19	20.03	12.86
27.	PKN-29	17.60	0.84	8.79	2.14	10.93	20.95	13.01
28.	PKN-30	16.50	0.99	7.43	2.21	9.64	16.67	9.74
29.	PKN-31	17.30	0.96	7.36	3.12	10.48	18.02	10.92
30.	PKN-32	16.70	1.23	7.02	2.35	9.37	13.58	7.62
31.	PKN-34	16.50	0.94	7.24	3.01	10.25	17.55	10.90
32.	PKN-37	17.20	0.87	7.67	2.65	10.32	19.77	11.86
33.	PKN-39	16.60	1.25	7.08	2.68	9.76	13.28	7.81
34.	PKN-47	16.70	1.00	6.79	2.53	9.32	16.70	9.32
	S.Em±	0.24	0.02	0.12	0.04	0.15	0.34	0.19
	CD @ 5%	0.67	0.04	0.35	0.11	0.42	0.95	0.55

4.4.5 Total sugars (%)

The results showed significant variation on total sugars which is presented in Table 10. The highest total sugars content were observed in PKN-24 (11.97 %) which was statistically on par with PKN-02 (11.94 %), PKN-15 (11.90 %), PKN-26 (11.83 %), PKN-16 (11.64 %) and PKN-03 (11.61 %). Genotype PKN-47 (9.32 %) recorded lowest total sugars content.

4.4.6 TSS: acid

Total soluble solids (TSS) to acid ratio was observed maximum in PKN-24 (24.64) followed by genotype PKN-26 (24.27) which was statistically on par with PKN-06 (24.13), PKN-15 (24.13), PKN-05 (23.53), PKN-16 (23.51) and PKN-03 (23.21). It was observed minimum in genotype PKN-39 (13.28) according to the results furnished in Table 10.

4.4.7 Sugar: acid

Variation in ratio of sugar and acid content was found significantly maximum in PKN-24 (16.18) which was statistically on par with the genotype PKN-15 (15.87) and PKN-26 (15.77). However, it was observed minimum in PKN-39 (7.81) which is represented in Table 10.

4.4.8 Ascorbic acid (mg/100g)

Significant variations were observed in ascorbic acid content among the genotypes. Maximum ascorbic acid content of 22.68 mg/100 g fruit pulp was recorded in PKN-02 genotype followed by PKN-26 (22.63 mg/100 g of fruit pulp) which were statistically on par with the PKN-20 (22.05 mg/100 g of fruit pulp) and PKN-14 (21.91 mg/100 g of fruit pulp). Whereas, minimum was recorded in PKN-37 genotype (16.12 mg/100 g of fruit pulp) which is furnished in Fig. 1.

4.4.9 Antioxidant activity (%)

The data pertaining to antioxidant activity of fruits showed significant differences during experimental period, which is furnished in Fig. 2. Significantly highest antioxidant activity was observed in PKN-03 (70.13 %) followed by PKN-21 (70.02 %) and lowest was observed in PKN-31, PKN-37 and PKN-47 (65.38 %, respectively) genotypes.

4.4.10 Total phenolic content (mg GAE/g dry weight)

The genotypes showed significant difference on total phenolic content which is illustrated in Fig. 3. The highest total phenolic content of pulp was recorded in PKN-02 and PKN-24 (126.48 mg GAE/g dry weight) which was statistically on par with PKN-26 (126.07 mg GAE/g dry weight), PKN-20 (124.55 mg GAE/g dry weight),

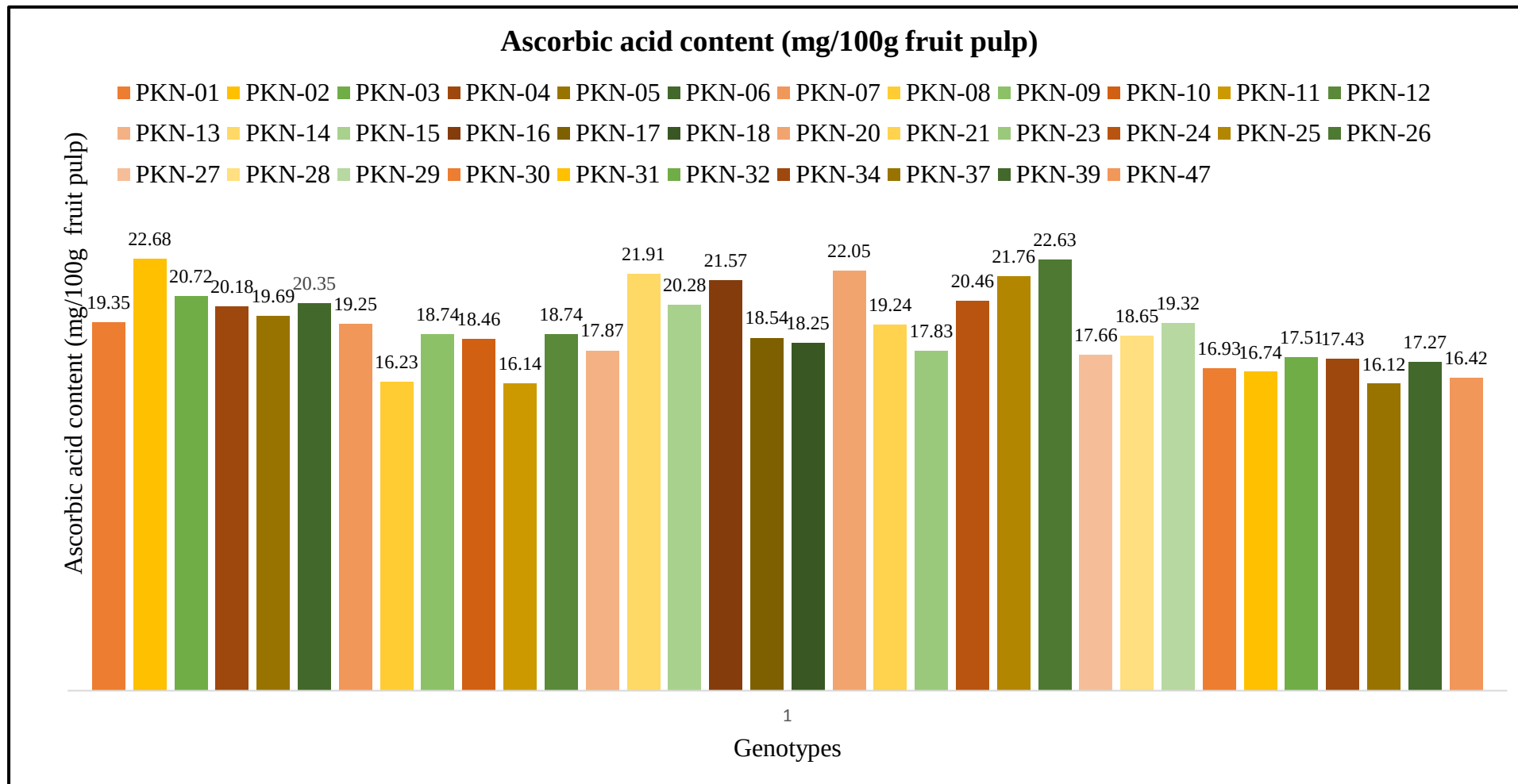


Fig. 1. Graphical representation of ascorbic acid content in *Annona muricata* L. genotypes

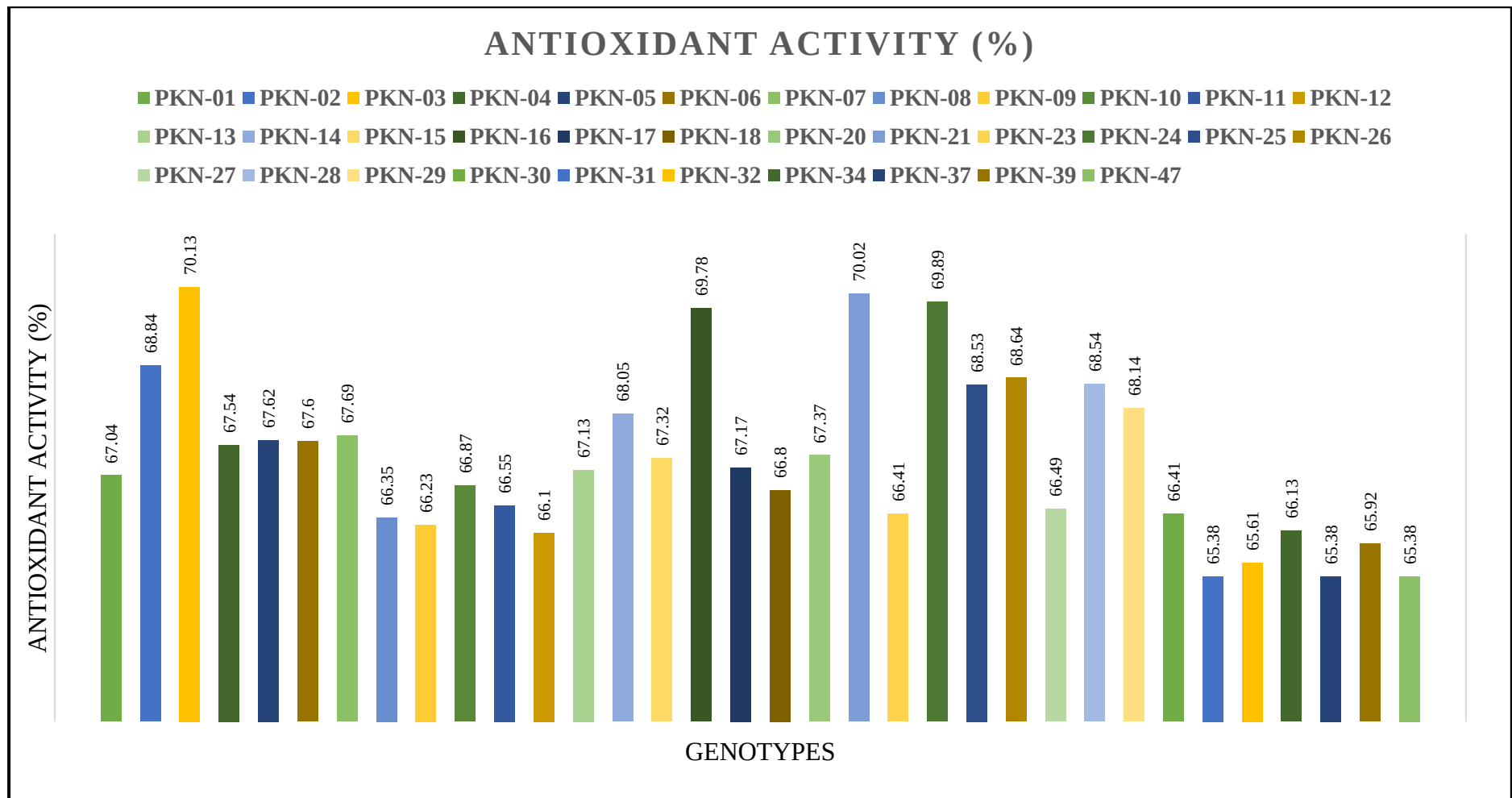


Fig. 2. Graphical representation of antioxidant activity in different genotypes of *Annona muricata* L. genotypes

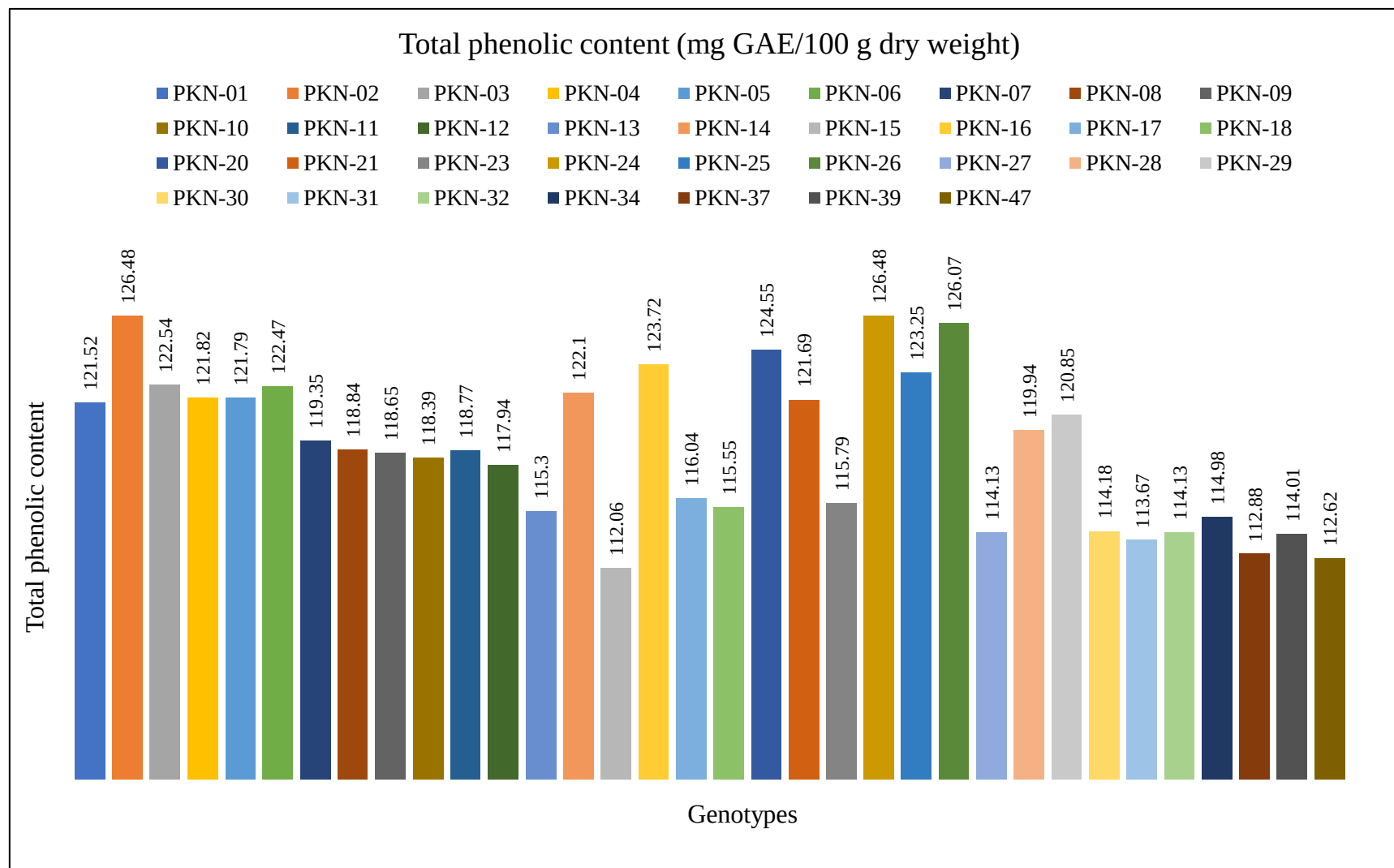


Fig. 3. Graphical representation of total phenolic content in *Annona muricata* L. genotypes

PKN-16 (123.72 mg GAE/g dry weight), PKN-25 (123.25 mg GAE/g dry weight), PKN-03 (122.54 mg GAE/g dry weight), PKN-06 (122.47 mg GAE/g dry weight) and PKN-14 (122.10 mg GAE/g dry weight). Whereas, minimum was observed in PKN-15 (112.06 mg GAE/g dry weight).

4.5 Genetic variability

4.5.1 Tree height (m)

The average tree height observed was 4.05 m with range of 2.42 m to 5.12 m. Tree height recorded moderate value for GCV (17.06 %) and PCV (18.78 %). The high heritability (82.47 %) recorded along with high genetic advance as per cent of mean (31.92 %). It is delineated in Table 11.

4.5.2 Stem girth (cm)

The stem girth recorded mean of 46.52 cm and range (22.80 cm to 70.00 cm). The values for GCV and PCV were high with 25.51 per cent and 22.75 per cent, respectively. The high heritability (89.39 %) was observed along with high genetic advance as per cent of mean (41.89 %) for this trait which is illustrated in Table 11.

4.5.3 Leaf length (cm)

The leaf length recorded mean value of 13.14 cm with the range of 10.63 cm to 16.60 cm. Moderate genotypic and phenotypic coefficient of variations were 12.59 per cent and 12.82 per cent, respectively. The estimates of broad sense heritability (96.43 %) was high which was coupled with high genetic advance as per cent mean (25.49 %) for this trait (Table 11).

4.5.4 Leaf breadth (cm)

The leaf breadth recorded mean value of 5.18 cm along with the range of 3.30 cm to 6.60 cm. The values of GCV (12.35 %) and PCV (12.62 %) were moderate. The estimates of broad sense heritability 95.72 per cent coupled with genetic advance as per cent of mean 24.89 per cent were high for this trait as shown in Table 11.

4.5.5 Petiole length (cm)

The petiole length recorded mean value of 0.68 cm ranged from 0.50 to 0.90 cm. The estimated GCV (14.13 %) and PCV (15.65 %) were moderate for this trait. The high heritability (81.59 %) was observed along with low genetic advance as per cent mean (26.29 %) which is depicted in Table 11.

4.5.6 Chlorophyll 'a' (mg/g)

The average chlorophyll 'a' content was 1.69 mg/g with a range of 1.20 mg/g to 1.99 mg/g. The moderate GCV (11.26 %) and PCV (11.62 %) were observed for this trait with high heritability (93.91 %) coupled with high genetic advance as per cent of mean (22.48 %) (Table 11).

Table 11. Genetic variability components for tree and leaf parameters of *Annona muricata* L. genotypes

Sl. No	Characters	Mean	Range	GCV (%)	PCV (%)	h^2 (%)	GA (%)	GAM (%)
01.	Tree height (m)	4.05	2.42 – 5.12	17.06	18.78	82.47	1.29	31.92
02.	Stem girth (cm)	46.52	22.80 – 70.00	25.51	22.75	89.39	19.49	41.89
03.	Leaf length (cm)	13.14	10.63 – 16.60	12.59	12.82	96.43	3.35	25.49
04.	Leaf breadth (cm)	5.18	3.30 – 6.60	12.35	12.62	95.72	1.29	24.89
05.	Petiole length (cm)	0.68	0.50 – 0.90	14.13	15.65	81.59	0.18	26.29
06.	Chlorophyll 'a' (mg/g)	1.69	1.20 – 1.99	11.26	11.62	93.91	0.38	22.48
07.	Chlorophyll 'b' (mg/g)	0.63	0.31 – 0.83	20.98	21.99	90.95	0.26	41.22
08.	Total chlorophyll (mg/g)	2.32	1.51 – 2.82	13.20	15.47	72.84	0.54	23.22

GCV- Genotypic coefficient of variation

PCV- Phenotypic coefficient of variation

h^2 (broad sense)- Heritability

GA- Genetic advance

GAM- Genetic advance as per cent mean

4.5.7 Chlorophyll 'b' (mg/g)

The chlorophyll 'b' content recorded mean value of 0.63 mg/g with the range of 0.31 mg/g to 0.83 mg/g. The values of GCV (20.98 %) and PCV (21.99 %) were high along with high heritability (90.95 %) and genetic advance as per cent mean (41.22 %) for this trait which is furnished in Table 11.

4.5.8 Total chlorophyll (mg/g)

The total chlorophyll content ranged from 1.51 mg/g to 2.82 mg/g with the mean value of 2.32 mg/g. The estimated GCV and PCV were found to be 13.20 per cent and 15.47 per cent, respectively. The high heritability (72.84 %) coupled with high genetic advance as per cent mean (23.22 %) were recorded for this trait which is presented in Table 11.

4.5.9 Fruit length (cm)

The average value for fruit length was 19.71 cm with the range of 13.60 cm to 29.10 cm. The trait fruit length showed high level of GCV (22.42 %) and PCV (23.55 %). The experimental results also revealed that high broad sense heritability (90.59 %) coupled with high genetic advance as per cent of mean (43.95 %). It is illustrated in Table 12.

4.5.10 Fruit width (cm)

The fruit width ranged from 10.07 cm to 16.40 cm with the mean value of 12.67 cm. The fruit width showed a moderate level of GCV (11.32 %) and PCV (13.03 %). The calculated broad sense heritability (75.42 %) was high with high genetic advance as per cent of mean (20.24%). It is presented in Table 12.

4.5.11 Fruit weight (g)

The fruit weight varied from 1035.34 g to 2352.92 g with the mean value of 1617.96 g. In the present investigation, the estimates of GCV (22.13 %) and PCV (22.28 %) were found to be high in fruit weight. The calculated broad sense heritability (98.60 %) and genetic advance as per cent of mean (45.26 %) were high for this trait (Table 12).

4.5.12 Fruit volume (cc)

The average value for fruit volume 1549.85 cc ranged from 987.30 to 2262.46 cc. The magnitude of observed GCV (23.15 %) and PCV (23.29 %) values were high for a trait fruit volume. The estimates of heritability (98.79 %) was higher with high genetic advance as per cent of mean (47.39 %). It is furnished in Table 12.

Table 12. Genetic variability components for fruit and yield parameters of *Annona muricata* L. genotypes

Sl. No	Characters	Mean	Range	GCV (%)	PCV (%)	h ² (%)	GA (%)	GAM (%)
01.	Fruit length (cm)	19.71	13.60 - 29.10	22.42	23.55	90.59	8.66	43.95
02.	Fruit width (cm)	12.67	10.07 - 16.40	11.32	13.03	75.42	2.57	20.24
03.	Fruit weight (g)	1617.96	1035.34 - 2352.92	22.13	22.28	98.60	732.35	45.26
04.	Fruit volume (cc)	1549.85	987.30 - 2262.46	23.15	23.29	98.79	734.46	47.39
05.	Pulp weight (g)	967.96	572.30 - 1624.40	27.82	28.81	93.26	535.70	55.34
06.	Pericarp thickness (mm)	2.63	2.20 - 3.10	8.24	9.71	72.03	0.38	14.41
07.	Number of seeds per fruit	62.71	40.67 - 99.33	25.88	29.01	79.59	29.82	47.55
08.	Seed weight per fruit	28.22	18.30 - 44.70	25.87	29.00	79.58	13.42	47.56
09.	Number of fruits per tree	30.44	26.00 - 34.00	6.96	9.58	52.79	3.12	10.42
10.	Fruit yield per tree (kg)	49.34	31.27 - 80.00	24.16	25.60	89.06	23.18	46.97
11.	Fruit yield per ha (t/ha)	13.72	8.69 - 22.24	24.35	25.25	93.04	6.64	48.39

GCV- Genotypic coefficient of variation

PCV- Phenotypic coefficient of variation

h² (broad sense)- Heritability

GA- Genetic advance

GAM- Genetic advance as per cent mean

4.5.13 Pulp weight (g)

The pulp weight ranged from 572.30 g to 1624.40 g with average value of 967.96 g. From the experimental results, the results related that GCV (27.82 %) and PCV (28.81 %) values were high for pulp weight, the results also showed that high heritability (93.26 %) coupled with higher genetic advance as per cent of mean (55.34 %). It is depicted in Table 12.

4.5.14 Pericarp thickness (mm)

The pericarp thickness recorded mean value of 2.63 mm with the range of 2.20 mm to 3.10 mm. In the present investigation, the GCV (8.24 %) and PCV (9.71 %) estimates were low for pulp weight. The calculated heritability (72.03 %) was high and genetic advance as per cent of mean (14.41 %) was moderate for this trait. It is illustrated in Table 12.

4.5.15 Number of seeds per fruit

The number of seeds per fruit varied from 40.67 to 99.33 with range of 62.71. The variability study revealed that GCV (25.88 %) and PCV (29.01 %) were found to be high for number of seeds per fruit. It was also revealed that higher per centage of broad sense heritability (79.59 %) and high genetic advance as per cent of mean (47.55 %). It is presented in Table 12.

4.5.16 Seed weight per fruit (g)

The seed weight per fruit ranged from 18.30 g to 44.70 g with the mean value of 28.22 g. In the present investigation, the results related to GCV (25.87 %) and PCV (29.00 %) were found to be high. Higher per cent of broad sense heritability (79.58 %) and genetic advance as per cent of mean (47.56 %) observed in this trait. It is furnished in Table 12.

4.5.17 Number of fruits per tree

The number of fruits per tree exhibited mean value of 30.44 ranged from 26.00 to 34.00. The estimated GCV (6.96 %) and PCV (9.58 %) were low along with high heritability (52.79 %) coupled with moderate genetic advance as per cent of mean (10.42 %) which is represented in Table 12.

4.5.18 Fruit yield per tree (kg)

The fruit yield/tree varied from 31.27 kg to 80.00 kg with the mean value of 49.34 kg. The values of genotypic coefficient variation and phenotypic coefficient variation were high [(24.16 %) and (25.60 %), respectively]. The high heritability (89.06 %) coupled with high genetic advance as per cent of mean (46.97 %) were recorded for this trait which is depicted in Table 12.

4.5.19 Fruit yield per ha (t)

The fruit yield/ha recorded mean value of 13.72 t/ha with the range of 8.69 t/ha to 22.24 t/ha. The estimates of GCV (24.35 %) and PCV (25.25 %) were high with high heritability (93.04 %) along with high genetic advance as per cent of mean (48.39 %) for this trait. It is illustrated in Table 12.

4.5.20 TSS (°B)

The average value for TSS was 17.27 °B with the range of 16.30 °B to 18.23 °B. TSS exhibited low GCV (3.43 %) and PCV (4.18 %) values for this trait. The high heritability (67.18 %) with low genetic advance as per cent of mean (5.79 %) were high for this trait. It is furnished in Table 13.

4.5.21 Titratable acidity (%)

The mean value for titratable acidity was 0.90 per cent with the range of 0.74 per cent to 1.25 per cent. The variability study revealed that moderate GCV (13.68 %) and PCV (13.97 %) for titratable acidity. The values observed for heritability (95.69 %) and genetic advance as per cent of mean (27.54 %) were high for this trait. It is furnished in Table 13.

4.5.22 Reducing sugars (%)

The average value for reducing sugars was 7.97 per cent and it ranged from 6.79 per cent to 8.87 per cent. The experimental results revealed that, the GCV (6.82 %) and PCV (7.32 %) were found to be low for reducing sugars. The calculated heritability (86.79 %) was high and genetic advance as per cent of mean (13.09 %) were found to be moderate for this trait. It is presented in Table 13.

4.5.23 Non-reducing sugars (%)

The non-reducing sugars recorded mean value of 2.89 per cent with the range from 2.14 per cent to 3.79 per cent. The results from the experiment revealed that the obtained values for GCV (15.77 %) and PCV (15.94 %) were found to be moderate for non-reducing sugars. The estimated broad sense heritability (97.96 %) was high with high genetic advance as per cent of mean (32.16 %) (Table 13).

4.5.24 Total sugars (%)

The total sugars varied from 9.32 per cent to 11.97 per cent with the mean value of 10.85 per cent. The estimated GCV (6.59 %) and PCV (7.01 %) values were found to be low for total sugars. The study revealed that heritability (88.34 %) was high with moderate genetic advance as per cent of mean (12.76 %) which is represented in Table 13.

Table 13. Genetic variability components for biochemical parameters of *Annona muricata* L. genotypes

Sl. No	Characters	Mean	Range	GCV (%)	PCV (%)	h ² (%)	GA (%)	GAM (%)
01.	TSS (°B)	17.27	16.30 - 18.23	3.43	4.18	67.18	0.99	5.79
02.	Titratable acidity (%)	0.90	0.74 - 1.25	13.68	13.97	95.69	0.25	27.54
03.	Reducing sugars (%)	7.97	6.79 - 8.87	6.82	7.32	86.79	1.04	13.09
04.	Non-reducing sugars (%)	2.89	2.14 - 3.79	15.77	15.94	97.96	0.93	32.16
05.	Total sugars (%)	10.85	9.32 - 11.97	6.59	7.01	88.34	1.38	12.76
06.	TSS: acid	19.59	13.28 - 24.64	15.76	16.04	96.53	6.25	31.89
07.	Sugar: acid	12.34	7.62 - 16.18	18.22	18.42	97.81	4.58	37.12
08.	Ascorbic acid (mg/100g)	19.03	16.12 - 22.68	10.04	10.36	93.89	3.81	20.04
09.	Antioxidant activity (%)	67.33	65.38 - 70.13	1.25	3.03	17.04	0.72	1.06
10.	Total phenolic content (mg GAE/ 100g dry weight)	118.90	112.06 - 126.48	3.36	4.10	67.15	6.75	5.68

GCV- Genotypic coefficient of variation

PCV- Phenotypic coefficient of variation

h² (broad sense)- Heritability

GA- Genetic advance

GAM- Genetic advance as per cent mean

4.5.25 TSS: acid

The TSS: acid ratio ranged from 13.28 to 24.64 with the mean value of 19.59. The magnitude of observed GCV (15.76 %) and PCV (16.04 %) values were moderate for trait TSS: acid ratio. The experimental results showed that heritability (96.53 %) and genetic advance as per cent of mean (31.89 %) were higher for this trait. It is presented in Table 13.

4.5.26 Sugar: acid

The sugar: acid recorded mean value of 12.34 with the range of 7.62 to 16.18. The variability study revealed that GCV (18.22%) and PCV (18.42 %) for sugar: acid ratio were moderate. It was also revealed that higher per cent of broad senses heritability (97.81 %) along with high genetic advance as per cent of mean (37.12 %). It is depicted in Table 13.

4.5.27 Ascorbic acid (mg/100g)

The ascorbic acid exhibited mean value of 19.03 mg/100g which is ranged from 16.12 mg/100g to 22.68 mg/100g. Ascorbic acid had recorded moderate magnitude of GCV (10.04 %) and PCV (10.36 %). Heritability (93.89 %) was high coupled with higher genetic advance as per cent of mean (20.04 %) (Table 13).

4.5.28 Antioxidant activity (%)

The mean value of antioxidant activity was 67.33 per cent with the range of 65.38 per cent to 70.13 per cent. In the present experiment the performance of GCV and PCV values were low with 1.25 per cent and 3.03 per cent, respectively for this trait. The experiment also revealed that moderate heritability and low genetic advance as per cent mean were with 17.04 per cent 1.06 per cent, respectively. Antioxidant activity recorded low heritability with low genetic advance per cent of mean. It is presented in Table 13.

4.5.29 Total phenolic content (mg GAE/100g)

The average value for total phenolic content 118.90 mg GAE/100g with the range of 112.06 mg GAE/100g to 126.48 mg GAE/100g. In the present investigation, the GCV (3.36 %) and PCV (4.10 %) estimates were low for total phenolic content. The calculated broad sense heritability (67.15 %) was high and genetic advance as per cent of mean (5.68 %) were also low for this trait (Table 13).

4.6 Correlation studies

4.6.1 Phenotypic correlation

4.6.1.1 Fruit length (cm)

The correlation studies revealed that fruit length had positive and highly significant correlation with fruit width (0.353**), fruit weight (0.752**), fruit volume (0.688**), pulp weight (0.672**), TSS (0.525**), total sugars (0.508**), ascorbic acid

(0.681**), antioxidant activity (0.439**) and fruit yield per tree (0.629**). While, number of seeds (-0.699**) and titratable acidity (-0.534**) recorded highly negative significant correlation with fruit length which is presented in Table 14.

4.6.1.2 Fruit width (cm)

During experimental period, fruit width exhibited highly significant and positive correlation with fruit weight (0.469**), fruit volume (0.448**), pulp weight (0.439**), total sugars (0.380**), ascorbic acid (0.423**) and fruit yield per tree (0.439**). The antioxidant activity (0.203*) shown significant positive correlation with fruit width. The non-significant positive correlation was exhibited by TSS (0.1322) for fruit width. Whereas, fruit width was highly significant and negatively correlated with number of seeds per fruit (-0.338**). The titratable acidity (-0.251*) had significant negative correlation with fruit width (Table 14).

4.6.1.3 Fruit weight (g)

The result revealed that fruit weight had highly significant and positive correlation with fruit volume (0.932**), pulp weight (0.837**), TSS (0.641**), total sugars (0.752**), ascorbic acid (0.842**), antioxidant activity (0.507**) and fruit yield per tree (0.899**). However, fruit weight showed highly significant and negative correlation with number of seeds (-0.836**) and titratable acidity (-0.663**) which is represented in Table 14.

4.6.1.4 Fruit volume (cc)

The data showed that fruit volume was highly significant and positively correlated with pulp weight (0.858**), TSS (0.597**), total sugars (0.670**), ascorbic acid (0.831**), antioxidant activity (0.485**) and fruit yield per tree (0.834**). Whereas, number of seeds per fruit (-0.764**) and titratable acidity (-0.649**) were highly significant and negatively correlated with fruit volume which is presented in Table 14.

4.6.1.5 Pulp weight (g)

During the study, pulp weight showed highly significant and positive correlation with TSS (0.474**), total sugars (0.474**), ascorbic acid (0.661**), antioxidant activity (0.393**) and fruit yield per tree (0.806**). While, pulp weight had highly significant and negative correlation with number of seeds per fruit (-0.646**) and titratable acidity (-0.533**). It is furnished in Table 14.

4.6.1.6 Number of seeds per fruit

The result observed in the present study revealed that number of seeds per fruit was highly significant and positive correlation with titratable acidity (0.618**).

Table 14. Phenotypic correlation coefficient between yield and quality parameters of *Annona muricata* L. genotypes

Traits	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X1	1.000	0.353**	0.752**	0.688**	0.672**	-0.699**	0.525**	-0.534**	0.508**	0.681**	0.439**	0.629**
X2		1.000	0.469**	0.448**	0.439**	-0.338**	0.1322	-0.251*	0.380**	0.423**	0.203*	0.439**
X3			1.000	0.932**	0.837**	-0.836**	0.641**	-0.663**	0.752**	0.842**	0.507**	0.899**
X4				1.000	0.858**	-0.764**	0.597**	-0.649**	0.670**	0.831**	0.485**	0.834**
X5					1.000	-0.646**	0.474**	-0.533**	0.474**	0.661**	0.393**	0.806**
X6						1.000	-0.603**	0.618**	-0.719**	-0.758**	-0.490**	-0.735**
X7							1.000	-0.681**	0.692**	0.676**	0.456**	0.523**
X8								1.000	-0.759**	-0.606**	-0.449**	-0.572**
X9									1.000	0.722**	0.499**	0.620**
X10										1.000	0.462**	0.712**
X11											1.000	0.426**
X12												1.000

* Significance at 5 per cent

X1 - Fruit length (cm)

X2 - Fruit width (cm)

X3 - Fruit weight (g)

X4 - Fruit volume (cc)

** Significance at 1 per cent

X5 - Pulp weight (g)

X6 - Number of seeds per fruit

X7 - Total soluble solids (TSS) (°B)

X8 - Titratable acidity (%)

X9 - Total sugars (%)

X10 - Ascorbic acid (mg/100g)

X11 - Antioxidant activity (%)

X12 - Fruit yield per plant (kg)

However, number of seeds per fruit was highly significant and negatively correlated with TSS (-0.603**), total sugars (-0.719**), ascorbic acid (-0.758**), antioxidant activity (-0.490**) and fruit yield per tree (-0.735**) which is represented in Table 14.

4.6.1.7 Total soluble solids (°B)

In the present study, total soluble solids (TSS) was highly significant and positively correlated with total sugars (0.692**), ascorbic acid (0.676**), antioxidant activity (0.456**) and fruit yield per tree (0.523**). Whereas, TSS was highly significant and positively correlated with titratable acidity (-0.681**) which is given in Table 14.

4.6.1.8 Titratable acidity (%)

The titratable acidity trait studied in correlation exhibited highly significant and negative correlation with total sugars (-0.759**), ascorbic acid (-0.606**), antioxidant activity (-0.449**) and fruit yield per tree (-0.572**) which is furnished in Table 14.

4.6.1.9 Total sugars (%)

The present study revealed that total sugars is highly significant and positive correlation with ascorbic acid (0.722**), antioxidant activity (0.499**) and fruit yield per tree (0.620**) which is documented in Table 14.

4.6.1.10 Ascorbic acid (mg/100g)

The trait ascorbic acid exhibited highly significant and positive correlation with antioxidant activity (0.462**) and fruit yield per tree (0.712**) which is presented in Table 14.

4.6.1.11 Antioxidant activity (%)

The experimental study revealed that antioxidant activity showed highly significant and positive correlation with fruit yield per tree (0.426**) which is depicted in Table 14.

4.6.2 Genotypic correlation

4.6.2.1 Fruit length (cm)

The correlation studies revealed that fruit length had positive and highly significant correlation with fruit width (0.351**), fruit weight (0.751**), fruit volume (0.687**), pulp weight (0.670**), TSS (0.516**), total sugars (0.506**), ascorbic acid (0.680**), antioxidant activity (0.439**) and fruit yield per tree (0.629**). While, number of seeds (-0.697**) and titratable acidity (-0.533**) recorded highly negative significant correlation with fruit length which is depicted in Table 15.

4.6.2.2 Fruit width (cm)

During experimental period, fruit width exhibited highly significant and positive correlation with fruit weight (0.468**), fruit volume (0.446**), pulp weight (0.434**), total sugars (0.368**), ascorbic acid (0.417**) and fruit yield per tree (0.437**). The antioxidant activity (0.211*) shown significant positive correlation with fruit width. The non-significant positive correlation was exhibited by TSS (0.1384) for fruit width. Whereas, fruit width was highly significant and negatively correlated with number of seeds per fruit (-0.332**). The titratable acidity (-0.251*) had significant negative correlation with fruit width (Table 15).

4.6.2.3 Fruit weight (g)

The result revealed that fruit weight had highly significant and positive correlation with fruit volume (0.932**), pulp weight (0.836**), TSS (0.637**), total sugars (0.749**), ascorbic acid (0.840**), antioxidant activity (0.504**) and fruit yield per tree (0.899**). However, fruit weight showed highly significant and negative correlation with number of seeds (-0.835**) and titratable acidity (-0.663**) which is represented in Table 15.

4.6.2.4 Fruit volume (cc)

The experimental results showed that fruit volume was highly significant and positively correlated with pulp weight (0.858**), TSS (0.593**), total sugars (0.668**), ascorbic acid (0.830**), antioxidant activity (0.483**) and fruit yield per tree (0.834**). Whereas, number of seeds per fruit (-0.763**) and titratable acidity (-0.649**) were highly significant and negatively correlated with fruit volume which is furnished in Table 15.

4.6.2.5 Pulp weight (g)

During the study, pulp weight showed highly significant and positive correlation with TSS (0.471**), total sugars (0.474**), ascorbic acid (0.660**), antioxidant activity (0.385**) and fruit yield per tree (0.806**). While, pulp weight had highly significant and negative correlation with number of seeds per fruit (-0.646**) and titratable acidity (-0.532**) which is presented in Table 15.

4.6.2.6 Number of seeds per fruit

The result observed in the present study revealed that number of seeds per fruit was highly significant and positive correlation with titratable acidity (0.617**). However, number of seeds per fruit was highly significant and negatively correlated with TSS (-0.597**), total sugars (-0.718**), ascorbic acid (-0.757**), antioxidant activity (-0.483**) and fruit yield per tree (-0.734**) which is illustrated in Table 15.

Table 15. Genotypic correlation coefficient between yield and quality parameters of *Annona muricata* L. genotypes

Traits	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X1	1.000	0.351**	0.751**	0.687**	0.670**	-0.697**	0.516**	-0.533**	0.506**	0.680**	0.439**	0.629**
X2		1.000	0.468**	0.446**	0.434**	-0.332**	0.1384	-0.251*	0.368**	0.417**	0.211*	0.437**
X3			1.000	0.932**	0.836**	-0.835**	0.637**	-0.663**	0.749**	0.840**	0.504**	0.899**
X4				1.000	0.858**	-0.763**	0.593**	-0.649**	0.668**	0.830**	0.483**	0.834**
X5					1.000	-0.646**	0.471**	-0.532**	0.474**	0.660**	0.385**	0.806**
X6						1.000	-0.597**	0.617**	-0.718**	-0.757**	-0.483**	-0.734**
X7							1.000	-0.675**	0.678**	0.664**	0.447**	0.517**
X8								1.000	-0.756**	-0.606**	-0.447**	-0.572**
X9									1.000	0.722**	0.487**	0.618**
X10										1.000	0.458**	0.712**
X11											1.000	0.423**
X12												1.000

* Significant at 5 per cent

** Significant at 1 per cent

X1 - Fruit length (cm)
X2 - Fruit width (cm)
X3 - Fruit weight (g)
X4 - Fruit volume (cc)

X5 - Pulp weight (g)
X6 - Number of seeds per fruit
X7 - Total soluble solids (TSS) (°B)
X8 - Titratable acidity (%)

X9 - Total sugars (%)
X10 - Ascorbic acid (mg/100g)
X11 - Antioxidant activity (%)
X12 - Fruit yield/plant (kg)

4.6.2.7 TSS (°B)

In the present study, total soluble solids (TSS) was highly significant and positively correlated with total sugars (0.678**), ascorbic acid (0.664**), antioxidant activity (0.447**) and fruit yield per tree (0.517**). Whereas, TSS was highly significant and positively correlated with titratable acidity (-0.675**) (Table 15).

4.6.2.8 Titratable acidity (%)

The data showed that titratable acidity exhibited highly significant and negative correlation with total sugars (-0.756**), ascorbic acid (-0.606**), antioxidant activity (-0.447**) and fruit yield per tree (-0.572**) which is represented in Table 15.

4.6.2.9 Total sugars (%)

The present study revealed that total sugars is highly significant and positive correlation with ascorbic acid (0.722**), antioxidant activity (0.487**) and fruit yield per tree (0.618**) which is shown in Table 15.

4.6.2.10 Ascorbic acid (mg/100g)

During experimental study ascorbic acid exhibited highly significant and positive correlation with antioxidant activity (0.458**) and fruit yield per tree (0.712**) which is furnished in Table 15.

4.6.2.11 Antioxidant activity (%)

The experimental study revealed that antioxidant activity showed highly significant and positive correlation with fruit yield per tree (0.423**) which is given in Table 15.

4.7 Path co-efficient analysis

The correlation coefficient does not specify a cause-and-effect relationship; it just indicates the link between an independent variable and the dependent variable. The path coefficient analysis's output reveals the relative contributions of several factors to the bulb yield for per plot. The direct and indirect effects of a chosen feature on fruit yield per tree and its indirect effects through other traits were computed and given in Table 16.

4.7.1 Phenotypic path co-efficient analysis

The phenotypic path coefficient analysis for fruit yield per tree was carried out using a set of 11 independent characters: fruit length, fruit width, fruit weight, fruit volume, pulp weight, number of seeds per fruit, total soluble solids, titratable acidity, total sugars, ascorbic acid and antioxidant activity (Table 16).

4.7.1.1 Fruit length (cm)

Results revealed that fruit length exerted a negative direct effect on fruit yield per tree (-0.1491) through a indirect positive effect of number of seeds per fruit (0.1042), titratable acidity (0.0796) and negative indirect effect of fruit width (-0.0526), fruit weight (-0.1122), fruit volume (-0.1026), pulp weight (-0.1002), total soluble solids (-0.0784), total sugars (-0.0758), ascorbic acid (-0.1015) and antioxidant activity (-0.0655) which is delineated in Table 16.

4.7.1.2 Fruit width (cm)

During the investigation fruit width had showed positive direct effect on fruit yield per tree (0.0181) through a indirect positive effect of fruit length (0.0064), fruit weight (0.0085), fruit volume (0.0081), pulp weight (0.0080), TSS (0.0024), total sugars (0.0069), ascorbic acid (0.0077), antioxidant activity (0.0037). However, a negative indirect effect of number of seeds per fruit (-0.0061) and titratable acidity (-0.0046) which is represented in Table 16.

4.7.1.3 Fruit weight (g)

Fruit weight exhibited a positive direct effect on fruit yield per tree (0.8838) through an indirect positive effect of fruit length (0.8151), fruit width (0.5086), fruit volume (1.0102), pulp weight (0.9070), TSS (0.6947), total sugars (0.8148), ascorbic acid (0.9120), antioxidant activity (0.5489). While, a negative indirect effect of number of seeds per fruit (-0.9063) and titratable acidity (-0.7181) which is presented in Table 16.

4.7.1.4 Fruit volume (cc)

In the present study, fruit volume showed a negative direct effect on fruit yield per tree (-0.1782) through an indirect positive effect of number of seeds per fruit (0.1361) and titratable activity (0.1157). In contrast, a negative indirect effect of fruit length (-0.1226), fruit width (-0.0798), fruit weight (-0.1661), pulp weight (-0.1530), TSS (-0.1064), total sugars (-0.1194), ascorbic acid (-0.1481) and antioxidant activity (-0.0864) (Table 16).

4.7.1.5 Pulp weight (g)

The results revealed that, pulp weight exerted a positive direct effect on fruit yield per tree (0.1856) through a positive indirect effect of fruit length (0.1247), fruit width (0.0815), fruit weight (0.1553), fruit volume (0.1593), TSS (0.0880), total sugars (0.0880), ascorbic acid (0.1227) and antioxidant activity (0.0729). Whereas, negative indirect effect was expressed by number of seeds per fruit (-0.1199) and titratable acidity (-0.0989) which is illustrated in Table 16.

Table 16. Phenotypic path coefficient of yield and quality parameters of *Annona muricata* L. genotypes

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X1	-0.1491	-0.0526	-0.1122	-0.1026	-0.1002	0.1042	-0.0784	0.0796	-0.0758	-0.1015	-0.0655	0.629**
X2	0.0064	0.0181	0.0085	0.0081	0.0080	-0.0061	0.0024	-0.0046	0.0069	0.0077	0.0037	0.439**
X3	0.8151	0.5086	0.8838	1.0102	0.9070	-0.9063	0.6947	-0.7181	0.8148	0.9120	0.5489	0.899**
X4	-0.1226	-0.0798	-0.1661	-0.1782	-0.1530	0.1361	-0.1064	0.1157	-0.1194	-0.1481	-0.0864	0.834**
X5	0.1247	0.0815	0.1553	0.1593	0.1856	-0.1199	0.0880	-0.0989	0.0880	0.1227	0.0729	0.806**
X6	0.0287	0.0139	0.0343	0.0313	0.0265	-0.0410	0.0247	-0.0254	0.0295	0.0311	0.0201	-0.735**
X7	-0.0180	-0.0045	-0.0220	-0.0205	-0.0163	0.0207	-0.0343	0.0233	-0.0237	-0.0232	-0.0156	0.523**
X8	0.0280	0.0132	0.0347	0.0340	0.0279	-0.0324	0.0357	-0.0524	0.0398	0.0318	0.0236	-0.572**
X9	-0.0561	-0.0419	-0.0830	-0.0740	-0.0524	0.0793	-0.0763	0.0838	-0.1104	-0.0797	-0.0551	0.620**
X10	-0.0267	-0.0166	-0.0330	-0.0326	-0.0259	0.0297	-0.0265	0.0238	-0.0283	-0.0392	-0.0181	0.712**
X11	-0.0011	-0.0005	-0.0013	-0.0012	-0.0010	0.0012	-0.0011	0.0011	-0.0012	-0.0011	-0.0025	0.426**

NOTE: Diagonal values indicates direct effect

Residual effect = 0.207

** Significant at 1 per cent

X1 - Fruit length (cm)
X2 - Fruit width (cm)
X3 - Fruit weight (g)
X4 - Fruit volume (cc)

X5 - Pulp weight (g)
X6 - Number of seeds per fruit
X7 - Total soluble solids (TSS) (°B)
X8 - Titratable acidity (%)

X9 - Total sugars (%)
X10 - Ascorbic acid (mg/100g)
X11 - Antioxidant activity (%)
X12 - Fruit yield/plant (kg)

4.7.1.6 Number of seeds per fruit

During the investigation, the results revealed that number of seeds per fruit exhibited a negative direct effect on fruit yield per tree (-0.0410) through a positive indirect effect of fruit length (0.0287), fruit width (0.0139), fruit weight (0.0343), fruit volume (0.0313), pulp weight (0.0265), TSS (0.0247), total sugars (0.0295), ascorbic acid (0.0311) and antioxidant activity (0.0201). In contrast, negative indirect effect of titratable acidity (-0.0254) which is depicted in Table 16.

4.7.1.7 TSS (°B)

Total soluble solids on fruit yield per tree showed a negative direct effect (-0.0343) through a positive indirect effect of number of seeds per fruit (0.0207) and titratable acidity (0.0233). While, negative indirect effect was expressed by fruit length (-0.0180), fruit width (-0.0045), fruit weight (-0.0220), fruit volume (-0.0205), pulp weight (-0.0163), total sugars (-0.0237), ascorbic acid (-0.0232) and antioxidant activity (-0.0156) which is presented in Table 16.

4.7.1.8 Titratable acidity (%)

Titratable acidity showed negative direct effect on fruit yield per tree (-0.0524) through a positive indirect effect of fruit length (0.0280), fruit width (0.0132), fruit weight (0.0347), fruit volume (0.0340), pulp weight (0.0279), TSS (0.0357), total sugars (0.0398), ascorbic acid (0.0318) and antioxidant activity (0.0236). Whereas, negative indirect effect was expressed by number of seeds per fruit (-0.0324) which is furnished in Table 16.

4.7.1.9 Total sugars (%)

In the present study, total sugars exerted a negative direct effect on fruit yield per tree (-0.1104) through a positive indirect effect of number of seeds per fruit (0.0793) and titratable acidity (0.0838). Whereas, negative indirect effect was expressed by fruit length (-0.0561), fruit width (-0.0419), fruit weight (-0.0830), fruit volume (-0.0740), pulp weight (-0.0524), TSS (-0.0763), ascorbic acid (-0.0797) and antioxidant activity (-0.0551) which is represented Table 16).

4.7.1.10 Ascorbic acid (mg/100g)

The path estimates disclosed that, ascorbic acid exhibited a negative direct effect on fruit yield per tree (-0.0392) through a positive indirect effect of number of seeds per fruit (0.0297) and titratable acidity (0.0238). Whereas, negative indirect effect was expressed by fruit length (-0.0267), fruit width (-0.0166), fruit weight (-0.0330), fruit volume (-0.0326), pulp weight (-0.0259), TSS (-0.0265), total sugars (-0.0283) and antioxidant activity (-0.0181) which is delineated in Table 16.

4.7.1.11 Antioxidant activity (%)

The trait antioxidant activity had negative direct effect on fruit yield per tree (-0.0025) through a positive indirect effect of number of seeds per fruit (0.0012) and titratable acidity (0.0011). While, negative indirect effect was expressed by fruit length (-0.0011), fruit width (-0.0005), fruit weight (-0.0013), fruit volume (-0.0012), pulp weight (-0.0010), TSS (-0.0011), total sugars (-0.0012) and antioxidant activity (-0.0011) which is presented Table 16.

4.8 Genetic divergence

4.8.1 Contribution of individual character towards total divergence

The genetic diversity of 34 genotypes of *Annona muricata* was assessed by Mahalanobis D^2 statistics, which resulted in six clusters using Tocher's method. The trait fruit yield per tree contributed maximum towards the total divergence with 15.32 per cent followed by titratable acidity (9.32 %), antioxidant activity (9.32), total soluble solids (9.13 %), ascorbic acid (8.99 %), number of seeds per fruit (8.9 %), pulp weight (7.88 %), fruit width (7.22 %), fruit volume (6.88 %), fruit weight (6.76 %), total sugars (5.78 %) and fruit length (4.5 %) (Fig. 4).

4.8.2 Grouping genotypes into various clusters

The genotypes were grouped into six different clusters which is presented in Table 18 (Fig. 5). The cluster II had the ten genotypes (PKN-27, PKN-34, PKN-32, PKN-18, PKN-17, PKN-13, PKN-47, PKN-31, PKN-30 and PKN-39) followed by cluster III with nine genotypes (PKN-08, PKN-09, PKN-12, PKN-01, PKN-11, PKN-07, PKN-10, PKN-28 and PKN-23), cluster I with seven genotypes (PKN-03, PKN-24, PKN-06, PKN-15, PKN-04, PKN-26 and PKN-02), cluster IV with four genotypes (PKN-20, PKN-25, PKN-16 and PKN-14), cluster VI with three genotypes (PKN-21, PKN-29 and PKN-05) and cluster V had only one genotype (PKN-37). The details is presented in Table 17.

4.8.3 Inter and inter-cluster distances

4.8.3.1 Inter-cluster distances

Inter cluster D^2 values ranged from 107608.80 to 1666838.00. The highest inter-cluster distance (1666838.00) was noticed in between cluster V and cluster VI, followed by between cluster I and cluster V (1492830.00) and least inter-cluster distance (107608.80) was documented between cluster II and cluster V (Table 18).

4.8.3.2 Intra-cluster distances

Intra cluster D^2 values ranged from 0.00 to 70776.34. The maximum intra cluster distance was found in cluster III (70776.34) followed by cluster IV (70174.50), cluster II (56129.41), cluster VI (45765.20), cluster I (42509.45) and minimum was found to be in cluster V (0.00) which is depicted in Table 18.

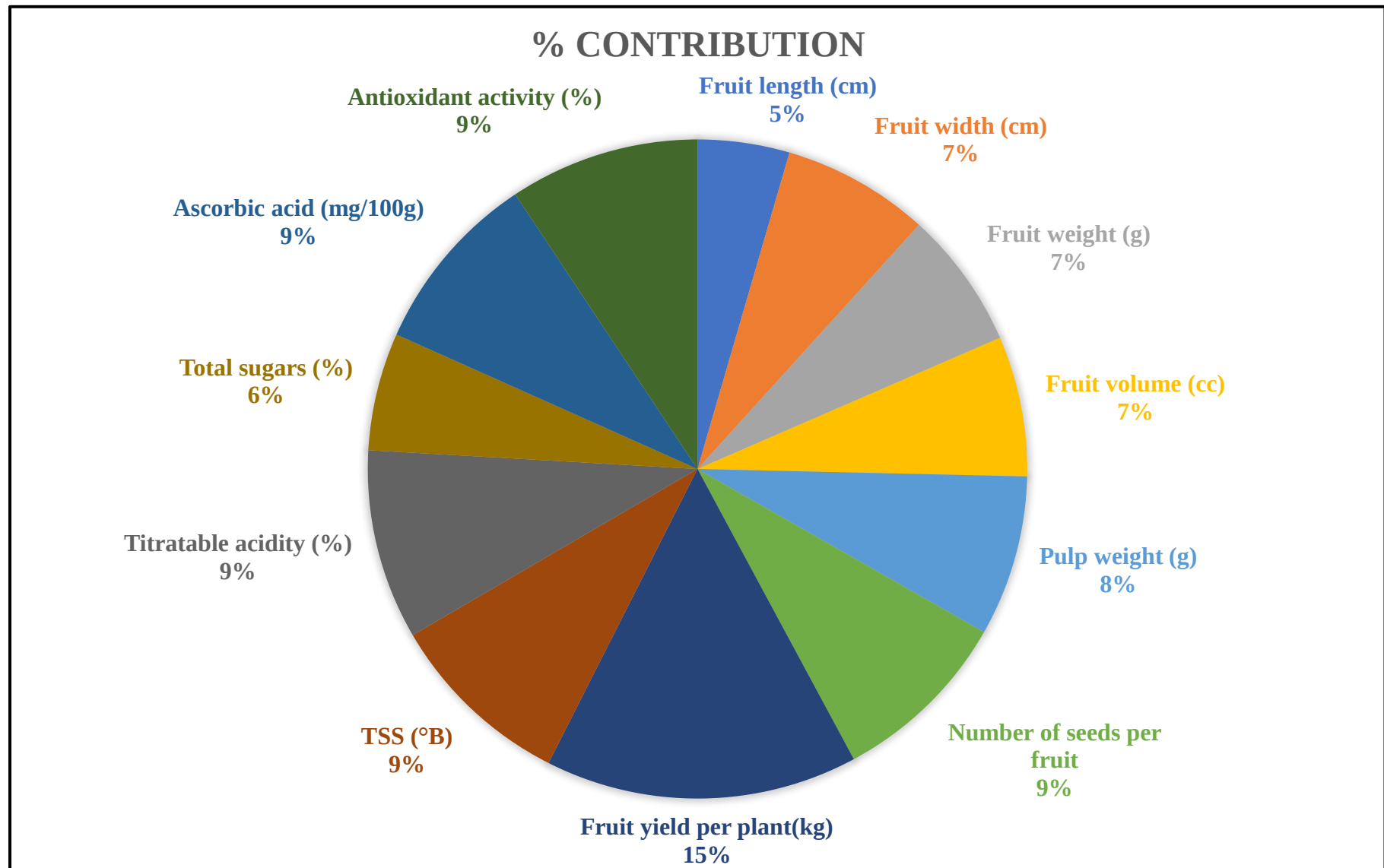


Fig. 4. Pie chart showing contribution of different characters towards total genetic divergence in *Annona muricata* L. genotypes

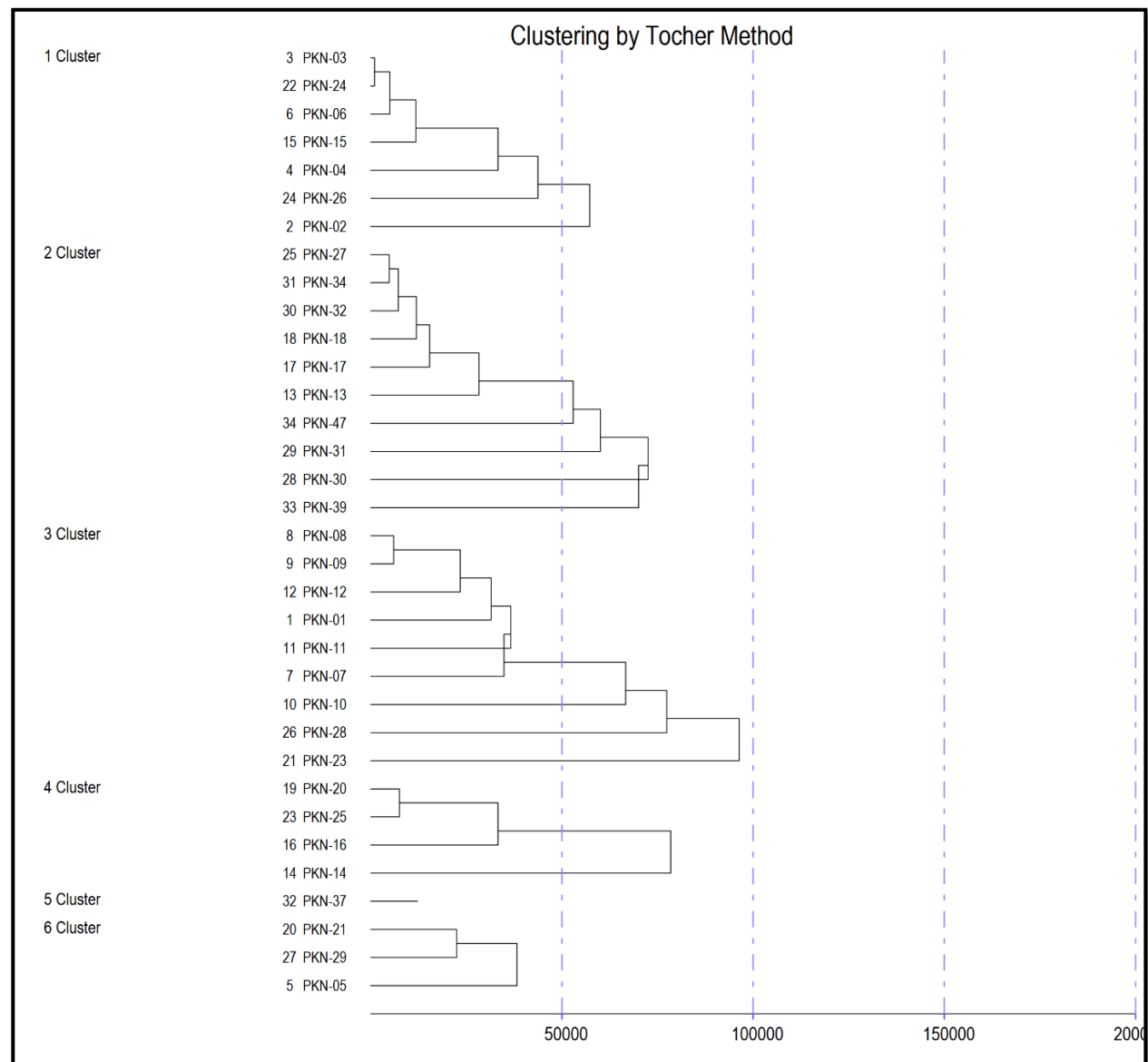


Fig. 5. Dendrogram showing the genetic diversity among different genotypes of *Annona muricata* L.

Table 17. Grouping of genotypes of *Annona muricata* L. into different clusters

Cluster number	Total no. of genotypes in each cluster	Genotypes included in the cluster
Cluster I	7	PKN-03, PKN-24, PKN-06, PKN-15, PKN-04, PKN-26 and PKN-02
Cluster II	10	PKN-27, PKN-34, PKN-32, PKN-18, PKN-17, PKN-13, PKN-47, PKN-31, PKN-30 and PKN-39
Cluster III	9	PKN-08, PKN-09, PKN-12, PKN-01, PKN-11, PKN-07, PKN-10, PKN-28 and PKN-23
Cluster IV	4	PKN-20, PKN-25, PKN-16 and PKN-14
Cluster V	1	PKN-37
Cluster VI	3	PKN-21, PKN-29 and PKN-05

Table 18. Average intra and inter cluster distance (D²) for yield and quality parameters formed by different genotypes of *Annona muricata* L.

Clusters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Cluster I	42509.45	908391.20	232712.00	658453.90	1492830.00	117121.90
Cluster II		56129.41	318657.30	2715829.00	107608.80	1045341.00
Cluster III			70776.34	1337166.00	667566.80	300910.30
Cluster IV				70174.50	3698252.00	447237.30
Cluster V					0.00	1666838.00
Cluster VI						45765.20

NOTE: Diagonal bold values indicate intra cluster distances

4.8.4 Cluster mean for various characters

The detailed cluster mean values for different yield and quality traits in 34 genotypes of *Annona muricata* are presented in Table 19.

4.8.4.1 Fruit length (cm)

The results revealed that the mean cluster value for fruit length was maximum in cluster IV (27.51) followed by cluster I (22.35), cluster VI (19.88), cluster III (18.14), cluster II (16.53) and minimum was recorded in cluster V (15.50) which is given in the Table 19.

4.8.4.2 Fruit width (cm)

The cluster mean values for fruit width was found to be highest in cluster IV (14.97) followed by cluster I (12.86), cluster III (12.58), cluster VI (12.40), cluster II (12.22) and lowest cluster mean value was recorded in cluster V (10.37) which is represented in Table 19.

4.8.4.3 Fruit weight (g)

The cluster IV (2250.74) recorded maximum cluster mean value for fruit weight followed by cluster I (1878.38), cluster VI (1806.00), cluster III (1559.65), cluster II (1236.89) and minimum in cluster V (1035.34) which is furnished in Table 19.

4.8.4.4 Fruit volume (cc)

The fruit volume recorded highest cluster mean value in cluster IV (2135.16) followed by cluster VI (1806.00), cluster I (1792.15), cluster III (1510.63), cluster II (1159.81) and lowest was in cluster V (987.30) which is illustrated in Table 19.

4.8.4.5 Pulp weight (g)

The diversity studies revealed that the maximum cluster mean value for pulp weight was recorded in cluster IV (1559.15) followed by cluster VI (1240.88), cluster I (961.42), cluster III (918.34), cluster II (733.14) and minimum was recorded in cluster V (625.08) which is presented in Table 19.

4.8.4.6 Number of seeds per fruit

The cluster mean value for number of seeds per fruit was highest in cluster V (96.33) followed by cluster II (80.30), cluster III (63.96), cluster VI (50.67), cluster I (47.76) and lowest was reported in cluster IV (42.67) which is delineated in Table 19.

4.8.4.7 Fruit yield per tree (kg)

Fruit yield per tree recorded higher cluster mean value in cluster IV (72.09) followed by cluster I (55.29), cluster VI (54.00), cluster III (48.49), cluster II (37.17) and lower in cluster V (32.10) which is given in the Table 19.

Table 19. Cluster mean values for yield and quality parameters in different genotypes of *Annona muricata* L.

SL. No.	Characters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
01.	Fruit length (cm)	22.35	16.53	18.14	27.51	15.50	19.88
02.	Fruit width (cm)	12.86	12.22	12.58	14.97	10.37	12.40
03.	Fruit weight (g)	1878.38	1236.89	1559.65	2250.74	1035.34	1806.00
04.	Fruit volume (cc)	1792.15	1159.81	1510.63	2135.16	987.30	1809.40
05.	Pulp weight (g)	961.42	733.14	918.34	1559.15	625.08	1240.88
06.	Number of seeds per fruit	47.76	80.30	63.96	42.67	96.33	50.67
07.	Fruit yield per tree (kg)	55.29	37.17	48.49	72.09	32.10	54.00
08.	TSS (°B)	18.06	16.75	16.87	17.81	17.20	17.71
09.	Titratable acidity (%)	0.78	1.02	0.93	0.80	0.87	0.82
10.	Total sugars (%)	11.72	10.16	10.66	11.41	10.32	11.14
11.	Ascorbic acid (mg/100g)	21.04	17.46	18.15	21.82	16.12	19.12
12.	Antioxidant activity (%)	68.57	66.24	66.86	68.43	65.38	68.59

4.8.4.8 Total soluble solids (°B)

The study revealed that, total soluble solids was highest in cluster I (18.06) followed by cluster IV (17.81), cluster VI (17.71), cluster V (17.20), cluster III (16.87) and lowest was reported in cluster II (16.75) which is furnished in Table 19.

4.8.4.9 Titratable acidity (%)

The trait titratable acidity recorded maximum cluster mean value in cluster II (1.02) followed by cluster III (0.93), cluster V (0.87), cluster VI (0.82), cluster IV (0.80) and minimum was documented in cluster I (0.78) which is presented in Table 19.

4.8.4.10 Total sugars (%)

The total sugars exhibited higher cluster mean value in cluster I (11.72) followed by cluster IV (11.41), cluster VI (11.14), cluster III (10.66), cluster V (10.32) and lowest value was found in cluster II (10.16) which is given in Table 19.

4.8.4.11 Ascorbic acid (mg/100g)

The cluster mean value for ascorbic acid found to be maximum in cluster IV (21.82) followed by cluster I (21.04), cluster VI (19.12), cluster III (18.15), cluster II (17.46) and minimum was found to be cluster V (16.12) which is depicted in Table 19.

4.8.4.12 Antioxidant activity (%)

Highest cluster mean value for antioxidant activity was found in cluster VI (68.59) followed by cluster I (68.57), cluster IV (68.43), cluster III (66.86), cluster II (66.24) and lowest value was found to be in cluster V (65.38) (Table 19).

DISCUSSION

V DISCUSSION

The salient features of these observations have been discussed and interpreted below in the light of available literature under the following heads

- 5.1 Morphological traits of the tree
- 5.2 Morphological traits of the tree foliage
- 5.3 Fruit and yield parameters
- 5.4 Biochemical parameters
- 5.5 Genetic variability studies
- 5.6 Correlation studies
- 5.7 Path co-efficient analysis
- 5.8 Genetic divergence studies

5.1 Morphological traits of the tree

Among 50 genotypes studied, the maximum tree height was recorded in PKN-03 (5.12 m) while, the minimum tree height was observed in PKN-22 (2.42 m) and the highest value for stem girth was recorded in PKN-16 (70.00 cm) whereas, lowest value for the stem girth was recorded in PKN-44 (22.80 cm). Spreading growth habit was observed in maximum number of genotypes of 46. Whereas, erect growth habit was observed in only 4 genotypes. The variation with respect to tree height, stem girth and growth habit is due to the effect of genotypic difference among the genotypes and also due to the differential utilization of resources from the soil. Such factors are known to cause morphological and genetic evolutionary divergences among the population. The supporting results had been reported by Dasilva *et al.* (1999), Rao and Subramanyam (2011), Shukla *et al.* (2010), Pooja *et al.* (2022), Amulya *et al.* (2022) and Rajadurai *et al.* (2022).

5.2 Morphological traits of the tree foliage

Maximum leaf length was observed in PKN-05 (16.60 cm) and minimum leaf length was observed in PKN-41 (10.63 cm). Maximum leaf breadth was observed in PKN-20 (6.60 cm) whereas, minimum value for leaf breadth was observed in PKN-22 (4.10 cm) which were significantly different from other genotypes. Green colour was observed among 50 genotypes for colour of matured leaf. Such variation may be due to its better photosynthetic activity and their utilization for building up of new cells and also might be due to the genomic constitution of individual tree. These variation in leaf parameters was previously reported by Thakur and Singh (1967), Mathakar (2005), Jadhav (2008), Algabal *et al.* (2012), Singh *et al.* (2015) and Handique *et al.* (2022).

Among two different leaf shapes, maximum genotypes (31) had shown lanceolate leaf shape and ovate leaf shape was observed in only 19 genotypes. Variation in leaf shape may be due to their genetic variability and also might be due to physiological and metabolic changes in growth and development of tree. Acuminate leaf apex shape was observed in maximum (39) genotypes whereas, rounded leaf apex shape was observed in minimum (11) genotypes. All the 50 genotypes exhibited acute leaf base shape and entire leaf margin. Longer petiole length (0.9 cm) was observed in PKN-28 genotype whereas, shorter petiole length (0.5 cm) was observed in PKN-09, PKN-30, PKN-37 and PKN-43 genotypes. A greater variation in leaf parameters among the trees might be due to the presence of abundant genetic variability associated with their trees. This study was also in accordance with the result of George *et al.* (2013), Singh *et al.* (2015), Nkansah *et al.* (2017), Abraham *et al.* (2018), Sawitri *et al.* (2019), Handique *et al.* (2022) and Jagruthi *et al.* (2022).

5.3 Fruit and yield parameters

5.3.1 Fruit parameters

Maximum length of fruit (29.10 cm) was observed in genotype PKN-25 whereas, minimum length of fruit was observed in genotype PKN-47 (13.60 cm). Maximum fruit width was observed in genotype PKN-25 (16.40 cm) however, minimum was observed in genotype PKN-32 (10.07 cm) (Plate 7 and Plate 8). The variation in fruit size was influenced by several factors *viz.*, number of fruits on the tree, production of optimum photosynthates, soil moisture status and fertility of the soil. These factors might play an important role in production of optimum size of fruit and maintenance of its quality. Variation in fruit width might also due to accumulation of maximum seeds in horizontal plain of the fruit. Gibberellins produced in the seeds might also influence the size of the fruit. These findings are in agreement with the work of Thakur and Singh (1967), Mathakar (2005), Prakash *et al.* (2014), Vijay *et al.* (2017), Yadav *et al.* (2017), Chandel *et al.* (2018), Meghana *et al.* (2020) and Handique *et al.* (2022).

In commercial cultivation, both growers and consumers preference is always towards the larger size fruits. Maximum fruit weight was observed in PKN-25 (2352.92 g) however, minimum fruit weight was observed in PKN-37 (1035.34 g). Fruit volume was observed highest in genotype PKN-25 (2262.46 cc) which was statistically on par with PKN-20 (2251.72 cc) and lowest was observed in genotype PKN-37 (987.30 cc). This variation in fruit weight and volume may be due to higher canopy spread which contribute to the accumulation of higher photosynthates in fruit to attain optimum fruit size. Beside this, the age, vigour of plant and eco-physiological conditions may also influence the fruit weight. These results are in consonance with those of Thakur and Singh (1967), Mangave (1982), Agustin (1999), Dasilva *et al.* (1999), Liu (2000),

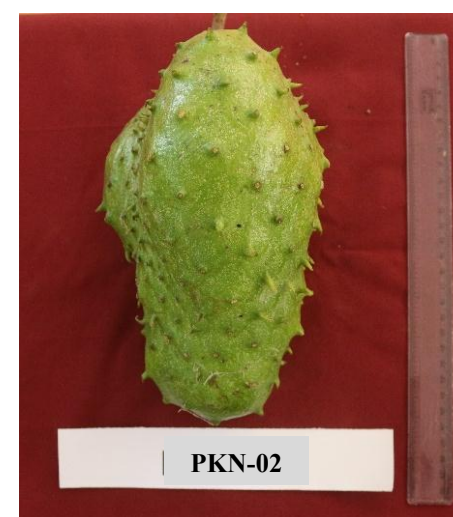
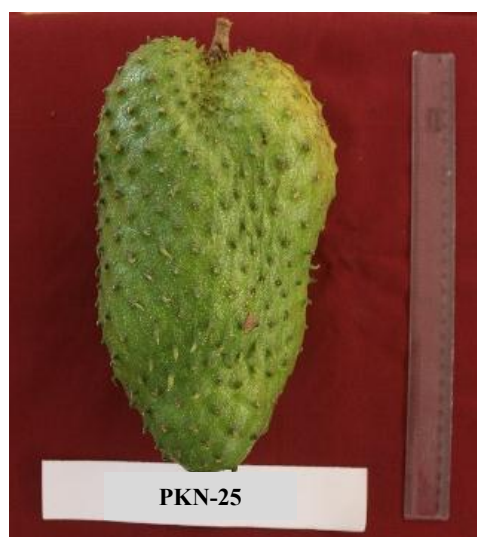


Plate 7. Variation in fruit parameters of superior genotypes of *Annona muricata* L.



PKN-25



PKN-20



PKN-24



PKN-03

Plate 8. Cross section of superior genotypes of *Annona muricata* L.

Mathakar (2005), Rao and Subramanyam (2011), Girwani *et al.* (2011), Hashmi and Pawar (2012), Ismadi *et al.* (2019), Priyanka *et al.* (2018), Kumar *et al.* (2018), Yashwant *et al.* (2018), Meghana *et al.* (2020), Handique *et al.* (2022) and Rajadurai *et al.* (2022).

Pulp content in fruit crops is considered as one of the important selection criteria for varietal development or recommendation. Higher pulp weight was observed in genotype PKN-25 (1624.40 g) followed by PKN-20 (1555.13 g) and lowest pulp weight (572.30 g) was observed in genotype PKN-39. Higher pulp weight is essential character for fruit to fetch higher market price. Many factors attribute to higher pulp weight viz., fruit weight, fruit size, thin peel and less number of seeds. The pulp weight, which solely contributes towards edible portion. The composition of minimum seed weight, minimum pericarp weight and maximum pulp weight was good criterion for selecting the superior genotypes. These findings are in accordance with the earlier reports of Dasilva *et al.* (1999), Dikshit *et al.* (2008), Bhatnagar *et al.* (2012), Yadav *et al.* (2017), Chandel *et al.* (2018), Meghana *et al.* (2020) and Rajadurai *et al.* (2022).

Usually lesser number of seeds per fruit preferred for table and processing purpose. Maximum number of seeds per fruit was observed in genotype PKN-34 (99.33) and minimum number of seeds per fruit was observed in genotype PKN-20 (40.67). Maximum seed weight per fruit was observed in PKN-34 having weight (44.70 g). However, minimum seed weight per fruit was observed in PKN-20 (18.30 g). The increased numbers of seeds were might be due to more number of areoles. Minimum number of seeds per fruit might be due to higher pulp per cent and also due to the accumulation of lesser photosynthates into the seeds. These findings are in accordance with the work of Dasilva *et al.* (1999), Mathakar (2005), Dikshit *et al.* (2008), Bhatnagar *et al.* (2012), Kumar (2015), Yadav *et al.* (2017), Chandel *et al.* (2018), Yashwant *et al.* (2018), Meghana *et al.* (2020) and Handique *et al.* (2022).

5.3.2 Yield parameters

Among fifty genotypes only thirty-four genotypes are fruiting in nature, it may be due to presence of irregular or alternate bearing habit. The causes for irregular bearing habit are environmental factors, biotic factors, effect of genotype, effect of leaves and flowering habit, effect of tree age and vigour, effect of pollination on fruit set, hormonal imbalance and crop overload. These results are confirmation with the findings of Nimisha *et al.* (2019) and Rakesh *et al.* (2023).

Development of high yielding varieties of crops requires information about the nature and magnitude of variability present in the available stock and selection depends on judicious assessment of available data on phenotypic characters that are connected with yield. PKN-25 had the highest number of fruits per tree (34) however, minimum

number of fruits per tree was observed in PKN-27(26). This variation might be due to genetic diversity among number of shoot, shoot length, number of flowers per shoot, fruit set percentage and fruit retention percentage of different selections as well as due to climatic conditions. Significantly maximum fruit yield per tree was observed in PKN-25 (80.00 kg) and it was followed by PKN-20 (75.97 kg) whereas, minimum was observed in PKN-30 (31.27 kg) (Plate 9). Some genotypes produce less yield even after more number of fruits per plant, this might be due to lesser accumulation of photosynthetic products. The yield potential is determined by the genetic architecture and it is a polygenically controlled expression where several other related characters can also contribute to it. Generally, the genotype that gives better performance in respect of growth is also considered to have more yield. Similar kind of variability among number of fruits and yield were also reported by Mathakar (2005), Rao and Subramanyam (2011), Pooja *et al.* (2022) and Rajadurai *et al.* (2022).

5.4 Biochemical parameters

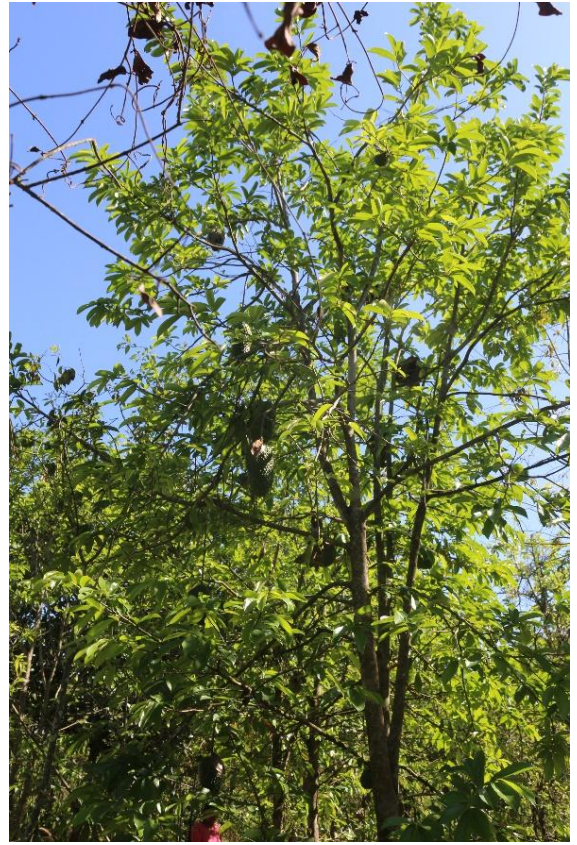
The total soluble solids is measurement of total amount of sugar and soluble minerals which are present in the fruits. The significantly highest total soluble solids were observed in PKN-24 (18.23 °B) however, least was recorded in PKN-12 (16.30 °B). The variation in total soluble solids may be due to genetic make up of plant. These findings were partially supplemented by Dasilva *et al.* (1999), Mathakar (2005), Rao and Subramanyam (2011), Yadav *et al.* (2017), Priyanka *et al.* (2018), Chandel *et al.* (2019) and Rajadurai *et al.* (2022).

Titrate acidity measures the total acid concentration in a fruits. Different kinds of organic acids and the extent of their concentration play an important role in the flavour of a fruit. Titrate acidity was observed maximum in PKN-39 (1.25%) followed by PKN-32 (1.23%) and minimum titrate acidity was recorded in PKN-24 (0.74%). In majority of fruit crops, if total soluble solids are increasing definitely acidity will be decreased. These findings were in conformity with the work of Mathakar (2005), Hashmi and Pawar (2012), Yadav *et al.* (2017), Priyanka *et al.* (2018) and Chandel *et al.* (2019).

The highest content of reducing, non-reducing and total sugars recorded in PKN-03 (8.87 %), PKN-20 (3.79 %) and PKN-24 (11.97 %), respectively. Lowest reducing, non-reducing and total sugars recorded in PKN-47 (6.79 %), PKN-29 (2.14 %) and PKN-32 (9.37 %), respectively. Sugars are the primary products of photosynthesis and perform multiple roles in plants as energy and carbon transport molecules, hormone like signalling factors, from which plants make proteins, polysaccharides, oils and woody materials. It is also responsible for resistance mechanism against biotic stresses. Sugars play important role in osmotic adjustment and in providing protection against various types of stresses. Sugar content of fruit is



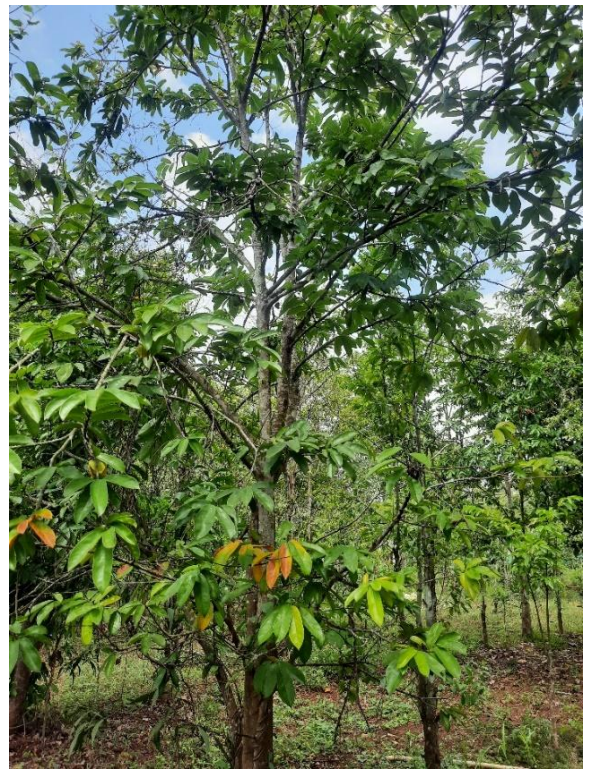
PKN-25



PKN-20



PKN-24



PKN-03

Plate 9. Superior genotypes of *Annona muricata* L. genotypes for yield (PKN-25 and PKN-20) and quality attributes (PKN-24 and PKN-03)

the only factor which determines the sweetness of pulp. These findings are in accordance with Mathakar (2005), Yadav *et al.* (2017) and Chandel *et al.* (2019).

TSS: acid is a key characteristic determining the taste, texture and feel of the fruit segment. TSS to acid ratio was observed maximum in PKN-24 (24.64) and minimum in genotype PKN-39 (13.28). The variation among genotypes attributed to the genetic make up of plant. These findings were in conformity with the work of Mathakar (2005), Yadav *et al.* (2017) and Idate *et al.* (2019).

For good taste and acceptance, sugar and acid ratio is one of the important parameter which contributes towards characteristic flavour of fruits. It is also indicator of commercial and sensory ripeness. The ratio of sugar and acid content was found maximum in PKN-24 (16.18) and minimum in PKN-39 (7.81). These differences in sugar: acid ratio in different genotypes were due to different level of sugars and titratable acidity. These difference might be due to their inherent characters. These findings were in line with the views reported by Yadav *et al.* (2017) and Idate *et al.* (2019).

Ascorbic acid plays a significant role in the control of cell division. Ascorbic acid functions as a major redox buffer and as a cofactor for enzymes involved in regulating photosynthesis, hormone biosynthesis and regenerating other antioxidants. Maximum ascorbic acid content of 22.68 mg/100 g was recorded in PKN-02 whereas, minimum was recorded in PKN-37 genotype (16.12 mg/100 g). It is a fact that, if total soluble solids content increase, the ascorbic acid contents of fruit also increases because the precursor of ascorbic acid is glucose-6-phosphate. Ascorbic acid concentration tends to increase with increased exposure of the plant to light during growth and development. The results were also supported by Santhoshkumar and Brindha (2015), Yadav *et al.* (2017), Vijay *et al.* (2017) and Chandel *et al.* (2019).

Antioxidants play a vital role in various diseases, which cause abiotic stress in plants. Biologically, these stresses can be controlled by the many bio-inoculants which can enhance the reactive oxygen species (ROS) inside the plant body during stress. The antioxidant activity reduces the toxic effects of oxidants and thus prevents the cellular damage caused by free radicals. Highest antioxidant activity was observed in PKN-03 (70.13 %) and lowest was observed in PKN-31, PKN-37 and PKN-47 (65.38 %, respectively) genotypes. Genetic, environmental conditions and physiological factors may modify the antioxidant activity in plants. These findings are in agreement with the study of Santhoshkumar and Brindha (2015), Victoria *et al.* (2016) and Hashim *et al.* (2020).

Plants accumulate phenolic compounds which act as inhibitor or toxicant to harmful nematodes, insects and herbivores. Hence, phenols regulate crucial

physiological functions in plants to resist against different stress conditions and also for therapeutic purpose in pharmaceuticals. The highest total phenolic content of pulp was recorded in PKN-02 and PKN-24 (126.48 mg GAE/100g) and minimum was observed in PKN-15 (112.06 mg GAE/g dry weight). The variation in quality parameters among the cultivars may be due to their genetic nature which determine the capability to absorb nutrients from 'source' and their metabolism for synthesis of sugars and other products for the sink. Interpretation of similar studies was carried out by Radunic *et al.* (2015), Santhoshkumar and Brindha (2015) and Amanda *et al.* (2015).

5.5 Genetic variability studies

Genetic variability is variation in the genetic traits within population. Genotypic and phenotypic coefficient of variation helps plant breeders to identify genotypes that exhibit high genetic potential and phenotypic performance for specific traits. Genotypes with high genotypic coefficient of variation (GCV) are likely to respond well to selective breeding efforts because they possess greater genetic diversity for the trait. Phenotypic coefficient of variation (PCV) helps in recognizing the overall variability in the trait, which includes genetic and environmental components.

Low GCV and PCV can indicate reduced genetic diversity within population, which can lead to genetic erosion and susceptibility to diseases and changing environmental conditions. Genetic variability parameters provides raw material for selecting and developing superior genotypes from the existing population. Hence, the mean, range, phenotypic coefficient of variation, genotypic coefficient of variation, heritability and genetic advance as per cent of mean for different characters in *Annona muricata* have been enumerated to drawn out the acceptable results from the genotypes studied in the present experiment.

5.5.1 Genetic variability for growth, yield and quality attributes

Among the different characters studied, stem girth, chlorophyll 'b', fruit length, fruit weight, fruit volume, pulp weight, number of seeds per fruit and seed weight per fruit recorded high GCV and PCV. These characters having higher range of variation in the germplasm and have better scope of improvement through selection. High variation of genotypic and phenotypic coefficients suggested the presence of considerable value of variability further selection could be practiced due to the effect of additive genes. These results were in confirmation with finding of Ranjan *et al.* (2009), Mir *et al.* (2010), Singh and Mishra (2010), Singh *et al.* (2012), Nayak *et al.* (2013), Rabha *et al.* (2013), Gupta *et al.* (2015), Rao *et al.* (2016), Marboh *et al.* (2018), Perveen *et al.* (2018), Sridhar *et al.* (2018), Anita *et al.* (2019) and Gupta and Kour (2019).

Moderate level of GCV and PCV were observed in tree height, leaf length, leaf breadth, petiole length, chlorophyll 'a', total chlorophyll, fruit width, titratable acidity,

non-reducing sugars, TSS: acid, sugar: acid and ascorbic acid. This suggests the need for generation of variability either by introduction, exploration or by hybridization to get substantial gain in their improvement. Similar results were also reported by Rabha *et al.* (2013) and Gill and Navprem (2015).

Pericarp thickness, TSS, reducing sugars, total sugars, antioxidant activity and total phenolic content recorded low level of GCV and PCV. The coefficient of variation was low for both genotypic and phenotypic level which emphasizing on low variation among the genotype for the traits which indicated limited scope of selection for respective traits due to the high effect of environment for their inheritance.

5.5.2 Heritability and genetic advance as percent of mean (GAM) for growth, yield and quality attributes

The heritability is the resemblance between parents and their progeny, whereas the genetic advance as mean per cent provide the information about expected gain for particular characters after selection. It is not just the magnitude of variation but the extent of heritable variation matters for achieving gains in selection programme. Heritability is measurement of transmission of traits from one generation to other next generation and consistent performance of progeny in succeeding generation which depends on the magnitude of inherent part of variant.

High heritability coupled with high genetic advance as percent of mean was recorded for the traits *viz.*, tree height, stem girth, leaf length, leaf breadth, petiole length, chlorophyll 'a', chlorophyll 'b', total chlorophyll, fruit length, fruit width, fruit weight, fruit volume, pulp weight, number of seeds per fruit, seed weight, fruit yield per tree, fruit yield per hectare, titratable acidity, reducing sugars, non-reducing sugars, total sugars, TSS: acid, sugar: acid and ascorbic acid. This indicates that selection based on phenotypic performance may be useful for these characters. These traits were less influenced by environmental factors. High heritability estimates coupled with high genetic advance, indicating predominance of additive gene action in the inheritance of these traits, hence simple selection would be effective for genetic improvement of said characters in desired direction. Effective selection can be achieved only when additive effects are sufficiently higher than the environmental effect. The effectiveness of selection depends not only on heritability but also on genetic advance. The similar results were proposed by Ranjan *et al.* (2009), Mir *et al.* (2010), Singh and Mishra (2010), Rabha *et al.* (2013), Jambhale *et al.* (2014), Gupta *et al.* (2015), Lal *et al.* (2016), Rao *et al.* (2016), Marboh *et al.* (2018), Perveen *et al.* (2018), Sridhar *et al.* (2018), Anita *et al.* (2019) and Gupta and Kour (2019).

High heritability with moderate genetic advance as percent of mean (GAM) was observed in pericarp thickness and number of fruits per tree. High heritability with low GAM was observed for traits total soluble solids (TSS) and total phenolic content. Low

heritability with low GAM was observed for the trait antioxidant activity. Low heritability indicates that the trait is controlled by environmental conditions, making it less responsive to selective breeding based on genetic factors. In practical terms, when dealing with traits that have low heritability and low GAM, plant breeders may find it challenging to make significant improvements through traditional breeding methods. They may need to consider other approaches such as changing environmental conditions, incorporating non-genetic factors or exploring alternative breeding strategies to achieve the desired improvements in the trait.

5.6 Correlation studies

Correlation studies helps to identify associations between different traits in plants. Positive correlation is relationship between two variables in which they move in the same direction. Positive correlations between traits may indicate that they share common genetic factors or that there are pleiotropic effects, where a single gene influences multiple traits. Negative correlation is situations where two or more traits of plants are inversely related. It can arise from various biological, genetic and physiological factors. Correlation studies are essential tools in plant breeding for understanding trait associations, prioritizing traits, uncovering genetic relationships and ultimately improving crop varieties to meet the changing demands of agriculture.

The present investigation revealed that the difference between values of genotypic correlation coefficients and phenotypic correlation coefficients, was very low indicating that there is a strong inherent association between the various characters studied. The narrow difference between genotypic and phenotypic correlation coefficients depicted a low environmental effect on the expression of these characters with fruit yield per tree and due to the strong genetic makeup of the evaluated material. A strong positive association of traits with yield may be due to linkage and pleiotropy.

Fruit length

The correlation studies revealed that fruit length had positive and highly significant correlation with fruit width, fruit weight, fruit volume, pulp weight, TSS, total sugars, ascorbic acid, antioxidant activity and fruit yield per tree. While, number of seeds and titratable acidity recorded highly negative significant correlation with fruit length at both phenotypic and genotypic level. These findings are in confirmation with the findings of Inamdar (2000), Sharma *et al.* (2006), Islam *et al.* (2010) and Pooja *et al.* (2018).

Fruit width

During experimental period, fruit width exhibited highly significant and positive correlation with fruit weight, fruit volume, pulp weight, total sugars, ascorbic acid and fruit yield per tree. The antioxidant activity shown significant positive

correlation with fruit width. The non-significant positive correlation was exhibited by TSS for fruit width. Whereas, fruit width was highly significant and negatively correlated with number of seeds per fruit. The titratable acidity had significant negative correlation with fruit width at both phenotypic and genotypic level. Similar results were observed in Inamdar (2000), Mir *et al.* (2006), Islam *et al.* (2010), Gill and Navprem (2015) and Pooja *et al.* (2018).

Fruit weight

The result revealed that fruit weight had highly significant and positive correlation at both phenotypic and genotypic level with fruit volume, pulp weight, TSS, total sugars, ascorbic acid, antioxidant activity and fruit yield per tree. However, fruit weight showed highly significant and negative correlation with number of seeds and titratable acidity. These results are similar to that of Mir *et al.* (2006), Sharma *et al.* (2006), Islam *et al.* (2010), Vartika *et al.* (2012), Jambhale *et al.* (2014), Gill and Navprem (2015) and Gangappa *et al.* (2022).

Fruit volume

The experimental results showed that fruit volume was highly significant and positively correlated at both phenotypic and genotypic level with pulp weight, TSS, total sugars, ascorbic acid, antioxidant activity and fruit yield per tree. Whereas, number of seeds per fruit and titratable acidity were highly significant and negatively correlated with fruit volume. These findings are in agreement with the findings of Mir *et al.* (2006), Vartika *et al.* (2012) and Reeta (2017).

Pulp weight

During the study, pulp weight showed highly significant and positive correlation with TSS, total sugars, ascorbic acid, antioxidant activity and fruit yield per tree at both phenotypic and genotypic level. While, pulp weight had highly significant and negative correlation with number of seeds per fruit and titratable acidity. These results were similar with that of Vartika *et al.* (2012), Reeta (2017) and Pooja *et al.* (2018).

Number of seeds per fruit

The result observed in the present study revealed that number of seeds per fruit was highly significant and positive correlation at both phenotypic and genotypic level with titratable acidity. However, number of seeds per fruit was highly significant and negatively correlated with TSS, total sugars, ascorbic acid, antioxidant activity and fruit yield per tree. These are agreement of with findings of Inamdar (2000).

Total soluble solids

In the present study, total soluble solids (TSS) was highly significant and positively correlated at both phenotypic and genotypic level with total sugars, ascorbic acid, antioxidant activity and fruit yield per tree. Whereas, TSS was highly significant

and positively correlated with titratable acidity. These are similar with results of Krishna *et al.* (2017) and Pooja *et al.* (2018).

Titratable acidity

The titratable acidity trait studied in correlation exhibited highly significant and negative correlation at both phenotypic and genotypic level with total sugars, ascorbic acid, antioxidant activity and fruit yield per tree. These results are agreement with the findings of Gill and Navprem (2015) and Gangappa *et al.* (2022).

Total sugars

The present study revealed that total sugars is highly significant and positive correlation at both phenotypic and genotypic level with ascorbic acid, antioxidant activity and fruit yield per tree. These are in line with findings of Krishna *et al.* (2017), and Pooja *et al.* (2018).

Ascorbic acid

The trait ascorbic acid exhibited highly significant and positive correlation at both phenotypic and genotypic level with antioxidant activity and fruit yield per tree. These are agreement with Meena and Singh (2003).

Antioxidant activity

The experimental study revealed that antioxidant activity showed highly significant and positive correlation with fruit yield per tree.

5.7 Path co-efficient analysis

Path analysis explore the direct and indirect relationship between multiple traits. Every component trait will have a direct and indirect effect on yield. Path co-efficient analysis offered a much more realistic interpretation of the factors involved. Based on these effects exerted by the characters on the yield, one can consider that particular trait for improvement of the crop.

Fruit length

Results revealed that fruit length exerted a negative direct effect on fruit yield per tree through a indirect positive effect of number of seeds per fruit, titratable acidity and negative indirect effect of fruit width, fruit weight, fruit volume, pulp weight, total soluble solids, total sugars, ascorbic acid and antioxidant activity. These results are similar with the Majumder *et al.* (2012).

Fruit width

During the investigation fruit width had showed positive direct effect on fruit yield per tree through a indirect positive effect of fruit length, fruit weight, fruit volume, pulp weight, TSS, total sugars, ascorbic acid, antioxidant activity. However, a negative

indirect effect of number of seeds per fruit and titratable acidity. These are similar with findings of Kumar *et al.* (2013), Gill and Navprem (2015), Gupta *et al.* (2015), Lal *et al.* (2016) and Lal *et al.* (2017).

Fruit weight

Fruit weight exhibited a positive direct effect on fruit yield per tree through an indirect positive effect of fruit length, fruit width, fruit volume, pulp weight, TSS, total sugars, ascorbic acid, antioxidant activity. While, a negative indirect effect of number of seeds per fruit and titratable acidity. These results are agreement with the results of Mir *et al.* (2006), Mir *et al.* (2009), Jambhale *et al.* (2014), Gill and Navprem (2015), Gupta *et al.* (2015), Lal *et al.* (2016) and Lal *et al.* (2017).

Fruit volume

In the present study, fruit volume showed a negative direct effect on fruit yield per tree through an indirect positive effect of number of seeds per fruit and titratable activity. In contrast, a negative indirect effect of fruit length, fruit width, fruit weight, pulp weight, TSS, total sugars, ascorbic acid and antioxidant activity. These are similar with the finding of Majumder *et al.* (2012).

Pulp weight

The path estimates disclosed that, pulp weight exerted a positive direct effect on fruit yield per tree through a positive indirect effect of fruit length, fruit width, fruit weight, fruit volume, TSS, total sugars, ascorbic acid and antioxidant activity. Whereas, negative indirect effect was expressed by number of seeds per fruit and titratable acidity. These findings are agreement with the results of Lal *et al.* (2016).

Number of seeds per fruit

During the investigation, the results revealed that number of seeds per fruit exhibited a negative direct effect on fruit yield per tree through a positive indirect effect of fruit length, fruit width, fruit weight, fruit volume, pulp weight, TSS, total sugars, ascorbic acid and antioxidant activity. In contrast, negative indirect effect of titratable acidity. These results are conformity with the results of Gupta and Kour (2019).

Total soluble solids

Total soluble solids on fruit yield per tree showed a negative direct effect through a positive indirect effect of number of seeds per fruit and titratable acidity. While, negative indirect effect was expressed by fruit length, fruit width, fruit weight, fruit volume, pulp weight, total sugars, ascorbic acid and antioxidant activity. These results are in agreement with the findings of Lal *et al.* (2016).

Titratable acidity

Titratable acidity showed negative direct effect on fruit yield per tree through a positive indirect effect of fruit length, fruit width, fruit weight, fruit volume, pulp

weight, TSS, total sugars, ascorbic acid and antioxidant activity. Whereas, negative indirect effect was expressed by number of seeds per fruit. These results are agreement with the results of Lal *et al.* (2017).

Total sugars

In the present study, total sugars exerted a negative direct effect on fruit yield per tree through a positive indirect effect of number of seeds per fruit and titratable acidity. Whereas, negative indirect effect was expressed by fruit length, fruit width, fruit weight, fruit volume, pulp weight, TSS, ascorbic acid and antioxidant activity. Similar results were obtained by Meena and Singh (2003).

Ascorbic acid

The path estimates disclosed that, ascorbic acid exhibited a negative direct effect on fruit yield per tree through a positive indirect effect of number of seeds per fruit and titratable acidity. Whereas, negative indirect effect was expressed by fruit length, fruit width, fruit weight, fruit volume, pulp weight, TSS, total sugars and antioxidant activity. These findings are in confirmation with the findings of Lal *et al.* (2016).

Antioxidant activity

The trait antioxidant activity had negative direct effect on fruit yield per tree through a positive indirect effect of number of seeds per fruit and titratable acidity. While, negative indirect effect was expressed by fruit length, fruit width, fruit weight, fruit volume, pulp weight, TSS, total sugars and antioxidant activity.

5.8 Genetic divergence studies

The success of a breeding program depends upon the selection of parents. It has been found that the progenies derived from crossing divergent parents give divergent and useful progenies. The multivariate analysis based on Mahalanobis D^2 statistics is employed as a powerful tool for measuring genetic divergence among the tested genotypes.

5.8.1 Mahalanobis generalized distance

The material used for the present study includes 34 genotypes of *Annona muricata* were grouped into six clusters using Tocher's method (Fig. 1). Among the six clusters studied, Cluster II was the largest having ten genotypes followed by cluster III having nine genotypes and cluster I, IV, VI and V were the least with one genotype each. The findings are similar to the results of Ranjan *et al.* (2009), Jana *et al.* (2015) and Gangappa *et al.* (2022).

The intra-cluster distance revealed that cluster III with nine genotypes showed maximum intra-cluster diversity depicting the presence of wide genetic divergence

among the constituent genotypes. The higher degree of divergence among the genotypes within a cluster would produce more segregating breeding material. Selection within such a cluster might be executed based on the maximum mean value for the desirable characters.

Based on the distance between clusters, *i.e.*, inter-cluster distances, the maximum divergence was observed between cluster V and cluster VI. Fruit yield per tree had contributed the maximum to the genetic divergence followed by titratable acidity, antioxidant activity, total soluble solids, ascorbic acid, number of seeds per fruit, pulp weight, fruit width, fruit volume, fruit weight, total sugars and fruit length.

5.8.2 Cluster mean analysis

The results revealed that the mean cluster value for fruit length was maximum in cluster IV followed by cluster I, cluster VI, cluster III, cluster II and minimum was recorded in cluster V. Therefore, crosses between these respective clusters may be used to improve fruit length which ultimately contributes towards yield.

The cluster mean values for fruit width was found to be highest in cluster IV followed by cluster I, cluster III, cluster VI, cluster II and lowest cluster mean value was recorded in cluster V. Hence, crosses between genotypes belonging to these respective clusters would be helpful for achieving improvement in fruit width.

The cluster IV recorded maximum cluster mean value for fruit weight followed by cluster I, cluster VI, cluster III, cluster II and minimum in cluster V. This indicates that crosses between genotypes belonging to these clusters may be tried to improve fruit weight.

The fruit volume recorded maximum cluster mean value in cluster IV followed by cluster VI, cluster I, cluster III, cluster II and minimum was in cluster V. This indicates that the crosses between genotypes belonging to this cluster may be tried to improve the character.

The diversity studies revealed that the maximum cluster mean value for pulp weight was recorded in cluster IV followed by cluster VI, cluster I, cluster III, cluster II and minimum was recorded in cluster V. Hence, crosses between genotypes includes in these respective clusters may be tried to improve this character which ultimately contributes for yield.

The cluster mean value for number of seeds per fruit was highest in cluster V followed by cluster II, cluster III, cluster VI, cluster I and lowest was reported in cluster IV. Hence, the crosses between the genotypes belonging to this cluster may be tried to improve number of seeds per fruit.

Fruit yield per tree recorded higher cluster mean value in cluster IV followed by cluster I, cluster VI, cluster III, cluster II and lower in cluster V. Hence, crosses between the genotypes of these clusters mentioned may be tried to improve the fruit yield.

The cluster I recorded highest value for total soluble solids followed by cluster IV, cluster VI, cluster V, cluster III and lowest was reported in cluster II. Therefore, crosses between these respective clusters may be used to improve the TSS content so it ultimately improves the quality of fruit.

The trait titratable acidity recorded maximum cluster mean value in cluster II followed by cluster III, cluster V, cluster VI, cluster IV and minimum was documented in cluster I. Hence, crosses between genotypes belonging to these respective clusters would be helpful for achieving improvement in acidity content.

The total sugars exhibited higher cluster mean value in cluster I followed by cluster IV, cluster VI, cluster III, cluster V and lowest value was found in cluster II. Therefore the crosses among the genotypes belonging to these clusters may be tried to improve total sugars.

The cluster mean value for ascorbic acid found to be maximum in cluster IV followed by cluster I, cluster VI, cluster III, cluster II and minimum was found to be cluster V. This indicates that the crosses between the genotypes belonging to this cluster may be tried to enhance ascorbic acid content.

The cluster VI recorded highest cluster mean value for antioxidant activity followed by cluster I, cluster IV, cluster III, cluster II and lowest value was found to be in cluster V. Crosses between genotypes belonging to these respective clusters may be tried to improve this character which ultimately contributes to quality.

Conclusion

From the present study, we can conclude that there was a considerable variations found in *A. muricata* genotypes. The PKN-25 genotype found to be superior compared to all other genotypes with respect to fruit and yield parameters followed by PKN-20 genotype. However, the genotype PKN-24 found to be promising for quality attributes in terms of TSS, total sugars, TSS: acid and sugar: acid and total phenolic content. However, PKN-03 genotype is most promising for antioxidant property.

In general, phenotypic coefficients of variation (PCV) were higher in magnitude than genotypic coefficients of variation (GCV) and narrow difference between them indicates the less environmental influence on expression of trait. High heritability coupled with high genetic advance was observed for all the characters except pericarp thickness, number of fruits per tree, total soluble solids (TSS), total phenolic content and antioxidant activity.

Correlation studies revealed that fruit length, fruit width, fruit weight, fruit volume and pulp weight exhibited highly significant and positive association with yield at both phenotypic and genotypic level. Whereas, biochemical parameters viz., total soluble solids, total sugars, ascorbic acid and antioxidant activity were highly significant and positive association with yield at both phenotypic and genotypic level. Path analysis for yield per tree showed direct and positive association with fruit width, fruit weight and pulp weight.

Fruit yield per tree contributed the maximum to the genetic divergence among the parameters studied followed by titratable acidity, antioxidant activity, total soluble solids, ascorbic acid, number of seeds per fruit, pulp weight, fruit width, fruit volume, fruit weight, total sugars and fruit length. Hence, these traits may be given high attention while selecting lines for hybridization programme to generate large variability.

Future line of work

- Analysis of acetogenin content in the genotypes which is having anti-cancerous property can be taken
- Diversity analysis using molecular markers can be taken up for further confirmation of present study
- Estimation of bio-chemical parameters of leaves and seeds need to be carried out

SUMMARY

VI SUMMARY

Annona muricata L. an important underutilized fruit crop is gaining importance day by day because of anti-cancerous property and ample use in the pharmaceutical industries. The non-availability of superior genotypes and varieties is the major drawback in the cultivation. So in order to identify superior genotypes, the present investigation was carried on “Evaluation of *Annona muricata* L. genotypes for growth, yield and quality parameters” in Muddinakoppa village of Shivamogga district. The salient findings of the present investigation are summarized below.

Among 50 genotypes, maximum tree height was recorded in PKN-03 (5.12 m) and minimum was in PKN-22 (2.42 m). The highest value for stem girth was observed in PKN-16 (70.00 cm) and lowest value was recorded in PKN-44 (22.80 cm). Spreading growth habit was observed in maximum number of genotypes (46) whereas, erect growth habit was observed in only 4 genotypes. Maximum leaf length was observed in PKN-05 (16.60 cm) and lowest was observed in PKN-41 (10.63 cm). Maximum leaf breadth was observed in PKN-20 (6.60 cm) whereas, minimum value was observed in PKN-22 (4.10 cm) which were significantly different from other genotypes. Green leaves were observed in all 50 genotypes.

Maximum genotypes (31) had shown lanceolate leaf shape, only 19 genotypes exhibited ovate leaf shape. Acuminate leaf apex shape was observed in maximum (39) genotypes whereas, rounded leaf apex shape was observed in minimum (11) genotypes. All the 50 genotypes exhibited acute leaf base shape and entire leaf margin. Longer petiole length (0.9 cm) was observed in PKN-28 genotype whereas, shorter petiole length (0.5 cm) was observed in PKN-09, PKN-30, PKN-37 and PKN-43 genotypes. The maximum value for chlorophyll ‘a’ was found in PKN-01 (1.99 mg/g) whereas, minimum was found in PKN-44 (1.20 mg/g). The maximum value for chlorophyll ‘b’ was found in PKN-01 and PKN-14 (0.83 mg/g) and minimum value was found in PKN-44 (0.31 mg/g). The maximum value for total chlorophyll was recorded in PKN-01 (2.82 mg/g) however, minimum value was found in PKN-44 (1.51 mg/g).

The PKN-25 genotype recorded maximum value for fruit length (29.10 cm), fruit width (16.40 cm), fruit weight (2352.92 g), fruit volume (2262.46 cc) and pulp weight (1624.40 g). However, minimum value for fruit length (13.60 cm) and fruit width (10.07 cm) were observed in genotypes PKN-47 and PKN-32, respectively. The genotype PKN-37 recorded lowest value for fruit weight (1035.34 g) and fruit volume (987.30 cc).

Pericarp thickness was observed maximum in PKN-17 (3.1 mm) and minimum was observed in genotype PKN-26 (2.2 mm). Highest number of seeds per fruit was observed in genotype PKN-34 (99.33) and lowest was observed in genotype PKN-20

(40.67). Significantly maximum seed weight per fruit was observed in PKN-34 having weight (44.70 g) however, minimum value was observed in PKN-20 (18.30 g).

The genotype PKN-25 recorded highest number of fruits per tree (34), fruit yield per tree (80.00 kg) and fruit yield per hectare (22.24 t/ha). Whereas, minimum number of fruits per tree was observed in PKN-27(26). The lowest fruit yield per tree (31.27 kg) and fruit yield per hectare (8.69 t/ha) were observed in PKN-30 genotype.

Significantly highest total soluble solids was recorded in PKN-24 (18.23 °B) and least was recorded in PKN-12 (16.30 °B). The maximum value for titratable acidity was observed in PKN-39 (1.25%) and minimum was recorded in PKN-24 (0.74%). The genotype PKN-03 had the highest content of reducing sugar (8.87 %) whereas, lowest content of reducing sugar (6.79 %) was observed in PKN-47. Highest content of non-reducing sugar was observed in PKN-20 (3.79 %) and lowest was observed in PKN-29 (2.14 %) genotype. Total sugar content was observed highest in PKN-24 (11.97 %) and genotype PKN-32 (9.37 %) recorded lowest total sugars content.

The TSS to acid ratio (24.64) and sugar to acid ratio (16.18) were observed maximum in PKN-24 genotype. The lowest TSS to acid ratio and sugar to acid ratio were recorded in the genotypes PKN-39 (13.28) and PKN-39 (7.81), respectively. Maximum ascorbic acid content of 22.68 mg/100 g was recorded in PKN-02 genotype, minimum was recorded in PKN-37 genotype (16.12 mg/100 g). Significantly highest antioxidant activity was observed in PKN-03 (70.13 %) and lowest was observed in PKN-31, PKN-37 and PKN-47 (65.38 %, respectively) genotypes. The highest total phenolic content of pulp was recorded in PKN-02 and PKN-24 (126.48 mg GAE/g dry weight) and minimum was observed in PKN-15 (112.06 mg GAE/g dry weight).

Among the different characters studied, fruit length, fruit weight, fruit volume, pulp weight, number of seeds per fruit and seed weight per fruit recorded high genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV). Moderate level of GCV and PCV were observed in fruit width, titratable acidity, non-reducing sugars, TSS: acid, sugar: acid and ascorbic acid. Pericarp thickness, TSS, reducing sugars, total sugars, antioxidant activity and total phenolic content recorded low level of GCV and PCV.

High heritability coupled with high genetic advance as percent of mean (GAM) was recorded for the traits viz., fruit length, fruit width, fruit weight, fruit volume, pulp weight, number of seeds per fruit, seed weight, titratable acidity, reducing sugars, non-reducing sugars, total sugars, TSS: acid, sugar: acid and ascorbic acid. High heritability with moderate GAM was observed in pericarp thickness. High heritability with low GAM was observed for traits total soluble solids (TSS) and total phenolic content. Low heritability with low GAM was observed for the trait antioxidant activity.

Correlation studies revealed that fruit parameters viz., fruit length, fruit width, fruit weight, fruit volume and pulp weight exhibited highly significant and positive association with yield at both phenotypic and genotypic level except number of seeds per fruit. Whereas, biochemical parameters viz., total soluble solids, total sugars, ascorbic acid and antioxidant activity were highly significant and positive association with yield at both phenotypic and genotypic level. The trait titratable acidity had highly significant and negative correlation with yield at both phenotypic and genotypic level.

During this investigation, the path coefficient analysis revealed that the highest positive direct effects towards fruit yield per tree were contributed by fruit width, fruit weight and pulp weight. Whereas, negative direct effect towards yield per tree was contributed fruit length, fruit volume, number of seeds per fruit, TSS, titratable acidity, total sugars, ascorbic acid and antioxidant activity.

Diversity studies revealed that 34 genotypes of *Annona muricata* were grouped into six clusters using Tocher's method. Among the six clusters studied, Cluster II had the highest number of genotypes (10) followed by cluster III having nine genotypes and cluster I, IV, VI and V were the least with one genotype each.

The intra-cluster distance revealed that cluster III with nine genotypes showed maximum intra-cluster diversity depicting the presence of wide genetic divergence among the constituent genotypes. Based on the distance between clusters, i.e., inter-cluster distances, the maximum divergence was observed between cluster V and cluster VI.

Fruit yield per tree had contributed the maximum to the genetic divergence followed by titratable acidity, antioxidant activity, total soluble solids, ascorbic acid, number of seeds per fruit, pulp weight, fruit width, fruit volume, fruit weight, total sugars and fruit length.

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APPENDICES

VIII APPENDICES

Appendix -I: Monthly mean weather data recorded at ZAHRS, Navile, Shivamogga

Month	Rainfall (mm)	No. of Rainy days	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	
					RH-I (%)	RH-II (%)
November	12.4	1	29.5	18.3	83	61
December	24	2	29.8	17.1	79.1	61.6
January	0	0	30.7	15.1	83.8	49.2
February	0	0	33.1	16.4	67.6	32.0
March	0	0	34.4	18.1	70.0	36.5
April	54	4	36.1	20.7	76.4	37.8
May	87.6	5	34.8	22.7	78.6	47.1
June	57.6	7	31.4	22.5	83.4	66.9
July	165	16	27.6	21.9	91.1	83.8
August	39.2	5	30.0	21.51	91.8	73.0
Total or Mean	439.8	40	31.74	19.43	80.48	54.89

Appendix -II: List of symbols and abbreviations used

Symbols	Abbreviations
No.	Number
@	at
<i>etc.</i>	Et cetera
%	Per cent
°C	Degree centigrade
°B	Degree brix
C.D	Critical difference
S. Em.	Standard error of mean
cm	Centimeter
m	Meter
<i>et al.</i>	and others
<i>i.e.,</i>	That is
<i>viz.,</i>	Namely
cc	Cubic centimeter
mg	Milligram
ml	Milliliter
mm	Millimeter
g	Gram
kg	Kilogram
µg	microgram
g/l	Gram per litre
NaOH	Sodium hydroxide
H ₂ SO ₄	Sulphuric acid
GAE	Gallic acid equivalent
DPPH	2,2 –Diphenyl-1-picrylhydrazyl
cv.	Cultivar
SD	Standard deviation
CV	Coefficient of variation
Fig.	Figure
t	ton

Appendix-III: List of non-bearing genotypes

Sl. No.	Genotypes
01.	PKN-19
02.	PKN-22
03.	PKN-33
04.	PKN-35
05.	PKN-36
06.	PKN-38
07.	PKN-40
08.	PKN-41
09.	PKN-42
10.	PKN-43
11.	PKN-44
12.	PKN-45
13.	PKN-46
14.	PKN-48
15.	PKN-49
16.	PKN-50