EVALUATION OF MACADAMIA (*Macadamia integrifolia* M.) GENOTYPES FOR YIELD AND YIELD ATTRIBUTING TRAITS

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CERTIFICATE

This is to certify that the thesis entitled **'EVALUATION OF MACADAMIA (*Macadamia integrifolia* M.) GENOTYPES FOR YIELD AND YIELD ATTRIBUTING TRAITS'** 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, University of Agricultural and Horticultural Sciences, Shivamogga is a bonafide record of research work carried out by **USHA, D. S. ID NO. MH2TAF0121** (ushads052@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.

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EVALUATION OF MACADAMIA (*Macadamia integrifolia* M.) GENOTYPES FOR YIELD AND YIELD ATTRIBUTING TRAITS

(USHA, D. S.)

ABSTRACT

An experiment was conducted to evaluate different macadamia genotypes (*Macadamia integrifolia* M.) for yield and yield attributing traits in the existing orchard of farmers field at Gajanur village, Shivamogga district of Karnataka during 2017-18. The experiment was laid out in randomized complete block design with three replications involving 10 genotypes. The morphological traits showed variation in terms of tree shape, tree stature, bearing habit, leaf colour, leaf tip, leaf spines, inflorescence colour and peak flowering period. The analysis of variance revealed significant difference for the traits *viz.,* tree height (G-11 : 14.10 m), stem girth (G-6 : 0.62 m), nut weight (G-5 : 10.66 g), nut diameter (G-5 : 2.99 cm), nut volume (G-5 : 11.40 cc), shell weight (G-6 : 6.53 g) shell thickness (G-4 : 3.00 mm), pericarp weight (G-9 : 3.53 g), kernel weight (G-5 : 3.17g), kernel thickness (G-5 : 12.89 mm), kernel recovery per cent (G-5 : 29.73 %), cluster length (G-5 : 10.80 cm), number of nuts per cluster (G-5 : 7.53) and nut yield per tree (G-5 : 16.16 kg). Correlation studies revealed that the nut yield per tree showed highly significant and positive association with kernel weight, kernel thickness, nut weight, cluster length and nuts per cluster. Whereas, nut weight, kernel weight, kernel thickness, cluster length and nuts per cluster exhibited positive direct effect on nut yield per tree. With respect to bio-chemical character higher protein (13.40 %) was recorded in G-5. Among 10 genotypes, G-5 was found superior with respect to nut weight, kernel weight, kernel thickness and kernel per cent. Hence, genotype G-5 found most promising and can be used either for further evaluation or as gene source in macadamia improvement programme.

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ಮಕಡಮಿಯ (*ಮಕಡಮಿಯ ಇಂಟಗ್ರಿಫೋಲಿಯ ಎಮ್.*) ಹಣ್ಣಿನ ವಂಶವಾಹಿ ರೂಪಗಳ ಇಳುವರಿ ಮತ್ತು ಇಳುವರಿಗೆ ಸಂಬಂಧ ಪಟ್ಟ ಗುಣಲಕ್ಷಣಗಳ ಕಾರ್ಯಕ್ಷಮತೆ

(ಉಷಾ, ಡಿ. ಎಸ್.)

ಸಾರಾಂಶ

೨೦೧೭-೧೮ ನೇ ಸಾಲಿನಲ್ಲಿ ಗಾಜನೂರು ಗ್ರಾಮ, ಶಿವಮೊಗ್ಗ ಜಿಲ್ಲೆಯ ರೈತರ ತಾಕುಗಳಲ್ಲಿ ೧೦ ಮಕಡಮಿಯ ಹಣ್ಣಿನ ವಂಶವಾಹಿ ರೂಪಗಳ ಇಳುವರಿ ಮತ್ತು ಇಳುವರಿಗೆ ಸಂಬಂಧ ಪಟ್ಟ ಗುಣಲಕ್ಷಣಗಳ ಬಗ್ಗೆ ಅರಿತುಕೊಳ್ಳಲು ಸಂಶೋಧನೆಯನ್ನು ಕೈಗೊಳ್ಳಲಾಯಿತು. ಈ ಪ್ರಯೋಗವನ್ನು ಮೂರು ಪುನರಾವರ್ತನೆಯೊಂದಿಗೆ ಯಾಧಚ್ಛಿಕ ಬ್ಲಾಕ್ ವಿನ್ಯಾಸದಲ್ಲಿ ಮೌಲ್ಯಮಾಪನ ಮಾಡಲಾಗಿದೆ. ಪ್ರಸ್ತುತ ಅಧ್ಯಯನದಲ್ಲಿ, ಎಲ್ಲಾ ವಂಶವಾಹಿ ರೂಪಗಳ ಇಳುವರಿ ಮತ್ತು ಇಳುವರಿಗೆ ಸಂಬಂಧಿಸಿದ ಗುಣಗಳಲ್ಲಿ ವೈವಿಧ್ಯತೆಯಿದೆ. ಅವುಗಳಲ್ಲಿ ಮರದ ಆಕಾರ, ಎತ್ತರ, ಬೆಳವಣಿಗೆ, ಎಲೆಯ ಬಣ್ಣ, ಎಲೆಯ ಮುಳ್ಳುಗಳು, ಹಣ್ಣುಬಿಡುವಿಕೆ , ಹೂಗೊಂಚಲಿನ ಬಣ್ಣ, ಮತ್ತು ಗರಿಷ್ಠ ಹೂ ಬಿಡುವ ಅವಧಿಯಲ್ಲಿ ವ್ಯತ್ಯಾಸ ಕಂಡುಬಂದಿದೆ. ಹಾಗೆಯೇ ಮರದ ಎತ್ತರ (ಜಿ-೧೧ : ೧೪.೧೦ ಮೀ), ಕಾಂಡದ ಸುತ್ತಳತೆ (ಜಿ-೬ : ೦.೬೨ ಮೀ), ಹಣ್ಣಿನ ತೂಕ (ಜಿ-೫ : ೧೦.೬೬ ಗ್ರಾಂ), ಹಣ್ಣಿನ ಅಗಲ (ಜಿ-೫ : ೨.೯೯ ಸೆಂ. ಮೀ.), ಹಣ್ಣಿನ ಗಾತ್ರ (ಜಿ-೫ : ೧೧.೪೪ ಸಿ.ಸಿ), ಕವಚದ ತೂಕ (ಜಿ-೬ : ೬.೫೩ ಗ್ರಾಂ), ಕವಚದ ದಪ್ಪ (ಜಿ-೪ : ೩.೦೦ ಮಿ.ಮೀ.), ಸಿಪ್ಪೆಯ ತೂಕ (ಜಿ-೯ : ೩.೫೩ ಗ್ರಾಂ), ತಿರುಳಿನ ತೂಕ (ಜಿ-೫ : ೩.೧೭ ಗ್ರಾಂ), ತಿರುಳಿನ ದಪ್ಪ (ಜಿ-೫ : ೧೨.೮೯ ಮಿ.ಮೀ.), ಶೇಕಡವಾರು ತಿರುಳು (ಜಿ-೫ : ೨.೭೩ %), ಹಣ್ಣು ಗೊಂಚಲಿನ ಉದ್ದ (ಜಿ-೫ : ೧೦.೮೦ ಸೆಂ. ಮೀ.), ಒಂದು ಗೊಂಚಲಿಗೆ ಒಟ್ಟು ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆ (ಜಿ-೫ : ೭.೫೩), ಪ್ರತಿ ಮರದ ಹಣ್ಣಿನ ಇಳುವರಿ (ಜಿ-೫ : ೧೬.೧೬ ಕೆ. ಜಿ.), ಮತ್ತು ಪ್ರೋಟಿನ್‌ನ (ಜಿ-೫ : ೧೩.೪೦ %) ಗುಣಗಳಲ್ಲಿ ಮಹತ್ವದ ವ್ಯತ್ಯಾಸವನ್ನು ಗಮನಿಸಲಾಗಿದೆ. ಸಹಯೋಗ ಅಧ್ಯಯನದ ಫಲಿತಾಂಶದ ಪ್ರಕಾರ, ಪ್ರತಿ ಮರದ ಹಣ್ಣಿನ ಇಳುವರಿಯು, ಹಣ್ಣಿನ ತೂಕ, ತಿರುಳಿನ ತೂಕ, ತಿರುಳಿನ ದಪ್ಪ, ಹಣ್ಣು ಗೊಂಚಲಿನ ಉದ್ದ, ಒಂದು ಗೊಂಚಲಿಗೆ ಒಟ್ಟು ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆಗಳೊಂದಿಗೆ ಅತ್ಯಂತ ಸಹಯೋಗವನ್ನು ವ್ಯಕ್ತಪಡಿಸುತ್ತದೆ. ಮಾರ್ಗ ಗುಣಾಂಕದ ಅಧ್ಯಯನದ ಮೂಲಕ ಕಂಡು ಬಂದಿರುವುದೇನೆಂದರೆ, ಹಣ್ಣಿನ ತೂಕ, ತಿರುಳಿನ ತೂಕ, ತಿರುಳಿನ ದಪ್ಪ, ಹಣ್ಣು ಗೊಂಚಲಿನ ಉದ್ದ ಮತ್ತು ಒಂದು ಗೊಂಚಲಿಗೆ ಒಟ್ಟು ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆ ಮರದ ಹಣ್ಣಿನ ಇಳುವರಿಯ ಮೇಲೆ ನೇರ ಸಕಾರಾತ್ಮಕ ಪರಿಣಾಮ ಬೀರಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಪ್ರಸ್ತುತ ಸಂಶೋಧನೆಯ ಪ್ರಕಾರ, ಮಕಡಮಿಯ ಹಣ್ಣಿನ ವಂಶವಾಹಿ ರೂಪಗಳ ಪೈಕಿ ಜಿ-೫ ತಳಿಯು ಉತ್ತಮ ಪ್ರತಿಕ್ರಿಯೆಯನ್ನು ನೀಡಿದ್ದು ಇಂತಹ ಗುಣಗಳನ್ನು ಹೊಂದಿರುವಂತಹ ತಳಿಯನ್ನು ಬಿಡುಗಡೆಗೊಳಿಸಲು ಅಥವಾ ಮುಂದಿನ ಅಭಿವೃದ್ಧಿಗೆ ಉಪಯೋಗಿಸಿಕೊಳ್ಳಬಹುದು.

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Introduction

I INTRODUCTION

Macadamia (*Macadamia integrifolia* M.) commonly known as the Queensland nut or Australian nut belongs to family Proteaceae, mainly cultivated for its edible nuts. Common names include Macadamia, Macadamia nut, Queensland nut, Bush nut, Bauple nut and Maroochi nut. These are the world's most favoured and expensive edible nuts. There are seven species of macadamia but only two species, *Macadamia integrifolia* Maiden Betche, and *M. Tetraphylla* L. are grown commercially (Wallace *et al.*, 1996). It is originated in Subtropical Eastern Australia having a diploid chromosome number of 2n= 48.

The genus includes seven Australian species (*Macadamia claudiensis, M. grandis, M. integrifolia, M. jansenii, M. ternifolia, M. tetraphylla, M. whelaniiseven*) and Indonesian species (*M. hildebrandii*). Only two species, *M. integrifolia* (smooth-shell) and *M. tetraphylla* (rough-shell) are of commercial importance. The remaining species in the genus produce poisonous or inedible nuts. *M. whelanii* and *M. ternifolia,* produce bitter nuts which contain cyanogenic glycosides and these must be consumed only after processing by grinding and steeping followed by cooking to remove these glycosides.

The macadamia nut contains high quantities of mono-unsaturated fatty acids. Human nutrition research in Australia reported that macadamia nut lowers the total and LDL cholesterol levels (Garg *et al*., 2003). Macadamia nut contains 75 per cent oil, carbohydrate (5.0 %), proteins (9.0 %), moisture (1.5 %), mineral matters (1.6 %) and fibre (2.0 %). They are also a good source of niacin, vitamin B_1 (2 %), riboflavin, Iron, calcium, phosphorous, potassium, sodium and selenium (Akhtar *et al*., 2006).

Worldwide production of macadamia nuts accounts for 48,544 MT (kernel basis). World’s 70 per cent of the macadamia production comes from Australia, South Africa and Kenya. Australia is leading in the production, accounting for 15,600 MT followed by South Africa and Kenya (Anon, 2017). In India, ideal locations for growing macadamia tree on a commercial scale are Tamil Nadu, Karnataka, Kerala, Andhra Pradesh, North-eastern States, Himachal Pradesh and Uttar Pradesh.

Macadamia is a medium sized tropical evergreen tree with spreading canopies, reaching width of 5 to10 m and height of 2 to12 m. Leaves are linear obviate, 10 to 15 cm long with a sharp tip with or without spines. Flowering occurs in mid-winter, each raceme of the macadamia tree produces 100 to 300 sweet scented white blossoms. Flowers are bisexual and self-fruitful but yields better when cross pollinated. Flowers are borne on a long, fragrant raceme (8-10 cm) which produces two to ten nuts/inflorescence encased in green fibrous husks, then smooth brown very hard shells around the kernels. Nuts harvested 7-8 months after flowering (Nagao *et* *al.,* 1994), by collecting fallen nuts from the ground. Post-harvest processing involves de-husking the nuts, drying of the nuts and separation of the kernel.

The varieties of *Macadamia integrifolia* are adaptive to diverse agro-climatic conditions; whereas the cultivars of *M. tetraphylla* are more adaptive to cooler climate. Macadamia in general prefers well-drained deep soil and comes up well in regions with temperature ranging 13 to 31 ^{o}C with mean annual rainfall above 125 cm. It is propagated through seeds and vegetative methods. Tree starts bearing four to five years after planting and having productive life span of 50 to 75 years.

The global demand for the macadamia nuts is growing over the years and its production has not kept pace with demand due to macadamia nut varieties perform differently in different climatic situation. Therefore, it is ideal to examine the climate of an orchard site to determine the suitability of a specific variety.

The breeding is a time consuming process in fruit crops especially in macadamia nut which has long juvenile period. Therefore, the selection of superior genotypes from a variable population is a simple and quick method of varietal improvement. So, there is a need to develop cultivars suited for different areas and it is more appropriate to broaden the genetic base by selecting genotypes suitable for different areas having variation in soil and climatic conditions. Hence, considering the likely profitability of the crop and expanding global demand for nuts the evaluation and identification of macadamia genotypes suitable for southern transitional zone of Karnataka is need of the hour.

Keeping in view the tremendous scope of macadamia nut cultivation in different states of India, and the above said fact the present investigation was carried out on the evaluation of macadamia (*Macadamia integrifolia* M.) genotypes for yield and yield attributing traits with the following objectives.

1. To identify the promising suitable macadamia genotypes for growth and yield parameters
2. To study the correlation among yield and yield components in macadamia nut and
3. To study the direct and indirect effects of yield components on yield through path analysis

Review of Literature

II REVIEW OF LITERATURE

Macadamia nut is promisingly a new fruit crop and world's most favoured and most expensive edible nut and it is a medium sized, tropical evergreen tree. The variability is more in sexually as well as cross pollinated crops and the greater diversity in population plays an important role in the selection of superior types and broadening the genetic base. In crop improvement of fruit crops, evaluation of superior chance seedlings from the existing seedling population is the quickest and best method of varietal improvement. The information on the study of evaluation of macadamia nut for morphological and yield attributing traits is very meagre in India. Therefore, the work carried out on other related fruit crops *viz.*, walnut, almond, pisthachio nut, hazelnut, mango, acid lime, guava, annona *spp*, ber, kokam and tamarind have also been reviewed for better understanding of the subject and presented under the following headings.

2.1 Morphological characters of the tree

2.2 Morphological and yield parameters of the nut

2.3 Bio-chemical characters

2.4 Correlation studies

2.5 Path co-efficient analysis studies

2.1 Morphological characters of the tree

2.1.1 Tree canopy

Akca and Tosum (2005) evaluated the performance of walnut cultivars Sebin, Bilecik, Yalova 1 and Yalova 3 in Niksar, Turkey and recorded that 'Yalova 1' exhibited a semi-upright growth habit, whereas 'Yalova 3' and 'Bilecik' had upright growth habit.

Solar and Stampar (2006) conducted research on evaluation of walnut genotypes from a different population of domestic walnut in Slovenia. A total of 1215 seedling trees were assessed and the main selection criteria were the bearing habit and nut qualities. The study indicated that majority of the genotypes exhibited semi erect to semi spreading growth habit. The exception was 'Z-62', which had markedly erect growth habit and 'C-6/7' with spreading branches.

Allan (2007) conducted research on evaluation and identification of old and new macadamia cultivars and selections at Pietermaritzburg and concluded that macadamia exhibits three types of tree canopy *viz*., spreading, upright and round.

A field survey was undertaken to select superior walnut trees of seedling origin in Chamba district of Himachal Pradesh, India. Twenty superior strains of seedling origin were selected and evaluated. The results showed that most of the selected trees were semi-vigorous with spreading growth, sparse branching habit with terminal bearing (Joolka *et al.,* 2008).

2.1.2 Tree height

Dubey *et al*. (2002) studied the growth behaviour of guava germplasm under Sabour conditions during rainy season and reported maximum plant height in Allahabad Safeda (5.4 m).

Athani *et al.* (2007) reported that cultivar Chittidar had maximum plant height of 457.67 and 475.33 cm during 2001-02 and 2002-03 respectively, while, plant girth was highest (11.10 and 13.25 cm) in cv. Seedless of guava.

Pandey *et al.* (2007) evaluated eleven newly developed guava hybrids/selections and reported maximum tree height, trunk girth and canopy spread was found in Hybrid-21.

Rao and Subramanyam (2009) evaluated seven varieties of aonla for scarce rainfall zone under rain fed situation at Horticultural Research Station, Anantapur for three years from 2005-2007 on ten year old trees and reported that highest plant height (4.2 m) was recorded in NA-10 followed by Kanchan (3.9 m).

Kumar *et al.* (2010) conducted a study to evaluate the different Mandarin, Sweet orange and rootstock species under mid-hill conditions of Arunachal Pradesh and recorded the maximum plant height and spread in Mediterranean orange followed by Zigardio mandarin. While, the minimum plant height and spread were recorded in Wilking orange.

2.1.3 Stem girth

Sharma and Sharma (1997) reported that the variability in seedling trees of walnut for trunk girth ranged from 50 to 497 cm among 125 bearing plants.

Sharma (1999) studied the variability of superior Persian walnut genotypes in Himachal Pradesh. The results revealed that great variation existed for tree girth which varied from 36 to 310 cm and considerable variation was also observed in 229 seedling trees for foliage and floral characters.

Prabhuraj (2001) surveyed at Gokak taluk of Belgaum district for jamun genotypes. He observed the highest (97.39 cm) and the lowest (18.77 cm) stem girth in AJB-l and AJG-67 genotypes, respectively.

Srinivas (2002) reported that the maximum trunk diameter (22.28 cm) was recorded in the strain KLN-83 and the minimum (12.82cm) was recorded in the strain KLS-176 in kagzilime during the survey in Indi and Sindagi taluk of Bijapur district, Karnataka.

2.1.4 Leaf characters

Jalikop and Kumar (2000) reported that Arka Sahan, interspecific hybrid, of custard apple produces dark green colour foliage in contrast to the green colour foliage observed in other varieties of custard apple.

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

Solar and Stampar (2006) reported that walnut genotypes ‘Z-62’ and ‘Z-60’ were late in production of leaves (beginning of May) and ‘Z-59’, ‘Z-61’ and NH-5/3 were early in leafing (25 to 30 April).

Allan (2007) reported that *Macadamia tetraphylla* plants have four leaves per node, very spiny leaf margins, short petioles, bronze flush, pink inflorescence and rougher shells. Hybrids usually have one or more of these characteristics *viz*., variable number of leaves per node, spiny leaf margins and bronze/pink flush/inflorescence. *M. integrifolia* plants have three leaves per node, smooth or moderately spiny margins, long petioles, green flush, white inflorescence, and smooth shells.

Gitonga *et al*. (2008) conducted a 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.

Algabal *et al*. (2012) conducted a study on tamarind genotypes and reported that among 36 genotypes studied, 26 were orthotropic, 10 were plagiotropic types and the leaf colour ranged from light green to dark green.

2.1.5 Inflorescence characters

Moncur *et al.* (1985) reported that floral initiation to anthesis took between 137 and 153 days, depending on cultivar and location. Floral initiation occurred during May when minimum temperature between 11 and 15°C, followed by a dormant bud phase lasting 50-96 days in *Macadamia integrifolia.*

Nagao *et al.* (1994) studied the flowering patterns of the macadamia cultivars, 'Kau' (HAES 344), 'Keaau' (HAES 660), and 'Kakea' (HAES 508) and reported that the cultivars had broad flowering peaks with maximum anthesis occurring between January and April and vegetative flushing occurred throughout the year.

Sharma (1999) conducted a variability study on walnut at Kullu, Mandi, Sirmour and Chamba districts of Himachal Pradesh and found that length of the male catkins varied from 6.00 to 16.50 cm, 6.00 to 14.50 cm, 3.00 to 15.90 cm and 5.00 to 18.00 cm respectively.

Olesen (2005) reported that flowering in macadamia ranged from 0 to 43 per cent in tip pruned branches. Most profuse flowering flushes appearing in July, control trees have less synchronized flowering than pruned trees.

Allan (2007) conducted a research on evaluation and identification of old and new macadamia cultivars at Pietermaritzburg and reported that there were two types of inflorescence colours in macadamia *i.e.*, white and pink in two different species of macadamia.

Majumder *et al.* (2011) studied the plant, inflorescence and fruit characteristics of 60 mango genotypes during the period 2007- 2008 and reported the wide variations with respect to per cent flowering shoot (24.00 - 71.33), per cent perfect flower (8.10 - 19.17), per cent fruit set per panicle (9.07 - 29.27).

Ghasemi *et al.* (2012) evaluated phenological and pomological characteristics of walnut and reported that genotypes MS27 and MS29 were completely homogamous.

Silva *et al.* (2014) conducted a study on evaluation of the new cultivars adaptation and yield potential of *Mangifera indica* L. It was found that Bourbon cultivar had the highest flowering period from April to October.

Mariana and Niculina (2017) reported that the flowering period in walnut is influenced by environmental factors, especially temperature. The high temperature in spring accelerates the evolution of the male flowers, but the female flowers are not greatly influenced by temperature.

2.2 Morphological and yield parameters of the nut

Stephenson and Gallagher (1986) reported that apart from cultivar which had the largest influence on yield, high leaf nitrogen (N) and tree dormancy during rapid nut growth and oil accumulation, high leaf boron (B) prior to and during anthesis were important and contributed to higher nut yield in macadamia.

Stephenson and Gallagher (1987) reported that four sprays of 0.02 per cent boron (B) applied monthly to macadamia (*Macadamia integrifolia*, Maiden and Betche) cultivars 'Keauhou' ('246') and 'Kakea' ('508') during early nut development stage increased the nut yield.

Nalini and Santhakumari (1991) observed a maximum number of nuts per panicle (16.0) in cashew cv. BLA-1 followed by K-22-1 (13.5) and the lowest in K-16-1 (5.8) under Annakyam conditions.

Manoj *et al.* (1993) recorded the highest fruits per panicle in H-376 (6.5) followed by H-342 (4.6) and the lowest in H-419 (3.0) in cashew.

Thakur (1993) observed notable differences in various morpho-physical nut characters in walnut, *i.e.*, nut weight (5.76 - 16.8 g), nut width (2.54 - 3.83 cm), nut length (2.94 - 4.46 cm), nut thickness (2.76 - 4.11 cm) and shell thickness (0.05 - 0.28 cm).

Wallace *et al.* (1996) studied the effect of supplementary pollination on initial and final fruit set and nut weight of macadamia cultivars and reported that supplementary cross pollination increased the final fruit set by 57 to 97 per cent, nut weight by 15 per cent and kernel weight by 20 per cent.

Akca and Sen (2001) reported that seedling population of walnut exhibits tremendous genetic variation in yield, tolerance to anthracnose disease and nut quality. Nut weight varied from 9.36 to 18.60 g, kernel weight (6.09-9.58 g), kernel ratio (50.89-65.17 %), shell thickness (0.91-1.76 mm) and nut diameter (29.93 -40.44 mm).

Lauri and Delort (2001) reported that terminal bearing cultivars of walnut are known to produce nuts of regular weight but have low yield and lateral bearing cultivars produce nuts with higher yield.

Mcfadyen *et al.* (2004) reported that macadamia yield increased over time for orchards with crowding levels up to a tree volume of 43500 m^3 / ha and light interception of 94 per cent and for the orchards with tree volume > 43500 m^3 / ha a slight decline in yield over time.

Acka and Tosum (2005) conducted the research on the selection of superior walnut genotypes and reported that maximum nuts per cluster (18) were observed in 'Karabodur' genotype.

Gazmend*et al*. (2005) reported the variability in walnut genotypes. Nut weight (3.8 - 21.1 g), kernel weight (1.85 - 9.8 g), ratio of kernel weight/nut weight (32.6 - 63.8 %) and fat content (42.0 - 71.5 %).

Joolka and Sharma (2005) reported that out of total population of walnut seedling trees, 10 genotypes were selected on the basis of nut and kernel characteristics. The results showed significant variation with respect to nut weight (9.55 - 18.33 g), nut length (3.13 - 4.76 cm), kernel weight (4.33 - 10.33 g), kernel length (2.58 - 3.65 cm) and kernel breadth (2.23 - 3.05 cm).

Sharma *et al.* (2006) reported the variation in nut weight (4.85 - 16.59 g), nut width (23.13 - 36.95 mm), shell thickness (0.64 - 2.45 mm), kernel weight (1.02 - 6.91 g), kernel percentage (16.68 - 51.66), fat per cent (40.30 - 73.25) and protein per cent (9.74 - 21.07) in walnut.

Solar and Stampar (2006) recorded the highest nut weight (10.17 g) in 'G139' while the lowest weight (7.97 g) in 'MB24' in walnut.

Allan (2007) evaluated new and old cultivars of different ages (5-35 years) of Macadamia at Pietermaritzburg and concluded that yield of most of the older selections was between 10 to 20 kg per tree. Yield of the many younger trees of newer selections was 10 kg for 814, 837, 842, 863 cultivars and Beaumont cultivar yielded 11.7 kg per tree.

Gitonga *et al*. (2008) conducted a 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 fruit cluster length, number of fruits per cluster and fruit length.

Miletic *et al.* (2010) reported that walnut trees with early growing season show highest kernel ratio (20.69 %) whereas those with late growing season shows lowest kernel ratio (0.07 %). Similar results were observed in oil and raw protein content in the kernel which was highest in nuts of early trees (33.62 %, 47.55 %), while it was remarkably lower in later ones (0.72 %, 0.49 %).

Rajan *et al*. (2013) reported that North Indian accessions of mango were superior for yield as well as quality attributes. Fruit weight in North Indian accessions ranged from 57 to 1250 g and pulp weight from 20 to 980 g, respectively.

Keles *et al.* (2014) studied the variability in walnut genotypes. Significant variations were observed with respect to nut weight (8.93 - 13.92 g), kernel weight (4.62 - 7.36 g) and kernel ratios (47.80 - 58.98 %). The average nut length, width and heights were found between 42.80 to 29.97 mm, 25.73 to 34.77 mm and 28.86 to 33.85 mm respectively.

Sharma *et al.* (2014) studied the clones of walnut which are having export standards like nut weight (20.10 g), nut size (45.45 mm × 42.07 mm), shell thickness (1.24 mm), kernel recovery (61.40 %), proportion of light coloured kernel (83.40 %), protein content (15.66 %) and oil content (68.42 %).

Marcos and Soratto (2015) reported that yield of macadamia intercropped with coffee increased compared with that of rain fed macadamia mono-cropping. The kernel yields were 51, 176 and 251 per cent higher in the rain fed macadamia-coffee intercropping, irrigated macadamia mono-cropping and irrigated macadamia-coffee intercropping treatments respectively.

Preez (2015) conducted the studies on macadamia nut quality and reported that high crop load, no cross pollination, low leaf nitrogen, zinc and high leaf potassium were associated with low kernel discolouration.

Katie *et al.* (2018) reported that yield component traits that contribute to resource availability for fruit formation includes floral and nut characteristics in macadamia.

2.3 Bio-chemical characters

Sawant *et al.* (2003) reported that the maximum reducing sugars (19.41 %) and minimum reducing sugars (6.50 %) were found in different selections of karonda from hills of Kolhapur district.

Pathak and Chakraborty (2006) studied the total and non reducing sugar percentage of different underutilized tropical fruits and they found (17.39, 7.48) per cent in bael, (12.50, 2.60) per cent in custard apple, (4.88, 1.12) per cent in carambola, (10.26, 4.75) per cent in jackfruit, (9.52, 1.29) per cent in jamun, and (11.11, 2.64) per cent in sapota respectively.

Akhtar *et al*. (2006) reported that kernels of macadamia contain vitamin A, B1, B2, niacin and essential elements such as calcium, iron, phosphorus, magnesium and potassium. The oil contains primarily monounsaturated fats up to 80 to 84 per cent which was high when compared to both olive and canola oils.

Marcela *et al.* (2008) reported that oil content of walnut was ranged between 71.4 to 73.9 per cent. Variations in unsaturated fatty acid contents were between 16.1 to 25.4 per cent (oleic acid), 52.5 to 58.9 per cent (linoleic acid), and 11.4 to 16.5 per cent (linolenic acid).

2.4 Correlation co-efficient studies

Correlation studies establish the extent of association between yield and its attributes. These yield components may form additional criteria for selection in the breeding programme. Yield is a complex entity associated with many characters which were themselves inter-related such inter-relationships of various yield components are essential to understand the relative importance of each factor involved. Correlation coefficient analysis helps to determine the nature and degree of relationship between any two measurable characters. It resolves the complex relations between essential characters, which are of immense help in the selection of suitable clones.

Sheikh and Hulamani (1993) carried out the correlation studies in guava with different physical and chemical characters. The fruit yield per branch was significantly and positively correlated with the number of branches, number of flowers and number of fruits, while the fruit yield per branch was negatively correlated with reducing sugars and ascorbic acid.

Desai (1994) studied the correlation for fruit characters *viz.,* fruit weight, juice per cent, peel thickness, TSS and acidity in kagzi lime. The study revealed the positive correlation for fruit weight with juice percentage and peel thickness, juice percentage with peel thickness and TSS with acidity. Among these, the correlation between TSS and acidity was significant. Percentage of juice was significantly and positively correlated with fruit weight. The juice percentage showed very low and non-significant values of correlation coefficient (r) with peel thickness, TSS and acidity and thus did not reveal any definite correlation. The TSS content showed highly significant positive correlation with acidity.

Inamdar (2000) observed that the fruit weight 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 Gili Hosur in Karnataka.

Hardner *et al*. (2001) reported that phenotypic variance of macadamia nut was high (H≈0.63) for nut and kernel mass and kernel recovery, moderate for percentage whole kernels (H≈0.30) and low for percentage 1st grade kernel (H≈0.20). The strong genetic correlation was between nut and kernel mass (r_g = 0.80).

Huett *et al.* (2001) reported that amount of nitrogen content in leaf in macadamia is very poorly correlated with kernel yield and phosphorous had a negative correlation with kernel yield.

Sharma and Sharma (2001) reported that Persian walnut genotypes nut weight was found significantly and positively associated with nut width, nut thickness, kernel weight, kernel width, kernel height, thickness and fat percentage, while it was found negatively correlated with protein percentage. Kernel weight had a significant positive relationship with kernel width, kernel height, kernel thickness, kernel percentage, while it had a negative relationship with protein percentage.

Hardner *et al.* (2002) reported that macadamia nut genotypes heritability was higher for canopy width (H ≈ 0.28) and yield efficiency (H ≈ 0.47) and cultivar performance was highly correlated across locations ($r_g$loc ≈ 0.70) for these traits. Genetic correlation among all measures of yield per tree were high (r_g > 0.73), but there was no genetic correlation with canopy width and also a slight negative correlation between yield per tree and kernel recovery ($r_{g\,=}$ – 0.37).

Sawant *et al.* (2003) studied and reported that fruit weight was significantly and positively associated with fruit diameter, fruit length, pomace content, seed weight per fruit and weight of single seed and negatively associated with seed number, TSS, moisture percentage and fruit number in karonda.

Sharma and Das (2003) reported that the nut weight was positively correlated with nut length, diameter at suture and at cheek and kernel weight but was negatively correlated with shelling percentage in walnut. Kernel weight was positively correlated with nut length, diameter at suture and at cheek respectively.

Asadian and Pieber (2005) studied that significant correlation was observed with number of fruits per tree, total yield per tree, and the flowering duration in walnut.

Arzani *et al.* (2008) reported that significant correlations were found between nut weight and nut length (0.57), nut width (0.68), nut thickness (0.67), kernel weight (0.75), and shell weight (0.32), whereas a negative correlation was detected between shell thickness and kernel ratio (-0.34) in walnut.

Bhowmick and Banik (2008) reported a significant positive correlation of fruit weight with pulp content and significant negative correlation with peel and acid content. Total soluble solids (TSS) showed high positive correlation with total sugar and non-reducing sugar. Whereas, acidity showed high negative correlation with non-reducing sugar, fruit weight, pulp content, TSS, Sugar and reducing sugar content in mango.

Karunakaran *et al*. (2010) studied the genotypic and phenotypic variation in papaya and reported that it was highest in S2 generation, while in S4 variation was low. High heritability was recorded for all the characters except inter nodal length and pulp thickness. High genetic advance as per cent mean was recorded for the characters of fruit weight, fruit length and number of seeds. The plant height at first fruiting was positively correlated with fruit length and first flowering height in papaya.

Reza *et al.* (2010) reported the correlation and causal relationships among 21 horticultural traits of 71 walnut genotypes. A highly significant correlation was observed between lateral bearing habit and yield. Kernel weight, nut weight, shell thickness and difficulty of extracting kernel halves were the most important traits accounting for kernel variation.

Srinivas *et al.* (2010) studied the correlation co-efficient for different characters in kagzi lime such as fruit weight, quality and yield characters. The result showed that fruit yield had a positive and significant association with an equatorial diameter of fruit, polar diameter, fruit size, fruit volume, TSS: acid ratio and fruit weight, while it was found to have a negative significant association with ascorbic acid.

Abedi and Parvaneh (2016) studied the correlations between horticultural traits and variables affecting kernel percentage of walnut (*Juglans regia* L.) and concluded that significant positive correlation was observed between fruit weight and kernel weight and a significant negative correlation existed between harvest time and tree vigour, fruit shape and fruit weight and kernel percentage with shell thickness. The most important characteristics that had a direct impact on kernel percentage were shell thickness and kernel plumpness.

Shiva *et al.* (2017) studied the correlation between different morphological characters in guava and reported that plant height was highly correlated with the plant spread as well as canopy volume. Leaf length and breadth was highly correlated with leaf area, whereas they were negatively correlated with stomata number. Fruit weight was highly correlated with fruit core diameter and seed number. Plant height showed significant positive correlation with plant spread (N-S and E-W) as well as canopy volume.

2.5 Path co-efficient analysis studies

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

Prasad and Rao (1989) reported that path-coefficient analysis of the polar and equatorial diameters of fruit and the total soluble solids are the most important characteristics to be considered for effective selection in favour of thin fruit rind and high acidity in acid lime.

Samal *et al.* (2001) studied the correlation and path coefficients between yield and yield components (plant height, canopy spread, number of flowering panicles, panicle length, staminate and perfect flowers, sex ratio, number of nuts, nut weight, apple weight and shelling percentage) of 16 cashew nut cultivars. Path analysis revealed that the number of nuts per panicle exhibited the highest positive direct effect on yield at genotypic and phenotypic levels. The number of nuts per panicle and apple weight showed highest positive direct effects on yield. A similar relationship was observed between the number of nuts per panicle and perfect flowers. Thus, the number of nuts per panicle should be considered independently to improve the yield of cashew nut.

Bayazit (2012) conducted an experiment to determine correlations among important fruit and plant characteristics using 12 walnut genotypes. Total fruit number per tree, fruit height and kernel percentage was determined as the most important characters that directly affected the yield per tree. Shell weight had negative effect on both the kernel percentage and the yield per tree whereas, fruit weight and tree canopy volume had the positive effect on both kernel percentage and nut yield per tree.

Kumar *et al.* (2013) conducted an experiment on heritability estimates, correlation and path analysis studies for nut and kernel characters of Pecan nut (*Carya illinoensis*). Path analysis revealed that nut yield efficiency (P = 0.964) had highest positive direct effect on nut yield followed by kernel weight (P = 0.226), kernel length (P = 0.087), kernel height (P = 0.039) and nut height (P = 0.033). Kernel height (P = 0.434) had a highest positive indirect effect on nut yield through nut yield efficiency and protein content (P = -0.397) gave highest negative effect on nut yield via nut yield efficiency.

Singh and Nandini (2014) investigated the genetic variability, character association and their direct and indirect effect on the fruit weight of tamarind, and studies revealed that positive direct effects were produced by pulp weight and seed weight, while ridges had direct adverse effects.

Correa *et al*. (2015) conducted an experiment on macadamia (*Macadamia integrefolia*) with aim of identifying the best genotypes to establish a base population for the breeding program and focussing on the macadamia nut yield. Results revealed that age of the plants had a direct and significant association with the production.

Mayavel *et al.* (2018) carried out the Path co-efficient analysis to identify suitable selection indices in 21 red tamarind genotypes for 15 characters. Path co-efficient analysis revealed that the length of inflorescence, fruit length, anthocyanin content and total sugar contributing directly to the yield and most other characters associated to fruit yield are contributing indirectly through these characters.

Material and Methods

III MATERIAL AND METHODS

The present investigation entitled "Evaluation of macadamia (*Macadamia integrifolia* M.) genotypes for yield and yield attributing traits" was conducted in farmer's field at Gajanur village in Shivamogga district during the year 2017-18. The details of materials used and the techniques adopted during the course of investigation are briefly described in this chapter.

3.1 Geographical location of the experimental site

The experimental site is situated in Gajanur village of Shivamogga district, which lies in Southern transitional zone (Zone -7) of Karnataka state at $13^{0}56^{1}$ North latitude and $75^{0}34^{1}$ East longitude at an altitude of 569 m above mean sea level.

3.2 Climatic conditions of the experimental site

The mean annual rainfall of the experimental site was about 829 mm distributed over a period of six to seven months (May to October) with prominent peaks during June to October. The average rainfall during the period of experimentation was 158.2 mm. The mean maximum temperature during the period of experimentation was 32.30 ^{0}C, while the mean minimum temperature was 14.90 ^{0}C with relative humidity ranging from 32.90 per cent to 90.42 per cent.

3.3 Experimental details

Location of Experiment	:	Farmer's field in Shivamogga District
1. Age of trees	:	9 Years old
2. Experimental Design	:	Randomized complete block design
4. Genotypes	:	10 (namely, G-1, G-3, G-4, G-5, G-6, G-9, G-10, G-11, G-12, G-13)
5. No. of replication	:	3

3.4 Observations recorded on morphological and yield parameters of macadamia

3.4.1 Morphological characters of the tree

Observations on morphological characters of tree, *viz.*, tree height, stem girth, growth habit, bearing habit, tree stature, leaf length, leaf breadth, leaf colour, leaf spines, number of spines per leaf, leaf tip, inflorescence length, inflorescence breadth, inflorescence colour, peak flowering period of the crop were recorded. For recording these observations, ten leaves and inflorescence were selected from each genotype randomly from all directions of the tree.

3.4.1.1 Tree height (m)

The tree height was recorded by measuring with wooden pole from the base to the terminal most growing point and was expressed in meters. The tree height of genotypes were classified based on the descriptor as dwarf (< 5 m), medium (5-10 m) and tall (> 10 m).

3.4.1.2 Stem girth (m)

The girth of the tree trunk (main stem at collar region of the plant) was measured at 30 cm above from the base and recorded as stem girth in metres.

3.4.1.3 Growth habit

Data on growth habit was recorded and following categories were made

a) Spreading: Side branches were spreading outward and not competing with central leader.

b) Upright: Branches grow conspicuously upward and tend to compete with central leader

c) Round: Side branches were less spreading outward somewhat parallel / upright to the central leader.

3.4.1.4 Bearing habit

The observation regarding the bearing habit was recorded and classified as,

a. Regular bearers

b. Alternate bearers

3.4.1.5 Tree stature

On the basis of tree height, the tree stature was classified as tall (>10 m), medium (5-10 m) and dwarf (< 5 m).

3.4.1.6 Leaf length (cm)

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

3.4.1.7 Leaf breadth (cm)

The leaf breadth was measured at the widest part of the leaf by ordinary measuring scale and expressed in centimetres.

3.4.1.8 Leaf colour

The observation regarding leaf colour was recorded by visual means and classified as,

a) Light green

b) Dark green

3.4.1.9 Leaf spines

Leaf spines were observed by visual observation and following classes were made.

a) Present

b) Absent

3.4.1.10 Number of spines per leaf

Number of spines per leaf was physically counted and expressed as "number of spines per leaf".

3.4.1.11 Leaf tip

Leaf tip was observed by visual observation and classified as, present and absent.

3.4.1.12 Inflorescence length (cm)

The length of inflorescence was measured vertically from base to the tip of inflorescence by ordinary scale and recorded in centimetres.

3.4.1.13 Inflorescence breadth (cm)

The width of inflorescence was measured horizontally at maximum breadth and recorded in centimetres.

3.4.1.14 Inflorescence colour

Inflorescence colour was recorded by visual observation.

3.4.1.15 Peak flowering period

Time of flowering was recorded by noting down the date of emergence of first 10 to 15 racemes per tree canopy. Based on this, the genotypes were identified as “Early” (July -August), “Mid-season” (September- October) and “late” (October) types.

3.4.2 Morphological and yield parameters of the nut

The observations on morphological parameters of nut were taken *viz.*, nut weight, nut diameter, nut volume, shell thickness, shell weight, kernel: shell ratio, pericarp weight, kernel weight, kernel thickness, kernel recovery percent. For recording these observations 10 nuts were collected from each genotype randomly from all directions of the tree. Yield parameters such as, cluster length, number of nuts per cluster, and nut yield per tree were recorded.

3.4.2.1 Nut weight (g)

Individual weight of 10 sun-dried nuts, collected from the peak period of season from different macadamia genotypes was recorded in digital analytical balance then mean weight was computed and expressed in grams.

3.4.2.2 Nut diameter (cm)

Data on nut diameter of 10 randomly collected nuts was measured with the help of digital vernier calliper at the maximum width and was expressed in centimetre. The nuts which were used for recording nut weight were also used for recording this parameter.

3.4.2.3 Nut volume (cc)

The volume of ten nuts was recorded by water displacement method and expressed in cubic centimetre.

3.4.2.4 Shell weight (g)

The nuts which were used for recording nut weight were cut open and the shell weight of individual nut obtained after cutting the nuts used for above parameter, recorded in digital analytical balance and the mean computed was expressed in grams.

3.4.2.5 Shell thickness (mm)

The nuts which were used for recording nut weight were cut open and the shell thickness of individual nut was measured with Vernier caliper and the mean was computed and expressed as shell thickness in millimetres.

3.4.2.6 Kernel weight (g)

Individual weight of 10 kernels, obtained after cutting the nuts used for above parameter, recorded in digital analytical balance and the mean was computed and expressed in grams.

3.4.2.7 Kernel thickness (mm)

The nuts which were used for recording nut weight were cut open and the kernel thickness of individual nut was measured with Vernier caliper and the mean computed was expressed as kernel thickness in millimetres.

3.4.2.8 Kernel: shell

For recording data on kernel: shell on each of the selected genotypes, weight of 10 kernels was taken and then the weight of its shell was recorded, then value of kernel: shell was calculated as, kernel weight /shell weight.

3.4.2.9 Kernel recovery percent

For recording data on recovery percentage on each of the selected genotypes, weight of 10 nuts was taken and then the weight of its kernel was recorded. The recovery percentage was worked out as under:

$$\text{Recovery percentage} = \frac{\text{Weight of kernel}}{\text{Weight of nut}} \times 100$$

3.4.2.10 Pericarp weight (g)

The pericarp obtained after cutting the nuts used for above parameter, recorded in digital analytical balance and the mean was computed and expressed in grams.

3.4.2.11 Cluster length (cm)

Ten randomly selected clusters in each direction from each genotype were measured vertically from base to the tip of cluster by ordinary measuring scale and average was calculated, expressed in centimetres.

3.4.2.12 Number of nuts per cluster

Number of nuts per cluster was physically counted when they were fully matured and were counted as number.

3.4.2.13 Nut yield (kg/tree)

Nuts were harvested when they were fully mature. Number of nuts and weight were recorded at every harvest the total yield was calculated by adding the values obtained in different harvest and was expressed in kilogram per tree.

3.5 Bio-chemical analysis of kernel

Observation on bio-chemical characters of different macadamia genotypes were taken, *viz.*, carbohydrate content, protein content, total sugar, reducing sugar and non-reducing sugar.

3.5.1 Carbohydrate content (%)

The total carbohydrates present in the macadamia kernel sample were estimated by Anthrone method (Hedge and Hofreiter, 1962). A dry tissue sample of 100 mg was taken in a boiling tube. It was hydrolysed by keeping in a boiling water bath for three hours using 5 ml of 2.5N HCl and cooled to room temperature. The sample was neutralised with solid sodium carbonate and the volume was made up to 100 ml and centrifuged. The supernatants were collected and saved at 0.5 ml and 1.0 ml volumes. Standards of glucose solution were prepared by taking 0, 0.2, 0.4, 0.6, 0.8 and 1 ml of working standard solution. The volume in all the tubes including the sample was made to 1 ml by adding distilled water.

Anthrone reagent of 4 ml was added and heated for eight minutes in a boiling water bath. The contents were rapidly cooled down and the absorbance was read at 630 nm against the different standards.

$$\begin{array}{c}\text{Amount of carbohydrate present in}\\ \text{100 mg of the sample}\end{array} = \frac{\text{mg of glucose}}{\text{Volume of test sample}} \times 100$$

3.5.2 Protein content (%)

The total nitrogen content in the macadamia kernel sample was estimated with the help of Kelplus equipment through Micro-Kjeldahl method (Anon, 1970). The method was consisting of two stages i.e. digestion and distillation which includes titration. A sample of 0.1 g was taken into 100 ml capacity micro digestion test tube. To this, 2 ml conc. H_2SO_4 was added and kept overnight. To the sample mixture, 1 g of catalyst mixture was added. The contents were transferred in to KELPLUS digestion unit with automatic settings.

The sample was digested for 30 minutes after attaining 450 °C. Later the test tubes were kept for cooling to room temperature.

The digested material was transferred to distillation unit. Twenty ml of 4 per cent boric acid containing mixed indicator was taken in a 150 ml conical flask and placed it under the receiver tube. The receiver tube end was dipped in the boric acid. Alkali addition was set to add 25 ml of 40 % sodium hydroxide (NaOH). After the addition of alkali, the time switch was set for 3 minutes and the distillation unit was run for three minutes. The contents were taken in a conical flask and titrated against with 0.02N H_2SO_4 till the blue color changed to pink colour. Taking the values of weight of sample as 0.1 g; Normality of H_2SO_4 as 0.02 and the Titration value (TV) as sample titration value minus blank titration value; the per cent nitrogen in the sample is calculated as,

$$\text{Per cent nitrogen} = \frac{TV \times 0.00028 \times 100}{0.1}$$

Where,

T.V. = Titration value,
0.00028 means weight of nitrogen per ml of 0.02N solution

The amount of nitrogen obtained is multiplied by conversion factor 6.25 to obtain amount of crude protein present in the sample.

3.5.3 Total sugars (%)

Total sugars present in the macadamia kernel samples were estimated by Anthrone reagent method and it is expressed in percentage (Ranganna, 1979). One ml of sample aliquot was pipetted out and different concentrations (0, 0.2, 0.4,0.6,0.8 and 1.0 ml) of standard glucose solution in different test tubes and make up the volume of 2.5 ml each with distilled water and all the tubes were kept in an ice bath and 5 ml of anthrone reagent was added slowly. 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 were measured at 630 nm against the blank. Then the sugar content was calculated through standard glucose curve.

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

3.5.4 Reducing sugars (%)

Reducing sugars present in the macadamia kernel samples were estimated by DNSA (Dinitro salicylic acid) reagent method and it is expressed in percentage (Ranganna, 1979).The clean and dried test tubes were taken to which 0.2, 0.4, 0.6, 0.8 and 1 ml of prepared standard glucose was added. This was make up to1ml using distilled water and 1ml of DNS reagent was added. The test tubes were closed with aluminum foil and were kept in boiling water bath for 10 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. Clean and dried test tubes were taken, to which 2.5 ml of prepared sample was added and O.D was measured at 540 nm. The amount of reducing sugar present in the sample was calculated using standard graph.

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

3.5.5 Non-reducing sugars (%)

Non-reducing sugar was calculated by deducting the quantity ofreducing sugar from total sugar and multiplied by a constant factor 0.95 and the results expressed as per cent of non - reducing sugar (Ranganna, 1979).

Non-reducing sugar (%) = (Total sugar - reducing sugar) × 0.95

3.6. Correlation co-efficient analysis

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

$$\text{Phenotypic correlation} = r_{ax}(p) = \frac{Cov_{xy}(p)}{\sqrt{V_x(p) \times V_y(p)}}$$

$$\text{Genotypic correlation} = r_{ax}(g) = \frac{Cov_{xy}(g)}{\sqrt{V_x(g) \times V_y(g)}}$$

Where,

Cov_{xy} (g) = Genotypic covariance between x and y

Cov_{xy} (p) = Phenotypic covariance between x and y

V_x (g) = Genotypic variance of character 'x'

V_x (p) = Phenotypic variance of character 'x'

V_y (g) = Genotypic variance of character 'y'

V_y (p) = Phenotypic variance of character 'y'

The test of significance for 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.

3.7 Path co-efficient analysis

Path coefficient analysis was done as suggested by Wright (1921) and Dewey and Lu (1959) and it was carried out to know the direct and indirect effect of the morphological traits on plant yield. The following set of simultaneous equations were formed and solved for estimating various direct and indirect effects.

$r_{1y} = a + r_{12}b + r_{13}c +$
$\ldots\ldots\ldots\ldots\ldots.. + r_{1Ii}$ $r_{2y} = a + r_{21}a + b$
$+ r_{23}c + \ldots\ldots\ldots\ldots.. + r_{2Ii}$ $r_{3y} = r_{31}a +$
$r_{32}b + c + \ldots\ldots\ldots\ldots.. + r_{3Ii}$

$r_{1y} = r_{11}a + r_{12}b + r_{13}c + \ldots\ldots\ldots\ldots. + I$

Where, r_{1y} to I_{1y} = Coefficient of correlation between causal factors 1 to I with dependent characters y.

r_{12} to r_1I = Coefficient of correlation among causal factors a, b, c……. i =
Direct effects of characters 'a' to 'I' on the dependent character 'y'
Residual effect (R) was computed as follows.
Residual effect (R) = 1- $\sqrt{}$ $a_2 + b_2 + c_2 + \ldots\ldots\ldots\ldots i_2 + 2abc_{12} + 2acr_{13}\ldots\ldots\ldots\ldots$

3.8 Statistical analysis of experimental data

The experimental data recorded on various parameters during the investigation were analyzed statistically using method of analysis of variance (ANOVA) for Randomized complete Block Design (RCBD) as given by Gomez and Gomez (1984). Whenever 'F' test was found significant for comparing the means of two treatments, critical difference (C.D. at 5 %) were worked out.

Experimental Results

IV EXPERIMENTAL RESULTS

The present investigation on "Evaluation of macadamia (*Macadamia integrifolia* M.) genotypes for yield and yield attributing traits" was conducted in farmer's field at Gajanur village of Shivamogga district during the year 2017-18. The results obtained during the course of investigation have been presented under the following headings.

4.1 Morphological parameters of the tree, flower traits, yield and yield parameters

4.2 Bio-chemical characters of kernel

4.3 Correlation studies

4.4 Path co-efficient analysis studies

4.1 Morphological traits of the tree, flower traits, yield and yield parameters

Observations on morphological traits of tree, *viz.*, tree height, stem girth, growth habit, bearing habit, tree stature, leaf length, leaf breadth, leaf colour, leaf spines, number of spines per leaf, leaf tip, inflorescence length, inflorescence breadth, inflorescence colour, peak flowering period of the crop were recorded.

4.1.1 Tree parameters

4.1.1.1 Tree height (m)

The data pertaining to tree height was recorded and are presented in Table 1. The observations indicated that there was significant difference among the macadamia genotypes with respect to tree height. It was ranged from 4.80 to 14.10 m. Significantly maximum tree height was observed in G-11 (14.10 m) followed by G-3 (12.10 m), while minimum was recorded in G-10 (4.80 m).

4.1.1.2 Stem girth (m)

The results presented in Table 1 revealed that there was a significant difference among the macadamia genotypes with respect to stem girth at collar region. It was ranged from 0.21 to 0.62 m. Significantly maximum stem girth was observed in G-6 (0.62 m), which was on par with G-5 (0.52 m), while minimum stem girth was recorded in G-13 (0.21 m).

Table 1. Variation in tree height and stem girth of different macadamia genotypes

Genotypes	Tree height (m)	Stem girth (m)
G-1	9.20	0.43
G-3	12.10	0.35
G-4	9.70	0.41
G-5	7.70	0.52
G-6	9.13	0.62
G-9	8.57	0.31
G-10	4.80	0.32
G-11	14.10	0.44
G-12	10.10	0.23
G-13	9.13	0.21
S. Em ±	**0.33**	**0.08**
C.D @ 5%	**0.98**	**0.21**

4.1.1.3 Tree canopy

The data pertaining to tree canopy was recorded and presented in Table 2. The tree canopy of the macadamia genotypes was grouped into three categories, namely, upright, spreading and round type. Among the genotypes studied, four genotypes belonged to upright growth habit (G-1, G-4, G-10, and G-12), five genotypes to spreading type (G-3, G-5, G-6, G-11, G-13) and one to round type (G-9).

4.1.1.4 Tree stature

Based on the height of the tree, tree stature was classified as tall, medium and dwarf stature (Table 2). Among the 10 genotypes studied, three genotypes (G-3, G-11 and G-12) were tall in stature, six genotypes (G-1, G-4, G-5, G-6, G-9, G-13) were medium in stature and one genotype (G-10) was dwarf in stature.

4.1.1.5 Bearing habit

The data observed with respect tobearing habit revealed that all the genotypes showed regularity in bearing habit (Table 2).

4.1.1.6 Leaf colour

The data pertaining to leaf colour was recorded and presented in Table 3 and Plate 1. The observations indicated that there was significant difference among the genotypes with respect to leaf colour. It varies from light green to dark green among the different macadamia genotypes. The genotypes G-1, G-3, G-4, G-6, G-11, G-12, and G-13 showed dark green leaf colour whereas in G-5, G-9 and G-10, the colour of leaves was light green.

4.1.1.7 Leaf tip

The data observed with respect toleaf tip for all the genotypes were recorded and presented in Table 3 and Plate 1. The genotypes (G-3, G-5, G-11 and G-12) showed presence of leaf tip while the genotypes (G-1, G-4, G-6, G-9, G-10 and G-13) showed absence of leaf tip.

4.1.1.8 Leaf spines

It is apparent from the data presented in Table 3 and Plate 1 that the genotypes G-3, G-4, G-6, G-11 and G-13 possess leaf spines whereas G-1, G-5, G-9, G-10 and G-12 possess no leaf spines. The data revealed that genotype G-6 showed maximum number of leaf spines (18.16) which was on par with G-4 (17.76) while minimum number of leaf spines (7.56) was observed in G-13.

Table 2. Variation in tree canopy, tree stature and bearing habit of macadamia genotypes

Genotypes	Tree canopy	Tree stature	Bearing habit
G-1	Upright	Medium	Regular
G-3	Spreading	Tall	Regular
G-4	Upright	Medium	Regular
G-5	Spreading	Medium	Regular
G-6	Spreading	Medium	Regular
G-9	Round	Medium	Regular
G-10	Upright	Dwarf	Regular
G-11	Spreading	Tall	Regular
G-12	Upright	Tall	Regular
G-13	Spreading	Medium	Regular

Table 3. Variation in leaf morphology of different macadamia genotypes

Genotypes	Leaf colour	Leaf tip	Leaf spines	Leaf length (cm)	Leaf breadth (cm)	Number of spines per leaf
G-1	Dark green	Absent	Absent	17.10	3.54	0.00
G-3	Dark green	Present	Present	12.68	3.26	15.76
G-4	Dark green	Absent	Present	18.00	3.43	17.76
G-5	Light green	Present	Absent	18.10	3.41	0.00
G-6	Dark green	Absent	Present	15.95	3.50	18.16
G-9	Light green	Absent	Absent	16.46	3.87	0.00
G-10	Light green	Absent	Absent	15.10	3.00	0.00
G-11	Dark green	Present	Present	15.43	3.71	8.40
G-12	Dark green	Present	Absent	15.40	3.75	0.00
G-13	Dark green	Absent	present	14.96	3.98	7.56
S. Em ±	-	-	-	**0.5**	**0.11**	**0.31**
C.D @ 5%	-	-	-	**1.46**	**0.33**	**0.93**

4.1.1.9 Leaf length (cm)

The observations presented in Table 3 and Plate 1 revealed significant variations among the genotypes with respect to leaf length. It varied from 12.68 to 18.10 cm. Significantly maximum leaf length was recorded in G-5 (18.10 cm) which was on par with G-4 (18.00 cm) and G-1(17.10 cm) while the minimum leaf length was observed in G-3 (12.68 cm).

4.1.1.10 Leaf breadth (cm)

The observations indicated that there was a significant difference among the genotypes with respect to leaf breadth (Table 3 and Plate 1). It varied from 3.26 to 3.98 cm. Significantly maximum leaf breadth was recorded in G-13 (3.98 cm) which was on par with G-9 (3.87 cm), G-10 (3.80 cm), G-12 (3.75 cm) and G-11 (3.71) while the minimum leaf breadth was observed in G-3 (3.26 cm).

4.1.2 Flower traits

4.1.2.1 Inflorescence colour

The data pertaining to inflorescence colour presented in Table 4. Results revealed that no significant differences were found among the macadamia genotypes with respect to inflorescence colour. All the genotypes bear white colour inflorescence.

4.1.2.2 Peak flowering period

The observations (Table 4) revealed that there was a significant difference among the macadamia genotypes with respect to peak flowering period. The genotype G-11 flowers in the month of August whereas, G-1, G-5, G-6, G-9, G-10, and G-12 flowers in the month of September-October and G-3, G-4 and G-13 flowers during October.

4.1.2.3 Inflorescence length (cm)

It is evident from the data presented in Table 4 that different macadamia genotypes showed significant difference with respect to inflorescence length. Significantly maximum inflorescence length was recorded in G-5 (15.78 cm) which was on par with G-10 (15.58 cm), G-4 (15.07 cm) and G-1 (14.86 cm), while the minimum was observed in G-13 (9.73 cm).

Plate 1. Variation in leaf morphology of different macadamia genotypes

Table 4. Variation in flower morphology of macadamia genotypes

Genotypes	Inflorescence colour	Peak flowering period	Inflorescence length (cm)	Inflorescence breadth (cm)
G-1	White	Sept-October	14.86	5.20
G-3	White	October	13.12	4.23
G-4	White	October	15.07	4.38
G-5	White	Sept-October	15.78	5.38
G-6	White	Sept-October	14.56	3.51
G-9	White	Sept-October	13.83	3.53
G-10	White	Sept-October	15.58	3.65
G-11	White	August	13.67	4.21
G-12	White	Sept-October	10.55	3.46
G-13	White	October	9.73	3.57
S. Em ±	-	-	**0.37**	**0.11**
C. D @ 5%	-	-	**1.11**	**0.34**

4.1.2.4 Inflorescence breadth (cm)

It is obvious from the result (Table 4) that there was a significant difference among the genotypes with respect to inflorescence breadth. It was ranged from 3.46 to 5.38 cm. Significantly maximum inflorescence breadth was recorded in G-5 (5.38 cm) which was on par with G-1 (5.20 cm), while the minimum was observed in G-12 (3.46 cm).

4.1.3 Yield and yield attributing traits

4.1.3.1 Nut weight (g)

The observations on nut weight indicated that, there was significant difference among the genotypes with respect to nut weight, which varied from 8.46 to 10.66g (Table 5). Significantly higher nut weight was recorded in G-5 (10.66 g) which was on par with G-6 (10.61 g), G-1 (9.96 g), G-9 (9.91 g) and lowest was observed in G-12 (8.46 g).

4.1.3.2 Nut diameter

The data pertaining to the nut diameter of different macadamia genotypes is furnished in Table 5 and Plate 3. Significantly maximum nut diameter (2.99 cm) was recorded in G-5, which was on par with G-1 (2.88 cm), G-4 (2.87 cm) and G-3 (2.80) while, the minimum (2.24 cm) was recorded in G-13.

4.1.3.3 Nut volume (cc)

The data presented in the Table 5 revealed that there was a significant difference among the macadamia genotypes with respect to nut volume. The maximum nut volume (11.40 cc) was observed in G-5, which was on par with G-1 (10.63 cc) while the minimum (4.46 cc) was observed in G-12.

4.1.3.4 Shell weight (g)

The data recorded on shell weight is presented in Table 6. It is evident from the data that the mean shell weight in different macadamia genotypes included in this study varied from 4.03 g (G-12) to 6.53 g (G-6). Significantly maximum shell weight was recorded in G-6 (6.53 g) which was on par with G-10 (6.43 g). The lowest shell weight was recorded in G-12 (4.03).

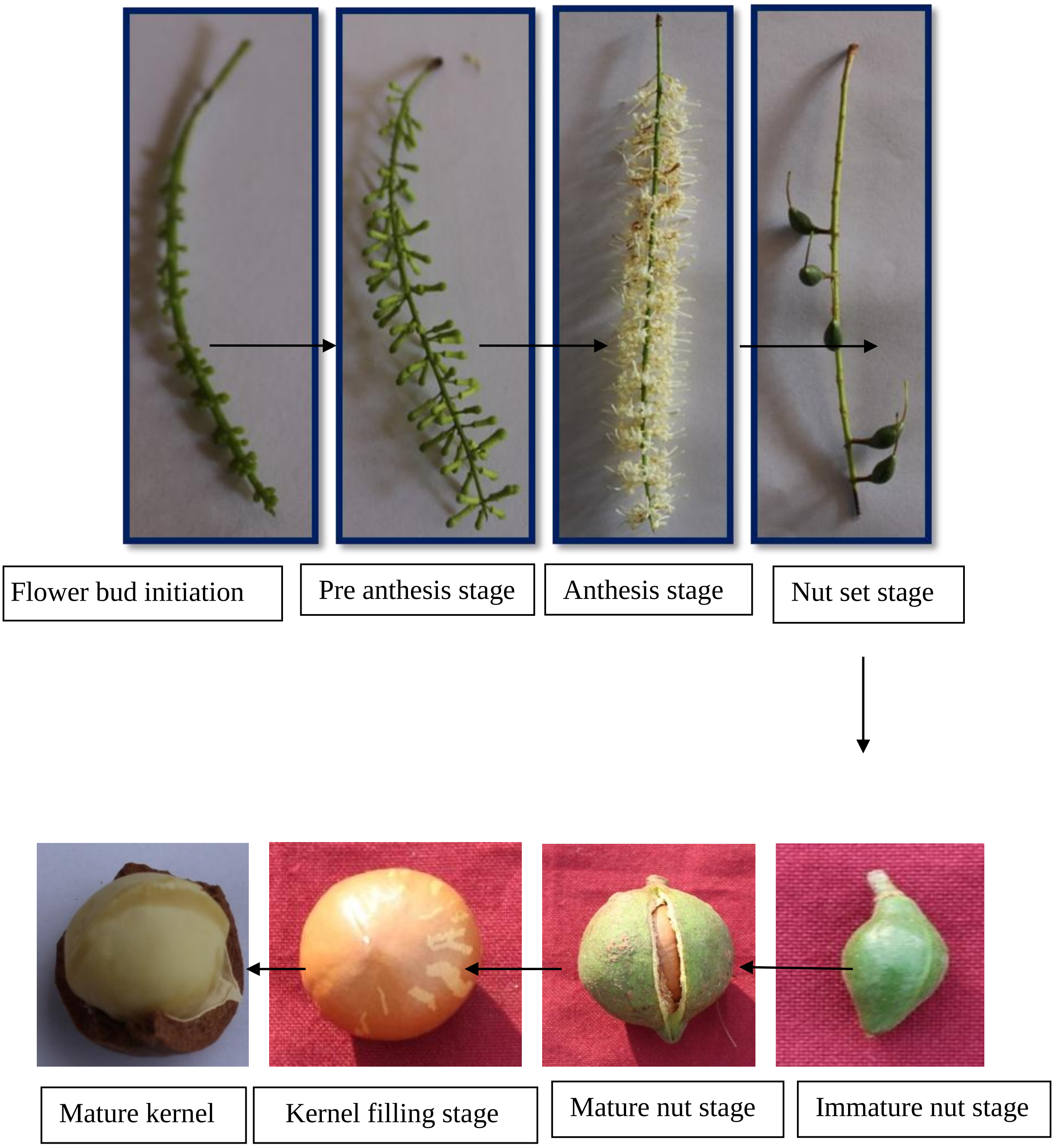

Plate 2. Different stages of flower and nut development of macadamia genotypes

Table 5. Variation in nut characters among different macadamia genotypes

Genotypes	Nut weight (g)	Nut diameter (cm)	Nut volume (cc)
G-1	9.96	2.88	10.63
G-3	8.82	2.80	5.13
G-4	9.31	2.87	5.94
G-5	10.66	2.99	11.40
G-6	10.61	2.73	9.82
G-9	9.91	2.55	5.96
G-10	9.83	2.73	9.60
G-11	8.69	2.66	9.23
G-12	8.46	2.36	4.46
G-13	9.11	2.24	4.51
S. Em ±	**0.27**	**0.08**	**0.26**
C.D @ 5%	**0.83**	**0.25**	**0.77**

Table 6. Variation in shell and pericarp characters of different macadamia genotypes

Genotypes	Shell weight (g)	Shell thickness (mm)	Pericarp weight (g)
G-1	5.60	2.80	2.16
G-3	4.72	2.67	1.94
G-4	4.70	3.00	2.15
G-5	5.87	2.65	1.62
G-6	6.53	2.99	0.95
G-9	4.46	2.67	3.53
G-10	6.43	2.82	1.39
G-11	5.15	2.96	1.57
G-12	4.03	2.90	2.93
G-13	4.51	2.89	3.10
S. Em ±	**0.13**	**0.11**	**0.42**
C.D @ 5%	**0.38**	**0.33**	**1.22**

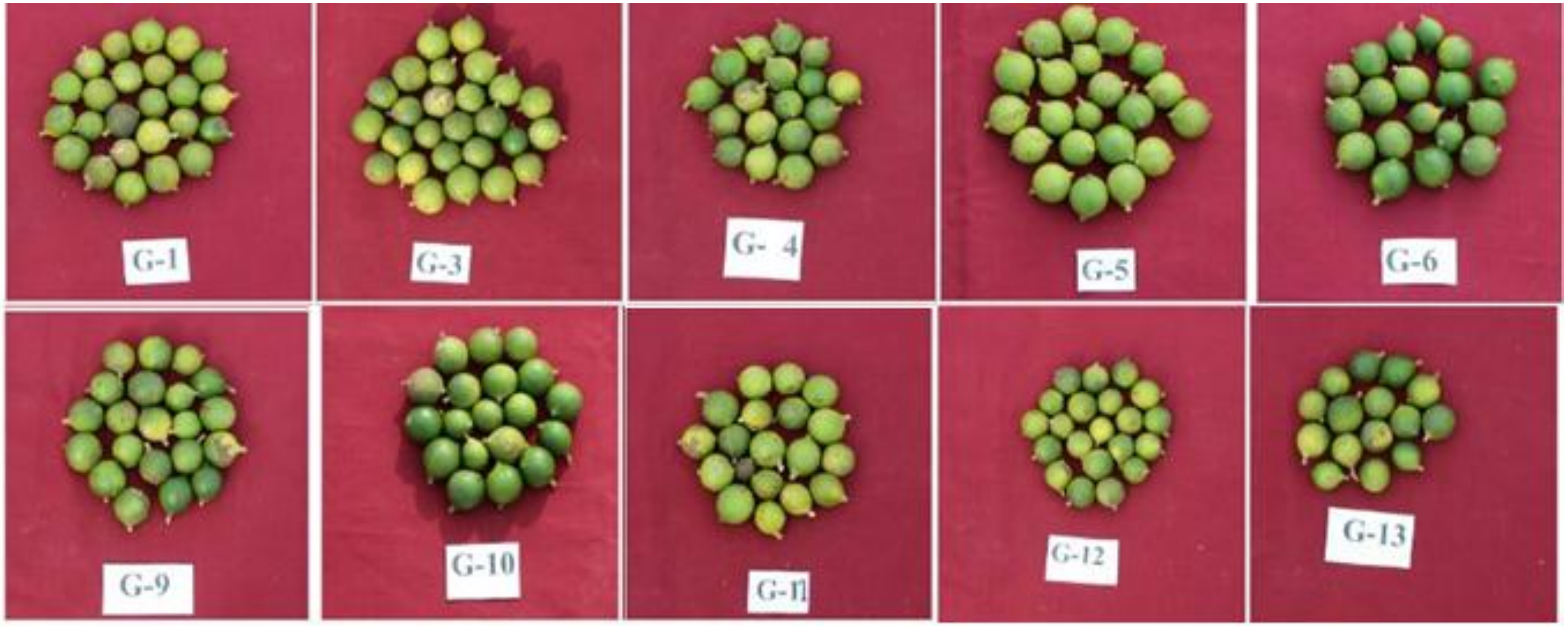

Plate 3. Variation in nut characters of different macadamia genotypes

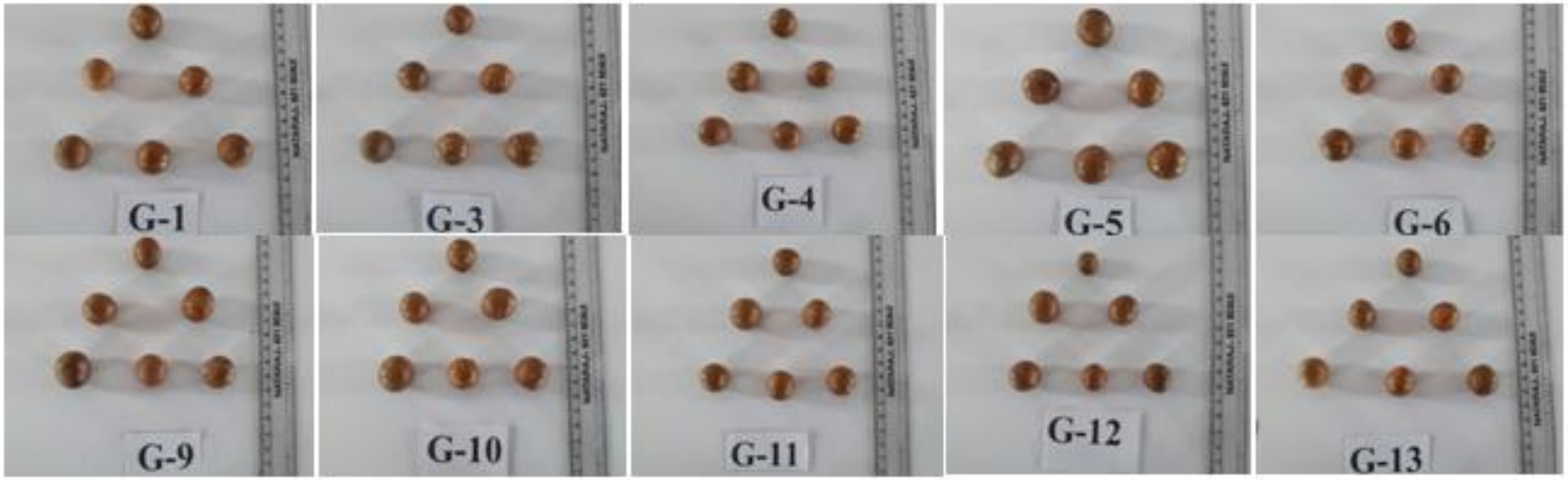

Plate 4. Variation in shell size of different macadamia genotypes

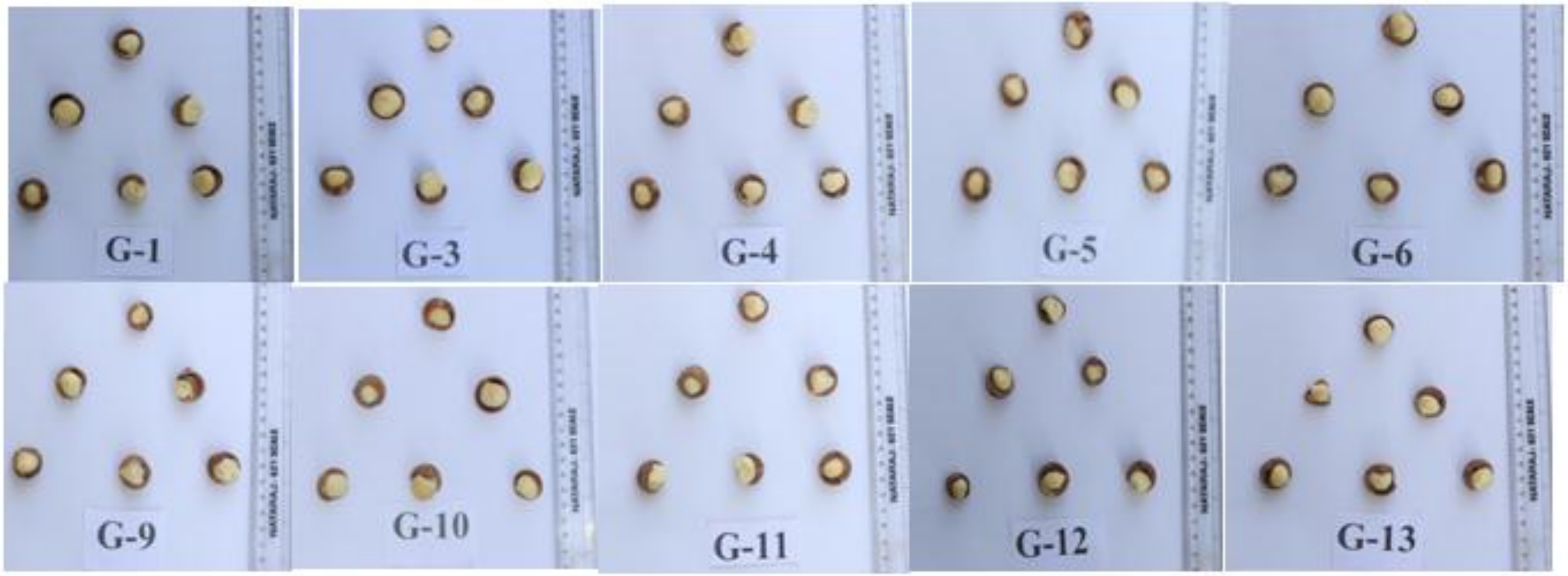

Plate 5. Variation in shell thickness of different macadamia genotypes

4.1.3.5 Shell thickness (mm)

The data pertaining to the shell thickness of different macadamia genotypes is furnished in Table 6 and Plate 5. The maximum shell thickness (3.00 mm) was recorded in G-4 which was on par with G-6 (2.99 mm), G-11 (2.96 mm), G-12(2.90 mm) G-13 (2.89 mm), G-10 (2.82 mm), G-1 (2.80 mm), G-3 and G-9 (2.67) minimum was recorded in G-5 (2.65 mm).

4.1.3.6 Pericarp weight (g)

The data in Table 6 indicated that significant difference among the macadamia genotypes with respect to pericarp weight. Significantly maximum pericarp weight was recorded in G-9 (3.53 g), which was on par with G-13 (3.10 g) and G-12 (2.93 g), minimum (0.95 g) was observed in G-6.

4.1.3.7 Kernel weight (g)

Kernel weight of different macadamia genotypes showed a wide variation (Table 7). It was ranged from 1.50 to 3.17 g. Significantly maximum (3.17 g) kernel weight was recorded in G-5, which was on par with G-6 (3.13 g) and lowest was recorded in G-12 and G-13 (1.50 g each).

4.1.3.8 Kernel thickness (mm)

The data presented in Table 7and Plate 6 clearly indicated the significant difference with respect to kernel thickness among the macadamia genotypes. The maximum kernel thickness was observed in the genotype G-5 (12.89 mm) which was on par with G-6 (12.72 mm) whereas minimum kernel thickness (10.85 mm) was recorded in the genotype G-12.

4.1.3.9 Kernel recovery per cent (%)

The data revealed significant difference in kernel per cent among the various macadamia genotypes (Table 7). Kernel percentage ranged from 16.46 to 29.73 per cent. Significantly maximum (29.73) kernel per cent was recorded in G-5, which was statistically on par with G-6 (29.50), while the minimum was recorded in G-13 (16.46).

4.1.3.10 Kernel to shell ratio

The observations indicated that there was significant difference among the genotypes with respect to kernel to shell ratio. Significantly maximum kernel to shell ratio (Table 7) was recorded in G-5 (0.54) which was on par with G-4 (0.52), G-6 (0.47), G-3 (0.45), and G-9 (0.43) and the lowest was recorded in G-10 (0.31).

Table 7. Variation in kernel characters of different macadamia genotypes

Genotypes	Kernel weight (g)	Kernel thickness (mm)	Kernel recovery per cent	Kernel to shell ratio
G-1	2.20	12.33	22.00	0.39
G-3	2.16	11.62	24.48	0.45
G-4	2.46	12.40	26.42	0.52
G-5	3.17	12.89	29.73	0.54
G-6	3.13	12.72	29.50	0.47
G-9	1.92	11.45	19.37	0.43
G-10	2.01	11.78	20.44	0.31
G-11	1.97	11.57	22.66	0.38
G-12	1.50	10.85	17.33	0.37
G-13	1.50	11.39	16.46	0.33
S. Em ±	**0.06**	**0.08**	**0.46**	**0.05**
C. D @ 5%	**0.19**	**0.24**	**1.38**	**0.14**

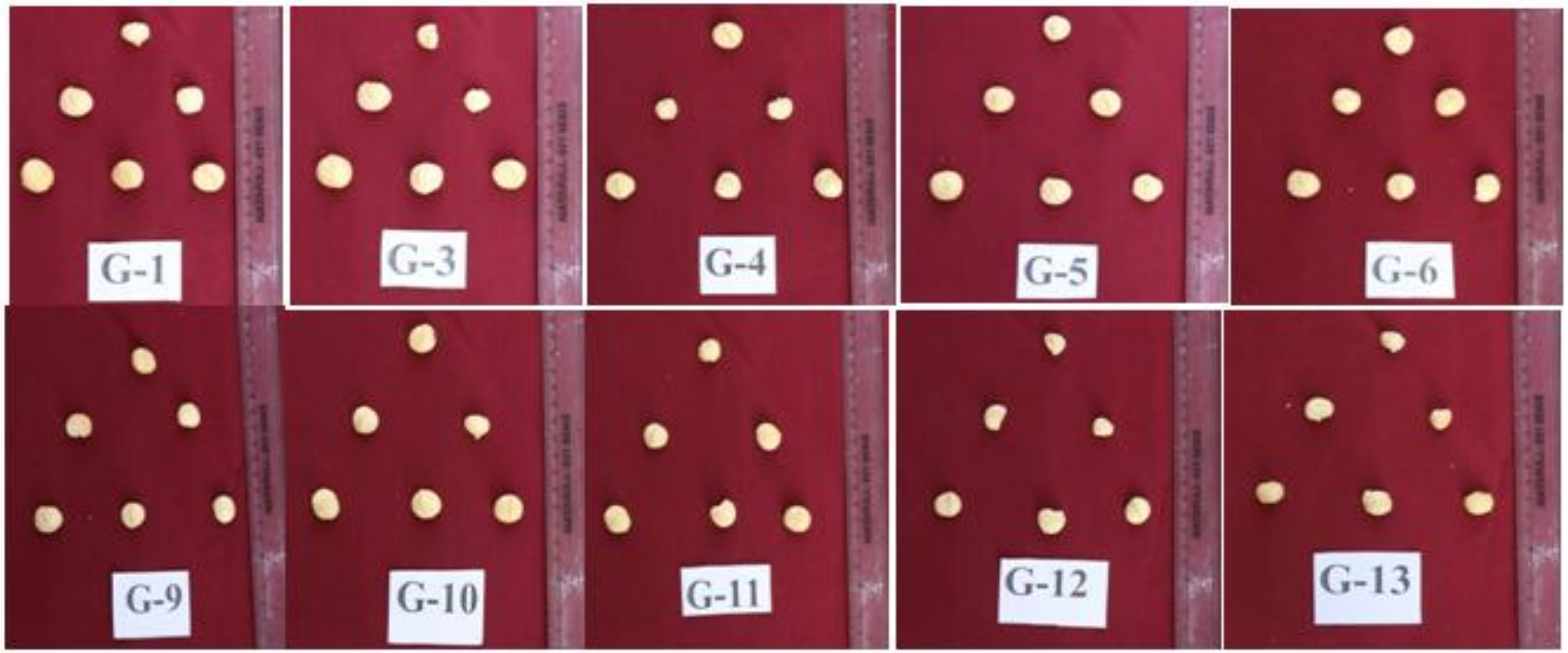

Plate 6. Variation in kernel characters of different macadamia genotypes

4.1.3.11 Cluster length (cm)

The observations presented in Table 8 indicated that there was significant difference among the macadamia genotypes with respect to cluster length. Significantly maximum cluster length was recorded in G-5 (10.80 cm) which was statistically on par with G-4 (10.50 cm), G-10 (10.48 cm), G-6 (10.41 cm), G-9 (10.37 cm) and G-11 (10.33 cm) while minimum was recorded in G-13 (4.51 cm).

4.1.3.12 Number of nuts per cluster

The data (Table 8) clearly indicated that there was significant difference among the macadamia genotypes with respect to number of nuts per cluster. It varied from 1.50 to 7.53. Significantly highest number of nuts per cluster was recorded in G-5 (7.53) and lowest number of nuts per cluster was recorded in G-13 (1.50).

4.1.3.13 Nut yield per tree (kg)

The observations recorded (Table 8) indicated that there was significant difference among the macadamia genotypes with respect to nut yield per tree. Significantly highest nut yield per tree was recorded in G-5 (16.16 kg) and lowest was recorded in G-13 (1.66 kg).

4.2 Bio-chemical characters of the kernel

4.2.1 Carbohydrates (%)

The data relating to carbohydrates per cent of mature kernels of different macadamia genotypes were analysed and presented in Table 9. Significantly maximum total carbohydrate content was recorded in G-6 (2.37 %) which was on par with G-5 (2.35 %) and minimum was recorded in G-12 (1.64 %).

4.2.2 Protein (%)

The data (Table 9) clearly indicated that there was significant difference among the macadamia genotypes with respect to protein content and it ranges from 5.53-13.40 per cent. Significantly maximum protein content was recorded in G-5 (13.40) and minimum was recorded in G-12 (5.53 %).

4.2.3 Reducing sugars (%)

The observations from Table 9 indicated that there was significant difference among the macadamia genotypes with respect to reducing sugars at mature nut stage. Significantly maximum reducing sugar content was observed in G-9 (0.37 %), which was statistically on par with G-4 (0.33 %) and lowest was observed in G-10 and G-11 (0.25 % each).

Table 8. Variation in yield parameters of different macadamia genotypes

Genotypes	Cluster length (cm)	Nuts/cluster	Nut yield/tree (kg)
G-1	7.55	3.13	10.83
G-3	9.47	3.13	12.66
G-4	10.50	6.20	15.00
G-5	10.80	7.53	16.16
G-6	10.41	3.30	14.50
G-9	10.37	4.43	9.33
G-10	10.48	4.03	8.50
G-11	10.33	3.63	7.33
G-12	5.32	2.00	2.35
G-13	4.51	1.50	1.66
S. Em ±	**0.20**	**0.14**	**0.35**
C.D @ 5%	**0.60**	**0.40**	**1.03**

Table 9. Bio-chemical quality parameters of macadamia genotypes

Genotypes	Carbohydrates (%)	Proteins (%)	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)
G-1	1.70	8.40	0.27	1.26	1.60
G-3	1.89	8.13	0.29	1.29	1.65
G-4	2.20	10.87	0.33	1.68	2.10
G-5	2.35	13.40	0.32	1.83	2.25
G-6	2.37	11.30	0.32	1.23	1.62
G-9	1.68	8.80	0.37	1.22	1.66
G-10	1.71	7.67	0.25	1.34	1.67
G-11	1.90	9.77	0.25	1.50	1.83
G-12	1.64	5.53	0.30	1.22	1.59
G-13	1.87	6.53	0.26	1.43	1.77
S Em ±	**0.04**	**0.24**	**0.02**	**0.10**	**0.07**
C. D@ 5%	**0.12**	**0.70**	**0.04**	**0.29**	**0.19**

4.2.4 Non-reducing sugars (%)

The observations indicated that there was significant difference among the genotypes with respect to non-reducing sugars at mature nut stage. Significantly maximum non reducing sugar content was observed in G-5 (1.83 %), which was statistically on par with G-4 (1.68 %) and lowest was observed in G-9 and G-12 (1.22 % each) (Table 9).

4.2.5 Total sugars (%)

It is evident from the data presented in Table 9 that macadamia genotypes showed significant difference with respect to total sugars at mature nut stage. Significantly maximum total sugar content was observed in G-5 (2.25 %), which was statistically on par with G-4 (2.10 %) and lowest total sugar content was observed in G-12 (1.59 %).

4.3 Association analysis through correlation studies

Selection for specific character is known to result in correlated response in certain other characters. Improvement of fruit yield is the most important target trait in macadamia nut. This can be achieved through direct selection of readily observable characters, but this needs a good understanding of association of different traits with fruit yield and their association among themselves. Phenotypic and genotypic correlation coefficients for yield and its attributing characteristics are presented in (Table 10 and 11)

4.3.1 Phenotypic correlation co-efficient

Phenotypic correlation coefficients among growth and yield attributes are presented in Table 10.

At phenotypic level, the association of nut yield was highly significant and positively correlated with kernel weight (0.8802**), nut diameter (0.8103**), kernel thickness (0.7974**), cluster length (0.7555**), nuts per cluster (0.5601**), nut weight (0.5318) nut volume (0.5287**), shell weight (0.4759**). Significantly negatively correlated with pericarp weight (-0.5571**) however its association was low, negligible and negative with shell thickness (-0.0106).

Nut weight showed highly significant positive association with shell weight (0.6925**) followed by kernel weight (0.6710**), kernel thickness (0.6520**), nut volume (0.5745**), only positive association with cluster length (0.3292), nut diameter (0.3061), shell thickness (0.1297). However, its association was low,

Table 10. Phenotypic correlation co-efficient for different yield parameters in macadamia genotypes

Traits	1	2	3	4	5	6	7	8	9	10	r_p
1	**1.0000**	0.3061	0.6925**	0.1297	0.6710**	-0.1650	0.6520**	0.5745**	0.3292	0.0780	0.5318**
2		**1.0000**	0.4284*	0.0189	0.6133**	-0.5711**	0.6864**	0.6143**	0.5881**	0.4533*	0.8103**
3			**1.0000**	-0.1134	0.6330**	-0.6093**	0.7164**	0.8143**	0.4367*	-0.0169	0.4759**
4				**1.0000**	-0.0897	0.2952	-0.0839	0.0538	0.0666	0.1406	-0.0106
5					**1.0000**	-0.5891**	0.8951**	0.6347**	0.5725**	0.3172	0.8802**
6						**1.0000**	-0.6825**	-0.6215**	-0.5043**	-0.1623	-0.5571**
7							**1.0000**	0.7912**	0.4817**	0.2093	0.7974**
8								**1.0000**	0.4052*	0.0087	0.5287**
9									**1.0000**	0.6881**	0.7555**
10										**1.000**	0.5601**

*and ** indicates Significant at 5 and 1 per cent level probability respectively

1. Nut weight (g)
2. Nut diameter (cm)
3. Shell weight (g)
4. Shell thickness (mm)
5. Kernel weight (g)
6. Pericarp weight (g)
7. Kernel thickness (mm)
8. Nut volume (cc)
9. Cluster length (cm)
10. Nuts per cluster

positive and non- significant with nuts per cluster (0.0780), While it exhibited non-significant negative correlation with pericarp weight (-0.1650).

Nut diameter was positively and highly significantly correlated with kernel thickness (0.6864**), nut volume (0.6143**), kernel weight (0.6133**), cluster length (0.5881**). Significant positive association with nuts per cluster (0.4533*) and shell weight (0.4284*). Only positive association with nut weight (3061). However, its association was low, positive and non- significant with shell thickness (0.0189), While it exhibited highly significant negative correlation with pericarp weight (- 0.5711**).

Shell weight had a highly significant and positive correlation with nut volume (0.8143**), kernel thickness (0.7164**), nut weight (0.6925**), kernel weight (0.6330**). Significant positive association with nut diameter (0.4284*) and cluster length (0.4367*). Highly significant negative correlation with pericarp weight (- 6093**). Non-significant negative correlation with shell thickness (- 0.1134), While it exhibited low, non-significant negative correlation with nuts per cluster (- 0.0169).

Shell thickness shows positive correlation with pericarp weight (0.2952), nuts per cluster (0.1406), and nut weight (0.1297). However, its association was low, positive but non-significant with cluster length (0.0666), nut volume (0.0538), nut diameter (0.0189), While it exhibited low, non-significant negative correlation with shell weight (- 0.1134), kernel weight (- 0.0897), kernel thickness (- 0.0839).

Kernel weight was highly significant and positively associated with kernel thickness (0.8951**), nut weight (0.6710**), nut volume (0.6347**), shell weight (0.6330**), nut diameter (0.6133**), and cluster length (0.5725**). Non-significant positive association with nuts per cluster (0.3172). Highly significant negative correlation with pericarp weight (- 0.5891**) and negligible negative correlation with shell thickness (- 0.0897).

Pericarp weight was non-significant and positively associated with shell thickness (0.2952). Significant negative correlation with kernel thickness (- 0.6825**), shell weight (- 0.6093**), nut volume (- 0.6215**), kernel weight (- 0.5891**), nut diameter (- 0.5711**), cluster length (- 0.5043**), nut weight (- 0.1650), nuts per cluster (- 0.1623).

Kernel thickness was highly significant and positively associated with kernel weight (0.8951**), nut volume (0.7912**), shell weight (0.7164**), nut diameter (0.6864**), nut weight (0.6520**) and cluster length (0.4817**), positively non-significant association with nuts per cluster (0.2093). Highly significant negative correlation with pericarp weight (- 0.6825**), negligible negative correlation with shell thickness (- 0.0839).

Nut volume was positively and highly significantly correlated with shell weight (0.8143**), kernel thickness (0.7912**), kernel weight (0.6347**), nut diameter (0.6143**), nut weight (0.5745**), significantly positively correlated with cluster length (0.4052*). However, its association was low, positive but non-significant with shell thickness (0.0538*), nuts per cluster (0.0087). Significantly negative association with pericarp weight (- 0.6215**).

Cluster length was positively and highly significantly correlated with nuts per cluster (0.6881**), nut diameter (0.5881**), kernel weight (0.5725**), and kernel thickness (0.4817**). Significant positive correlation with shell weight (0.4367*) and nut volume (0.4052*). Positive and non-significant correlation with nut weight (0.3292), shell thickness (0.0666). Significant negative correlation with pericarp weight (- 0.5043**).

Nuts per cluster was positively and highly significantly correlated with cluster length (0.6881**). Significantly correlated with nut diameter (0.4533*). Positive and non-significant association with kernel weight (0.3172), kernel thickness (0.2093), shell thickness (0.1406). Positive negligible correlation with nut weight (0.0780), nut volume (0.0087). Negatively association with pericarp weight (- 0.1623), shell weight (- 0.0169).

4.3.2 Genotypic correlation co-efficient

Genotypic correlation co-efficient among growth and yield attributes are presented in Table 11.

Nut yield was highly significantly, positively correlated with kernel weight (0.8985**), nut diameter (0.8925**), kernel thickness (0.8511**), cluster length (0.7648**), nut weight (0.6471**), nuts per cluster (0.5707**), nut volume (0.5472**), and shell weight (0.5020**). Highly significant negatively correlated with pericarp weight (- 0.7651**) however its association was low, negligible and negative with shell thickness (- 0.2417).

Nut weight showed highly significant positive association with kernel thickness (0.8763**), followed by kernel weight (0.8192**), shell weight (0.7668**), nut volume (0.7395**), nut diameter (0.5466**). Significant positive association with cluster length (0.4030*). However, its association was positive and non- significant with shell thickness (0.1428) and nuts per cluster (0.1079). While it exhibited highly significant negative correlation with pericarp weight (- 0.5665**).

Table 11. Genotypic correlation co-efficient for different yield parameters in macadamia genotypes

Traits	1	2	3	4	5	6	7	8	9	10	r_g
1	**1.0000**	0.5466*	0.7668**	0.1428	0.8192**	-0.5665**	0.8763**	0.7395**	0.4030**	0.1079	0.6471**
2		**1.0000**	0.5557**	0.2719	0.7005**	-0.7630**	0.8188**	0.7140**	0.6517**	0.4926**	0.8925**
3			**1.0000**	0.6327**	0.6669**	-0.9346**	0.8064**	0.8610**	0.4560**	-0.0053	0.5020**
4				**1.0000**	0.2155	-0.6093**	0.2395	-0.3343	-0.2295	-0.6280**	-0.2417
5					**1.0000**	-0.8269**	0.9612**	0.6439**	0.5900**	0.3194	0.8985**
6						**1.0000**	-0.8733**	-0.8155	-0.7265**	-0.2178	-0.7651
7							**1.0000**	0.8392**	0.5296**	0.2106	0.8511**
8								**1.0000**	0.4215*	0.0081	0.5472**
8									**1.0000**	0.7011**	0.7648**
10										**1.000**	0.5707**

*and ** indicates Significant at 5 and 1 per cent level probability respectively.

1. Nut weight (g)
2. Nut diameter (cm)
3. Shell weight (g)
4. Shell thickness (mm)
5. Kernel weight (g)
6. Pericarp weight (g)
7. Kernel thickness (mm)
8. Nut volume (cc)
9. Cluster length (cm)
10. Nuts per cluster

Nut diameter was positively and highly significantly correlated with kernel thickness (0.8188**), nut volume (0.7140**), kernel weight (0.7005**), cluster length (0.6517**), shell weight (0.5557**), nut weight (0.5466**). Significantly positively correlated with nuts per cluster (0.4926*). However, its association was positive and non-significant with shell thickness (0.2719), While it exhibited highly significant negative correlation with pericarp weight (- 0.7630**).

Shell weight had a highly significant and positive correlation with nut volume (0.8610**), kernel thickness (0.8064**), nut weight (0.7668**), kernel weight (0.6669**), and shell thickness (0.6327**) and nut diameter (0.5557**). Significant and positive correlation with cluster length (0.4560*). Highly significant negatively correlated with pericarp weight (- 0.9346**), While it exhibited low, non-significant negative correlation with nuts per cluster (- 0.0053).

Shell thickness had a highly significant and positive correlation with shell weight (0.6327**). Non-significant and positive correlation with nut diameter (0.2719), kernel thickness (0.2395), kernel weight (0.2155), nut weight (0.1428), significant negative correlation with nuts per cluster (-0.6280**) and pericarp weight (- 0.6093**), However, its association was low, negative and non-significant with nut volume (- 0.3343).

Kernel weight was highly significant and positively associated with kernel thickness (0.9612**), nut weight (0.8192**), nut diameter (0.7005**), shell weight (0.6669**), nut volume (0.6439**), cluster length (0.5900**). Non-significant positive association with nuts per cluster (0.3194), shell thickness (0.2155). Significant negative correlation with pericarp weight (- 0.8269**).

Pericarp weight was highly significant and negatively associated with, shell weight (- 0.9346**), kernel thickness (- 0.8733**), kernel weight (- 0.8269**), nut volume (- 0.8115**), nut diameter (- 0.7630**), cluster length (- 0.7265**), shell thickness (- 0.6093**), nut weight (- 0.5665**) non-significant negative association with nuts per cluster (- 0.2178).

Kernel thickness was highly significant and positively associated with kernel weight (0.9612**), nut weight (0.8763**), nut volume (0.8392**), nut diameter (0.8188**), shell weight (0.8064**), and cluster length (0.5296**). Positively non-significant with shell thickness (0.2395), nuts per cluster (0.2106). Significant negative correlation with pericarp weight (- 0.8733**).

Nut volume was positively and highly significantly correlated with shell weight (0.8610**), kernel thickness (0.8392**), nut weight (0.7395**), nut diameter (0.7140**), kernel weight (0.6439**). Significantly correlated with cluster length

(0.4215*). However, its association was low, positive but non-significant with nuts per cluster (0.0081). Highly significant negative correlation with pericarp weight (- 0.8115**). Non-significant negative correlation with shell thickness (- 0.3343).

Cluster length was positively and highly significantly correlated with nuts per cluster (0.7011), nut diameter (0.6517), kernel weight (0.5900), and kernel thickness (0.5296). Positive and significant correlation with shell weight (0.4560), nut volume (0.4215), and nut weight (0.4030). Significant negative correlation with pericarp weight (- 0.7265). Non-significant negative correlation with shell thickness (- 0.2295).

Nuts per cluster were positively and highly significantly correlated with cluster length (0.7011**), nut diameter (0.4926**). However, its association was positive but non-significant with kernel weight (0.3194), and kernel thickness (0.2106), nut weight (0.1079). Low, negligible, positive association with nut volume (0.0081). Highly significant negative association with shell thickness (- 0.6280**). Non-significant negative association with pericarp weight (- 0.2178). Low, negligible, negative association with shell weight (- 0.0053).

4.4 Path co-efficient analysis studies

4.4.1 Phenotypic path co-efficient analysis

All ten characters were subjected to phenotypic path coefficient analysis by considering yield per plant as a dependent variable and others as independent variables. The results are presented in the Table 12.

Nut weight showed positive direct effect (0.0912) on nut yield per tree. Positive indirect effect through shell weight (0.0632), followed by kernel weight (0.0612), kernel thickness (0.0595), nut volume (0.0524), cluster length (0.0300), nut diameter (0.0279), shell thickness (0.0118) and nuts per cluster (0.0071). Its indirect negative effect *via* pericarp weight (-0.0150).

Nut diameter showed positive direct effect (0.4087) on nut yield per tree. It also exhibited positive indirect effect through kernel thickness (0.2805), followed by nut volume (0.2511), kernel weight (0.2507), cluster length (0.2403), nuts per cluster (0.1853), shell weight (0.1751), nut weight (0.1251), shell thickness (0.0077). Its indirect negative effect through pericarp weight (- 0.2358).

Shell weight showed negative direct effect (- 0.1319) on nut yield per tree. Positive indirect effect was observed through pericarp weight (0.0804), shell thickness (0.0150), nuts per cluster (0.0022). Its indirect negative effect was recorded through nut volume (-0.1074), kernel thickness (- 0.0945), nut weight (- 0.0914), kernel weight (- 0.0835), cluster length (- 0.0576), nut diameter (- 0.0565).

Shell thickness showed negative direct effect (-0.0018) on nut yield per tree. Positive indirect effect was observed through shell weight (0.0002), kernel thickness (0.0002), kernel weight (0.0002) and nut diameter (0.0001). Its indirect negative effect was recorded through pericarp weight (- 0.0005), nuts per cluster (- 0.0003), nut weight (-0.0002), nut volume (- 0.0001), cluster length (-0.0001).

Kernel weight exhibited positive direct effect (0.5238) on nut yield per tree. Positive indirect effect through kernel thickness (0.4688) followed by nut weight (0.3515), nut volume (0.3324), shell weight (0.3315), nut diameter (0.3212), cluster length (0.2999) and nuts per cluster (0.1661). Its indirect negative effect through pericarp weight (- 0.3085), and shell thickness (0.0470).

Pericarp weight showed positive direct effect (0.0263) on nut yield per tree. Positive indirect effect through shell thickness (0.0078). Its indirect negative effect was recorded through kernel thickness (-0.0180), nut volume (-0.0163), shell weight (-0.0160), kernel weight (-0.0155), nut diameter (-0.0152), cluster length (-0.0133), nut weight (-0.0043), and nuts per cluster (-0.0043).

Positive direct effect (0.1199) of kernel thickness on nut yield per tree was observed. Positive indirect effect through kernel weight (0.1073), nut volume (0.0948), shell weight (0.0859), nut diameter (0.0823), nut weight (0.0782), cluster length (0.0577) nuts per cluster (0.0251). Its indirect negative effect through pericarp weight (- 0.0818) and shell thickness (- 0.0101).

Nut volume showed negative direct effect (-0.1964) on nut yield per tree. Positive indirect effect through pericarp weight (0.1221). Its indirect negative effect through shell weight (-0.1599), followed by kernel thickness (- 0.1554), kernel weight (- 0.1246), nut diameter (-0.1206), nut weight (- 0.1128), cluster length (- 0.0796), nuts per cluster (- 0.0017) and shell thickness (- 0.0106).

Cluster length recorded positive direct effect (0.2922) on nut yield per tree. It also exhibited positive indirect effect through nuts per cluster (0.2011), nut diameter (0.1718), kernel weight (0.2146), kernel thickness (0.1408), shell weight (0.1276), nut volume (0.1184), nut weight (0.0962), and shell thickness (0.0195). It exhibited indirect negative effect through pericarp weight (- 0.1474).

Nuts per cluster exhibited positive direct effect (0.0205) on nut yield per tree. Positive indirect effect through pericarp weight (0.0033), shell weight (0.0003). Its indirect negative effect was recorded through cluster length (- 0.0141), nut diameter (- 0.0093), kernel weight (0.0093), kernel thickness (- 0.0043), shell thickness (-0.0029), nut weight (- 0.0016), nut volume (- 0.0002).

Table 12. Direct (diagonal) and indirect effects of components characters on yield in macadamia genotypes at phenotypic level

Traits	1	2	3	4	5	6	7	8	9	10	r_p
1	**0.0912**	0.0279	0.0632	0.0118	0.0612	-0.0150	0.0595	0.0524	0.0300	0.0071	0.5318
2	0.1251	**0.4087**	0.1751	0.0077	0.2507	-0.2358	0.2805	0.2511	0.2403	0.1853	0.8103
3	-0.0914	-0.0565	**-0.1319**	0.0150	-0.0835	0.0804	-0.0945	-0.1074	-0.0576	0.0022	0.4759
4	-0.0002	0.000	0.0002	**-0.0018**	0.0002	-0.0005	0.0002	-0.0001	-0.0001	-0.0003	-0.0106
5	0.3515	0.3212	0.3315	-0.4070	**0.5238**	-0.3085	0.4688	0.3324	0.2999	0.1661	0.8802
6	-0.0043	-0.0152	-0.0160	0.0078	-0.0155	**0.0263**	-0.0180	-0.0163	-0.0133	-0.0043	-0.5571
7	0.0782	0.0823	0.0859	-0.0101	0.1073	-0.0818	**0.1199**	0.0948	0.0577	0.0251	0.7974
8	-0.1128	-0.1206	-0.1599	-0.0106	-0.1246	0.1221	-0.1554	**-0.1964**	-0.0796	-0.0017	0.5287
9	0.0962	0.1718	0.1276	0.0195	0.1673	-0.1474	0.1408	0.1184	**0.2922**	0.2011	0.7555
10	-0.0016	-0.0093	0.0003	-0.0029	-0.0065	0.0033	-0.0043	-0.0002	-0.0141	**0.0205**	0.5601

Residual effect = 0.1890

1. Nut weight (g)
2. Nut diameter (cm)
3. Shell weight (g)
4. Shell thickness (mm)
5. Kernel weight (g)
6. Pericarp weight (g)
7. Kernel thickness (mm)
8. Nut volume (cc)
9. Cluster length (cm)
10. Nuts per cluster

Discussion

V DISCUSSION

The investigation pertaining to "Evaluation of macadamia (*Macadamia integrifolia* M.) genotypes for yield and yield attributing traits" was conducted in farmer's field at Gajanur village in Shivamogga district during the year 2017-18 to study the yield and yield attributing characters and to select superior genotypes with majority of the desirable characters for further evaluation and release as a variety. The significance of current study discussed in this chapter under the following headings.

5.1 Morphological parameters of the tree, flower traits, yield and yield parameters

5.2 Bio-chemical characters

5.3 Correlation studies

5.4 Path co-efficient analysis studies

5.1 Morphological parameters of the tree, flower traits, yield and yield parameters

It is evident from the data presented in Table 1 that tree height varied among different genotypes. Significantly maximum tree height was recorded in G-11 (14.10 m) followed by G-3 (12.10 m), while minimum was recorded in G-10 (4.80 m). Variation in tree height is due to the genetic makeup of genotypes, presence of strong apical dominance and capacity of the plant root zone to absorb more nutrient matter which causes vigorous growth in genotypes G-11 and G-3. Similar results were obtained in guava by Dubey *et al*. (2002), Athani *et al*. (2007).

The data with respect to stem girth revealed significant difference among the various genotypes (Table 1). Significantly maximum stem girth was recorded in G-6 (0.62 m) and minimum was recorded in G-13 (0.21 m). The variation in stem girth of different genotypes is a genetic feature of individual genotype. The results are in agreement with the findings of Dubey *et al*. (2002) in guava and Prabhuraj (2001) in jamun.

The tree canopy of the macadamia genotypes (Table 2) showed wide variations and they were grouped into three categories, viz., upright, spreading and round type. Among them four genotypes belonged to upright growth habit (G-1, G-4, G-10, and G-12), five genotypes belonged to spreading type (G-3, G-5, G-6, G-11, G-13) and one to round shape (G-9). The supporting reference has also been reported by Allan (2007) in macadamia, Akca *et al.* (2005) in walnut.

Based on the height of the tree, tree stature was classified as tall, medium and dwarf stature (Table 2). Among the 10 genotypes studied, three genotypes (G-3, G-11 and G-12) were tall in stature, six genotypes (G-1, G-4, G-5, G-6, G-9, G-13) were medium in stature and one genotype (G-10) was dwarf in stature. It may be due to genetic makeup of individual genotype. Similar results were obtained by Rao and Subramanyam (2009) in aonla and Algabal *et al.* (2012) in tamarind.

The data observed with respect to bearing habit revealed that all the genotypes showed regularity in bearing (Table 2) during the study period. Similar results were obtained by Sharma (1999) in walnut.

Two different leaf colours were observed among the studied genotypes and categorized as light green and dark green. The light green colour was seen in three genotypes (G-5, G-9, and G-10) and dark green colour was seen in seven genotypes (G-1, G-3, G-4, G6, G-11, G-12, G-13) (Table 3 and Plate 1). It is attributed to genotypic characteristics of individual genotype. The similar results have been reported by Jalikop (2000) in *Annona species*.

The observations with respect to leaf tip for all the genotypes were categorized as present and absent. Among the genotypes studied three showed presence of leaf tip (G-3, G-5, G11, and G-12) and seven showed absence of leaf tip (G-1, G-4, G-6, G-9, G-10 and G13) (Table 3 and Plate 1). Variation in macadamia genotypes with regard to above character was earlier reported by Allan (2007), Gitonga *et al*. (2008).

The observations with respect to leaf spines for all the genotypes were categorized as present and absent. Among the genotypes studied five showed presence of leaf spines (G-3, G-4, G-6, G-11 and G-13) and five showed absence of leaf spines (G-1, G-5, G-9, G-10, G-12). The genotype G-6 showed maximum number of leaf spines (18.16) while the genotype G-13 had a minimum number (7.56) of leaf spines (Table 3 and Plate 1). The variation in number of spines on the leaves can vary depending on tree age and vigour of flush (Simpson and Allan, 1998). Similar results were reported by Allan (2007), Gitonga *et al*. (2008) in macadamia.

The length of the leaves in different genotypes (Table 3 and Plate 1) showed wide variations. The observations indicated that there was a significant difference among the genotypes with respect to leaf length and it was ranged from 12.68 to 18.10 cm. Significantly maximum leaf length was recorded in G-5 (18.10 cm) which was on par with G-4 (18.0 cm), G-1 (17.10 cm) while the minimum was observed in G-3 (12.68 cm). The variation in leaf length is due to genetic feature of individual genotype. The same observation regarding leaf length in macadamia nut was earlier reported by Storey and Salleeb (1966) and Allan (2007).

The leaf breadth of different selected genotypes showed wide variations (Table 3 and Plate 1). The observations indicated that there was a significant difference among the genotypes with respect to leaf breadth and it was ranged from 3.26 to 3.98 cm. Significantly maximum leaf breadth was recorded in G-13 (3.98 cm) which was on par with G-9 (3.87 cm), G-10 (3.8 cm), G-12 (3.75 cm) and G-11 (3.71 cm), while the minimum was observed in G-3 (3.26 cm). The variation in leaf breadth is due to genetic feature of individual genotype. The similar observation regarding leaf breadth in macadamia was earlier reported by Storey and Salleeb (1966), Allan (2007).

The data presented in Table 4 revealed that no significant differences were found among the macadamia genotypes with respect to inflorescence colour. All the genotypes bear the inflorescence which are white in colour. The similar results in macadamia have been reported by Allan (2007).

The data presented in Table 4 revealed that significant differences were found in macadamia genotypes with respect to peak flowering period. The observations recorded that the season of flowering started from August to October.

The genotype G-11 flowers in the month of August, whereas G-1, G-5, G-6, G-9, G10, G-12 flowers in month of September-October and G-3, G-4, G-13 during October. This might be due to the fact that the timing and intensity of flowering of macadamia related to the amount of carbohydrates stored in wood tissues in the summer prior to the flowering season (Stephenson *et al.* 1989). The similar results in macadamia have also been reported by Moncur *et al.* (1985) and Nagao *et al.* (1994), Polito and Pinney (1997) in walnut.

The observations indicated that there was a significant difference among the genotypes with respect to inflorescence length (Table 4). The inflorescence length ranged from 9.73 to 15.78 cm. Significantly maximum inflorescence length was recorded in G-5 (15.78 cm) which was on par with G-10 (15.58 cm), G-4 (15.07cm) and G-1(14.86 cm), while the minimum inflorescence length was observed in G-13 (9.73 cm). The similar results have been reported by Allan (2007) in macadamia and Sharma (1999) in walnut.

The observations with respect to inflorescence breadth of the different selected genotypes showed wide variation (Table 4) and was varied from 3.46 to 5.38 cm. Significantly maximum inflorescence breadth was recorded in G-5 (5.38 cm) while the minimum was recorded in G-12 (3.46 cm). The results are in conformity with the findings of Allan (2007) in macadamia and Sharma (1999) in walnut.

Among the 10 different macadamia genotypes studied, the nut weight varied from 8.46 to 10.66 g. Significantly higher nut weight was recorded in G-5 (10.66 g), which was statistically on par with G-6 (10.61 g), G-1 (9.96 g), G-9 (9.91 g) and lowest was observed in G-12 (8.46 g) (Table 5). The difference in nut weight in the present study may be attributed to nut diameter, nut volume, shell weight and kernel weight, among the different genotypes. The present results are in agreement with the findings of earlier studies conducted by Thakur (1993), Haqjuyan *et al*. (2005), Solar and stampar. (2006), Akhiani *et al.* (2017) in walnut.

Significantly maximum nut diameter was recorded in G-5 (2.99cm) whereas minimum was recorded in G-13 (2.24 cm) (Table 5 and Plate 3). The difference in nut diameter in the present study may be attributed to nut weight and nut volume among the different genotypes. The present results are in agreement with the findings of earlier studies conducted by Thakur (1993) and Sharma *et al.* (2006) in walnut.

The result of the present investigation (Table 5) revealed that nut volume significantly varied from (4.46 cc) G-12 to (11.40 cc) in G-5. The difference in nut volume in the present study may be attributed to nut weight and nut size among the different genotypes. The supporting references have been reported by Solar and Stampar (2006) in walnut.

Data recorded on shell weight (Table 6) revealed that the mean shell weight in different genotypes included in this study varied from 4.03 g (G-12) to 6.53 g (G-6). Maximum shell weight was recorded in G-6 (6.53 g) which was on par with G-10 (6.43 g). The lowest was recorded in G-12 (4.03 g). This variation in shell weight might be due to difference in nut weight and shell thickness. The results are in correspondence with the findings of Thakur (1993), Sharma *et al.* (2006), Sharma *et al.* (2014), and Akhiani *et al*. (2017) in walnut.

The data pertaining to the shell thickness (Table 6 and Plate 5) revealed that the maximum shell thickness was recorded in G-4 (3.00 mm) which was on par with G-6 (2.99 mm), G-11 (2.96 mm), G-12 (2.90 mm) and minimum was recorded in G-5 (2.65 mm). The results are in conformity with the findings of Arzani *et al*. (2008) in walnut who reported that hard shell thickness ranged between 0.75 to 1.76 mm in walnut.

The results on pericarp weight revealed that there was significant difference among the macadamia genotypes. Maximum pericarp weight was observed in G-9 (3.53 g) which was on par with G-13 (3.10 g) and G-12 (2.93 g), whereas minimum was observed in G-6 (0.95 g) (Table 6). The similar results have been reported by Islam *et al*. (2005) in hazelnut and Sharma *et al.* (2006) in walnut.

The data on kernel weight of different macadamia genotypes (Table 7) revealed that kernel weight was varied from 1.50 to 3.17 g. Significantly maximum kernel weight (3.17 g) was recorded in G-5 which was on par with G-6 (3.13 g) and lowest was recorded in G-12 and G-13 (1.50 g each). This variation in kernel weight in macadamia genotypes might be due to higher nut weight, higher kernel thickness, less pericarp weight and higher oil percentage. These results are in conformity with the findings of Akhtar *et al*. (2006), Allan (2007), in macadamia, Sharma *et al.* (2006), Miletic *et al.* (2010) in walnut.

The maximum kernel thickness was observed in the genotype G-5 (12.89 mm) which was on par with G-6 (12.72 mm) whereas, minimum (10.85 mm) was found in the genotypeG-12 (Table 7 and Plate 6). This variation in kernel thickness of different macadamia genotypes might be due to variation in kernel size. The supporting reference has been reported by Joolka and Sharma (2005) and Sharma*et al.* (2006) in walnut.

As regard to the kernel per cent, maximum (29.73 %) was recorded in G-5 which was on par with G-6 (29.50 %), while the minimum was noticed in G-13 (16.46 %) (Table 7). This variation in kernel percent in different macadamia genotypes might be due to variation in kernel weight and kernel recovery. The present results are in agreement with the findings of Allan (2007) in macadamia, Sharma *et al.* (2006), Sharma *et al.* (2014), Gazmend *et al*. (2005), and Akhiani *et al*. (2017) in walnut.

The observations indicated that, there was significant difference among the genotypes with respect to kernel to shell ratio (Table 7). Significantly maximum kernel to shell ratio was recorded in G-5 (0.54) which was on par with G-4 (0.52), G-6 (0.47), G-3 (0.45) and G-9 (0.43). The lowest was recorded in G-10 (0.31). This variation in kernel to shell ratio in different macadamia genotypes is due to variation in kernel weight, shell thickness and shell weight. The similar findings have been reported by Miletic *et al.* (2010) and Cosmulescu (2013) in walnut, Sepahvand *et al.* (2015) also reported variation in almond kernel to shell ratio which was ranged from 0.24 to 0.97.

The cluster length showed significant variation among the different genotypes considered for the present study. Significantly maximum cluster length was recorded in G-5 (10.80 cm) which was on par with G-4 (10.50 cm), G-10 (10.48 cm), G-6 (10.41 cm), G-9 (10.37 cm) and G-11 (10.33 cm), while minimum cluster length was recorded in G-13 (4.51 cm) (Table 8). This may be attributed to differences in species composition within the accessions (Peace *et al.* 2005). The similar findings have also been reported by Thakur (1993) who reported catkin length ranged from 2.5 to 9.7 cm and Sharma and Sharma (1998) in walnut.

The macadamia genotypes showed significant difference with respect to number of nuts per cluster (Table 8). The maximum number of nuts was recorded in G-5 (7.53), followed by G-4 (6.20) and G-9 (4.43), whereas minimum number of nuts per cluster was recorded in G-13 (1.50). This variation might be due to higher cluster length and higher percentage of fruit set. The results are in conformity with the findings of Acka and Sen (2001) who reported 18 nuts per cluster, while Akhiani *et al*. (2017) indicated two nuts per cluster in walnut, Manoj *et al.* (1993) reported six nuts per panicle in cashew.

Significantly highest yield per tree was observed in G-5 (16.16 kg) followed by G-4 (15 kg) and G-6 (14.50 kg) and lowest was recorded in G-13 (1.66 kg) (Table 8). This might be due to higher percentage of fruit set, fruit weight, number of nuts per cluster, cluster length, age of the plant and genotypic characteristics. Similar findings were reported by Allan (2007), Mcfadyen *et al.* (2004) and Marcos and Soratto (2015) in macadamia, Rajan *et al*. (2013) in mango.

5. 2 Bio-chemical characters of the kernel

The data relating to carbohydrate per cent of mature kernels of different macadamia genotypes showed wide variations (Table 9). Significantly maximum total carbohydrate content was recorded in G-6 (2.37 %) which was on par with G-5 (2.35 %) and minimum was recorded in G-12 (1.64 %). The variation might be due to metabolic transformation of starch and pectin into soluble sugars, carbohydrates and rapid translocation of sugars from leaves to the developing fruits. The results are in accordance with Pathak and Chakraborty (2006) in different underutilized tropical fruits.

There was significant difference among the macadamia genotypes with respect to protein content (Table 9). Significantly maximum protein content was recorded in G-5 (13.40 %), while the minimum was recorded in G-12 (5.53 %). The variation might be due to environmental and ecological conditions and also depending on the genotype. The result on similar lines was also reported by Haqjuyan *et al.* (2005) and Akhiani *et al.* (2017) in walnut.

Significant difference with respect to total sugars was recorded and is presented in Table 9. Significantly maximum total sugar content at mature nut stage was observed in G-5 (2.25 %) which was on par with G-4 (2.10 %) and lowest total sugar content was observed in G-12 (1.59 %). The increase in total sugar content in the nuts may be due to quick metabolic transformation of starch and pectin into soluble sugars and rapid translocation of sugars from leaves to the developing fruits by reducing vegetative growth of plants. Similar results have also been reported by Pathak and Chakraborty (2006) in bael (17.39 %), custard apple (12.50 %), carambola (4.88 %), jackfruit (10.26 %), and jamun (9.52 %).

Significantly maximum reducing sugar content at mature nut stage was observed in G-9 (0.37 %), which was on par with G-4 (0.33 %) and lowest reducing sugar content was observed in G-10 and G-11 (0.25 % each) (Table 9). similar observations were reported by Sawant *et al* (2003) in karonda.

There was significant difference among the macadamia genotypes with respect to non-reducing sugars at mature nut stage (Table 9). Maximum was observed in G-5 (1.83 %) which was on par with G-4 (1.68 %) and lowest was observed in G-9 and G-12 (1.22 % each). Similar kind of results were obtained by Pathak and Chakraborty (2006) in different underutilized tropical fruits *viz.*, bael (7.48 %), custard apple (2.60 %), carambola (1.12 %), jackfruit (4.75 %), jamun (1.29 %) and sapota (2.64 %).

5.3 Association analysis through correlation studies

In any crop improvement programme, it becomes necessary to have simultaneous progress of more than one character, especially in the complex character like yield which is influenced by many other traits. This is due to the physiological and linkage relationship of genes governing various characters. Hence, knowledge of correlations between different economical characters is of importance in selection programmes. Positive correlation makes simultaneous improvement in two or more attributes possible, whereas, negative association indicates the need to compromise between desirable characters.

The simple correlation study is inadequate to measure the association as different genotypes are susceptible to environment in varying degrees. Estimates of phenotypic and genotypic correlations gave way for understanding environmental influence on heredity expression. In the present study, character association among all the characters related to nut yield was estimated and the results (Table 10 and 11) obtained are discussed below.

Nut yield per tree showed positive and significant correlation with kernel weight, nut diameter, kernel thickness, cluster length, nuts per cluster, nut weight, nut volume, and shell weight both at genotypic and phenotypic level. Since, these association characters are in the desirable direction, selection for these traits may improve the nut yield per plant. Similar results were also reported by Ghasemi *et al*. (2012), Cosmulescu and Botu (2012), Eskandari *et al.* (2005) in walnut.

Nut weightwas significantly and positively associated with kernel thickness, followed by kernel weight, shell weight, nut volume and nut diameter both at genotypic and phenotypic level, whereas cluster length showed positive and significant correlation only at phenotypic level. Selection for this character will improve the yield. Similar results were reported by Sharma and Sharma (2001), Sharma and Das (2003), Arzani *et al.* (2008), Eskandari *et al.* (2005) in walnut.

Nut diameter was positively and highly significantly correlated with kernel thickness, nut volume, kernel weight, cluster length, nuts per cluster, shell weight and nut weight both at genotypic and phenotypic level. Similar results were reported by Ghasemi*et al*. (2012), Eskandari *et al.* (2005) in walnut.

Kernel weight was highly significant and positively associated with kernel thickness, nut weight, nut diameter, shell weight, nut volume and cluster length both at genotypic and phenotypic level. Whereas non-significant positive association with nuts per cluster, shell thickness at genotypic level only. Kernel thickness was significant and positively associated with kernel weight, nut volume, shell weight, nut diameter, nut weight, and cluster length, both at genotypic and phenotypic level. The supporting references have been reported by Amiri *et al.* (2010), Sharma and Sharma, (2001), Ahandani *et al,* (2014) in walnut, Kumar *et al.* (2013) in pecan nut.

Shell weight had a highly significant and positive correlation with nut volume, kernel thickness, nut weight, kernel weight, shell thickness and nut diameter both at genotypic and phenotypic level. Shell thickness had a highly significant and positive correlation with shell weight both at genotypic and phenotypic level, whereas significant and positive correlation with nuts per cluster, pericarp weight and nut weight only at phenotypic level. Similar findings were reported by Eskandari *et al.* (2005), Cosmulescu (2013), Bayazit (2012) in walnut.

Nut volume was positively and highly significantly correlated with shell weight, kernel thickness, kernel weight, nut diameter, nut weight, and cluster length, both at genotypic and phenotypic level. Similar results were reported by Arzani *et al.* (2008) in walnut, Anupa *et al.* (2015) in guava.

Cluster lengthwas positively and highly significantly correlated with nuts per cluster, nut diameter, kernel weight and kernel thickness. Positive and significant correlation with shell weight, nut volume and nut weight both at genotypic and phenotypic level. Whereas nuts per clusterwere positively and highly significantly correlated with cluster length, nut diameter both at genotypic and phenotypic level. Similar results were reported by Gitonga *et al*. (2008) in macadamia nut, Sawant *et al.* (2003) in karonda, Srinivas *et al.* (2010) in kagzilime.

5.4 Path co-efficient analysis studies

Path analysis is a useful technique to understand more clearly the association among different variables considering simple correlation co-efficient. It helps to partition the overall association of particular variables with dependent variable into direct and indirect effects. When the influence of a set of variables on the dependent variable is to be understood, it is possible with the help of path analysis that estimates the extent of direct contribution of a particular variable and the extent of its indirect contribution through other variables in a set to the total influence it has on the dependent variable. While dealing with a more complex character like yield, it enables to identify the important component traits of such a nature so that differential emphasis can be laid on such component characters for selection. In the present study, path analysis was carried out using all the ten component characters and the results (Table 12) of the analysis are discussed below.

Nut weight showed positive direct effect on nut yield per tree. Positive indirect effect through kernel thickness followed by kernel weight, shell weight, nut volume, nut diameter, cluster length, shell thickness, nuts per cluster. The results were in accordance with the observations of Samal *et al.* (2001), Madeni *et al*. (2017) in cashew, Singh and Nandini (2014) in tamarind, Bayazit *et al*. (2012) in walnut.

Nut diameter showed positive direct effect on nut yield per tree. It also exhibited positive indirect effect *via.*, kernel thickness, followed by nut volume, kernel weight, cluster length, nuts per cluster, shell weight, nut weight, shell thickness at phenotypic level. Similar findings were reported by Amiri *et al*. (2010), Bayazit *et al*. (2012) in walnut.

Shell weight showed negative direct effect on nut yield per tree. Positive indirect effect through pericarp weight, nuts per cluster, whereas Shell thickness showed positive direct effect on nut yield per tree. Positive indirect effect through shell weight, nut diameter, kernel thickness, kernel weight, and nut weight. Similar findings were reported by Amiri *et al*. (2010) and Bayazit *et al*. (2012) in walnut.

Kernel weight exhibited positive direct effect on nut yield per tree. Positive indirect effect through kernel thickness, followed by nut weight, nut volume, shell weight, nut diameter, cluster length, and nuts per cluster, whereas positive direct effect of kernel thickness on nut yield per tree was observed. Positive indirect effect was observed through kernel weight, nut weight, nut volume, nut diameter, shell weight, cluster length, and nuts per cluster. These results were in accordance with those of Bostan and Islam (1999) and Islam *et al.* (2005) in hazelnut, Amiri *et al.* (2010) in walnut, Kumar *et al.* (2013) in pecan nut.

Nut volume showed negative direct effect on nut yield per tree and positive indirect effect through pericarp weight. The pericarp weight showed positive direct effect on nut yield per tree and positive indirect effect through shell thickness. Similar findings were reported by Amiri *et al*. (2010), Bayazit *et al.* (2012) in walnut.

Cluster length recorded positive direct effect on nut yield per tree. It also exhibited positive indirect effect through nuts per cluster, nut diameter, kernel weight, kernel thickness, shell weight, nut volume, nut weight and shell thickness. Nuts per cluster exhibited positive direct effect on nut yield per tree. Positive indirect effect was observed through pericarp weight, shell weight. Similar findings were reported by Samal *et al.* (2001), Madeni *et al*. (2017) in cashew nut.

Conclusion

The evaluation study on different macadamia genotypes revealed that the variability exists with regard to different growth characters, yield characters, physical and bio-chemical (quality) characters of nuts. On the basis of the results obtained in the present investigation, it is concluded that, among the 10 genotypes studied, G-5 found superior with respect to nut weight, kernel weight, nut yield per tree and protein content. Therefore, the genotype G-5 can be selected as most promising and further research is required to get the consistent results for recommendation.

Future line of work

1. Desirable characters identified can be combined through introgression breeding.
2. Evaluation of genotypes for yield attributing traits using molecular markers.
3. Due to perennial nature of the crop further evaluation of genotypes is required.
4. Evaluation of genotypes for assessing different biochemical quality parameters of nuts.

Summary

VI SUMMARY

The present investigation entitled "Evaluation of macadamia (*Macadamia integrefolia* M.) genotypes for yield and yield attributing traits" was conducted in farmer's field at Gajanur village in Shivamogga district during the year 2017-18. Ten genotypes were used for the evaluation studies *viz.*, G-1, G-3, G-4, G-5, G-6, G-9, G-10, G-11, G-12 and G-13 in order to achieve the following objectives.

1. To identify the promising suitable macadamia genotypes for growth and yield parameters.
2. To study the correlation among yield and yield components in macadamia nut.
3. To study the direct and indirect effects of yield components on yield through path analysis.

The findings of the investigations are summarised below.

Among the 10 genotypes studied, significantly maximum plant height was observed in G-11 (14.10 m), while minimum plant height was recorded in G-10 (4.80 m).

The observations indicated that, there was significant difference among the genotypes with respect to stem girth at collar region. Significantly maximum stem girth was observed in G-6 (0.62 m), while minimum stem girth was recorded in G-13 (0.21 m).

The variation was observed among 10 genotypes with respect to tree canopy. Four genotypes belonged to upright growth habit, five genotypes to spreading habit and one to round category.

The observations indicated that, three genotypes were tall in stature, six genotypes were medium in stature and one genotype was dwarf in stature.

The data observed with respect tobearing habit revealed that all the genotypes showed regularity in bearing habit.

The observations on leaf colour indicated that, there was significant difference among the genotypes with respect to leaf colour. The leaf colour varies from light green to dark green among the different macadamia genotypes.

The data with respect toleaf tip for all the genotypes indicated that, four genotypes showed presence of leaf tip, while six genotypes showed absence of leaf tip.

The observations indicated that G-6 showed maximum number of leaf spines (18.16), while the minimum number (7.56) of leaf spines was observed in G-13.

Significantly maximum leaf length was recorded in G-5 (18.10 cm) and minimum leaf length was observed in G-3 (12.68 cm).

Significantly maximum leaf breadth was recorded in G-13 (3.98 cm), while the minimum leaf breadth was observed in G-3 (3.26 cm).

The data pertaining to inflorescence colour revealed that no significant differences were found in macadamia genotypes with respect to inflorescence colour. All the genotypes bear white colour inflorescence and the peak flowering period was observed from August to October.

The macadamia genotypes recorded significantly maximum inflorescence length in G-5 (15.78 cm), while the minimum inflorescence length was observed in G-13 (9.73 cm).

Significantly maximum inflorescence breadth was recorded in G-5 (5.38 cm), while the minimum inflorescence breadth was observed in G-12 (3.46 cm).

The variation was recorded in nut weight. Significantly higher nut weight was recorded in G-5 (10.66 g) and lowest was observed in G-12 (8.46 g).

The variation was also observed in nut diameter. Significantly maximum nut diameter (2.99 cm) was recorded in G-5, the minimum nut diameter (2.24 cm) was recorded in G-12.

Significantly maximum nut volume (11.40 cc) was observed in G-5, minimum (4.46 cc) was observed in G-12.

Significantly maximum kernel weight (3.17g) was recorded in G-5 and lowest was recorded in G-12 and G-13 (1.50 g each).

The maximum kernel thickness was observed in the genotype G-5 (12.89 mm) whereas, minimum (10.85 mm) was observed in the genotype G-12.

Significantly maximum (29.73) kernel percent was recorded in G-5, while minimum was recorded in G-13 (16.46).

The Maximum shell weight was recorded in G-6 (6.53g), the lowest shell weight was recorded in G-12 (4.03 g).

The maximum shell thickness (3.00 mm) was recorded in G-4 and minimum was recorded in G-5 (2.65 mm).

The maximum kernel to shell ratio was recorded in G-5 (0.54) the lowest was recorded in G-10 (0.31).

Maximum pericarp weight was recorded in G-9 (3.53 g), minimum pericarp weight (0.95 g) was recorded in G-6.

The maximum cluster length was recorded in G-5 (10.80 cm), while minimum cluster length was recorded in G-13 (4.51 cm). Highest number of nuts per cluster was recorded in G-5 (7.53) and lowest number of nuts per cluster was recorded in G-13 (1.50). Highest nut yield per tree was recorded in G-5 (16.16 kg) and lowest recorded in G-13 (1.66 kg).

The maximum carbohydrate content (2.37 %) was recorded in G-6, while minimum total carbohydrate content (1.64 %) was recorded in G-12.

The maximum protein was recorded in G-5 (13.40 %), while minimum protein content was recorded in G-12 (5.53 %).

The maximum total sugar content at maturity stage was observed in G-5 (2.25 %) and lowest total sugar content was observed in G-12 (1.59 %). Maximum reducing sugar content at maturity stage was observed in G-9 (0.37 %) and lowest reducing sugar content was observed in G-10 and G-11 (0.25 % each). Maximum non-reducing sugar content at maturity stage was observed in G-5 (1.83 %) and lowest was observed in G-9 and G-12 (1.22 % each).

Nut yield per tree showed positive and significant correlation with nut weight, nut diameter, kernel weight, kernel thickness, nut volume, shell weight, cluster length and nuts per cluster both at phenotypic and genotypic level. While, non-significant negative correlation with shell thickness and pericarp weight.

Nut weight, nut diameter, kernel weight, kernel thickness, cluster length, nuts per cluster exhibited positive direct effect on nut yield per tree while, nut volume, shell weight and shell thickness imparted negative direct effect on nut yield per tree.

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Appendix

VIII APPENDIX

APPENDIX I

List of symbols and abbreviations

Symbols	Abbreviations
%	Per cent
^0C	Degree centigrade
CD	Critical difference
wt	Weight
cm	Centimeter
m	meter
MT	Metric ton
et al.	Et allii (and other)
i.e.	That is
cc	Cubic centimeter
mg	Milligram
ml	Milliliter
mm	Millimeter
S. Em.	Standard error of mean
Viz.	Namely
g	Gram
kg	Kilogram
nm	Nanometer
Cov	Coefficient of variation
NaOH	Sodium hydroxide
HCl	Hydrochloric Acid
H_2SO_4	Sulphuric acid