Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area

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KERALA, INDIA
2020

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THESIS

Submitted in partial fulfilment of the

requirement for the degree of

Master of Science in horticulture

(FRUIT SCIENCE)

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF FRUIT SCIENCE

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **"Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area"** is a bonafide record of research work done by me during the course of research and that the thesis has not been previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara
Date: 25/1/2021

RESHMA RAVI P.
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CERTIFICATE

Certified that this thesis entitled **"Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area"** is a bonafide record of research work done independently by **Ms. Reshma Ravi P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Date: 25/1/2021

Dr. K. Ajith Kumar

(Major Advisor)
Associate Director of Research,
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We, the undersigned members of the Advisory Committee of **Ms. Reshma Ravi P.** (2018-12-006), a candidate for the degree of **Master of Science in Horticulture** with major field in Fruit Science, agree that the thesis entitled **"Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area"** may be submitted by **Ms. Reshma Ravi P.**, in partial fulfilment of the requirement for the degree.

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ACKNOWLEDGEMENT

First and foremost, I bow my head before the ***Almighty God*** *for enlightening and making me strong and confident throughout my life and enabled me to fruitfully complete the thesis work.*

It is with immense pleasure I avail this opportunity to express my deep sense of whole hearted gratitude and indebtedness to my major advisor ***Dr. K. Ajith Kumar*** *for his expert advice, inspiring guidance, valuable suggestions, constructive criticisms, constant encouragement, affectionate advice and above all, the extreme patience and wholehearted co-operation rendered throughout the course of my study. I really consider it my greatest fortune in having his guidance for my research work.*

I consider it as my privilege to express my deep-felt gratitude to ***Dr. Suma A.*** *former Professor and Head, Dept. of Fruit Science, CoH, Vellanikkara for her constant support and valuable suggestions throughout my research work.*

I sincerely thank ***Dr. Jyothi Bhaskar*** *Professor and Head, Dept. of Fruit Science, CoH, Vellanikkara for her expert advice, constant inspiration, precious suggestions, generous support, constructive criticisms and proactiveness during my entire study which helped in successful completion of this work.*

I express my sincere thanks to ***Dr.Vikram H. C.*** *Assistant Professor, Dept. of Fruit Science for his valuable suggestions, constructive criticism and critical scrutiny of the manuscript.*

*I express my gratitude to****, Dr. A. V. Santhoshkumar*** *Professor and Head, Department of Forest Biology and Tree Improvement, CoF, Vellanikkara for his valuable time, immense help and assistance provided for conducting the research work.*

I express my wholehearted gratitude to ***Dr. Arumughan*** *for generously allowing me to do my research in his orchard, his cooperation and valuable suggestions.*

I am in dearth of words to express my love and gratitude towards my beloved ***Parents Mr. P. A. Raveendran and Mrs. Usha Raveendran and my caring brother Mr. Rakesh Ravi P.*** *for their eternal love, boundless affection, moral and emotional support, deep concern, care, prayers and personal sacrifices in sustaining peace in my life.*

*I duly acknowledge the encouragement, moral support, precious suggestions and timely persuasions by the capable teaching faculty of our department (****Mrs. Lakshmi K. S, Ms. Sharaon Jacob, Ms. Jesabel George and Mrs. Geethumol)*** *and my dear seniors*

(Mrs. Poojashree, Mrs. Anu Ann Augustine, Mrs. Amritha Manohar, Mrs. Athira A. S, Ms. Annjoe V. Joseph and Mr. Lalit Dhurve) *not only in my research work but also throughout my PG programme. I express my sincere thanks to my classmates* ***(Ms. Anju Jayachandran and Mrs. Swega Antony K.)*** *for their affection and kind help offered during my thesis work. I have infinite pleasure to express my wholehearted gratitude to my loving juniors* ***(Ms. Keerthana, Mr. Ashish and Mr. Manjunath)*** *for their love, innumerable help and support.*

I thank my dear friends for the unconditional support, help, timely valuable suggestions and encouragement which gave me enough mental strength and perseverance to get through all odds and tedious circumstances and immense thanks to all M.Sc. classmates for their moral support and encouragement.

I express my sincere thanks to ***Mr. Shoukath Ali, Ms. Aparna Madhavan N., Ms. Anjana and Ms. Abhina*** *for extending their help throughout my research work.*

I am extremely thankful to all nonteaching staff ***(Mrs. Swathi and Mrs. Aswathy)*** *and workers* ***(Mrs. Ambili, Mrs. Gincy, Mrs. Vidhya and Mrs. Manju)*** *for their support during the conduct of research.*

I express my gratitude to ***Mrs. Liji*** *and* ***Mr. Prasad*** *for accompanying me to the experimental location even during the pandemic for collection of data.*

I sincerely thank my uncle ***Mr Santhosh Kumar P. A.*** *(District Education and Media Officer, Department of Health, Palakkad) for his efforts in collecting and delivering the samples from the experimental location during the lockdown period.*

I owe special thanks to Librarian, College of Horticulture, ***Dr. A.T. Francis*** *and all other staff members of Library, who immensely helped me for the collection of literature for writing my thesis.*

I express my deep sense of gratitude to Kerala Agricultural University for financial and technical support for persuasion of my study and research work. It is impossible to list out all those who have helped me in one way or another in the successful completion of this work. I once again express my heartfelt thanks to all those who helped me in completing this venture.

Reshma Ravi P.

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Introduction

1. INTRODUCTION

Mango (*Mangifera indica* L.), also known as the 'King of fruits' is one among the most sort after fruits in the world. The incomparable tasty fruit is known for its exceptionally good flavour and appearance as well as its nutritive qualities. Even though many studies have been conducted on this crop, the flowering behaviour of mango still remains as an enigma. Various factors such as climatic and edaphic factors are found to influence flowering and fruit set in mango and variations in flowering patterns are observed across different climatic zones.

Muthalamada, also known as the 'Mango city of Kerala' is well known for its early season export of quality mangoes. Muthalamada mangoes hail from the Elavancherry, Kollengode and Muthalamada panchayats of Chittoor Taluk in Palakkad district. Approximately 1707 ha of land is under mango cultivation in this area with an annual production of 13324 tons (GOK, 2019). The main varieties cultivated in this area are Alphonso, Banganapalli, Bennet Alphonso (Sindhooram), Imam Pasand, Totapuri and Banglora and are well known for their flavour, taste and juiciness. The flowering season in this area starts from September and extends till December and the harvesting season is from January to April. It is believed that the specific ecological and climatic conditions prevailing along with the soil characteristics are the major contributing factors for the earliness in fruit bearing and quality of mangoes produced from this area.

Even though conventional planting system is opted for planting trees in Muthalamada, high density mango orchards are gaining popularity in this region. The main advantage of High Density Planting (HDP) system in mango orchards is the easiness in conducting crop management practices including harvesting. As far as mango cultivation is considered, it is important to identify the key stages of growth in order to plan the cultural operations according to the growth stages to obtain maximum yield and quality.

Various factors such as climate, soil, biotic and abiotic stress, *etc*. are found to play a key role on the growth and development of mango. Among them the climatic factors have profound influence on the yield and qualitative parameters of mango. The qualities of mango such as total soluble sugars, colour, sweetness, blushing of peel,

flavour and aroma are highly influenced by the prevailing environmental conditions. The flowering behaviour is also highly influenced by the ambient temperature, rainfall, pests and diseases. The variations in environmental conditions beyond the optimum range results in stress and adversely affect the yield potential of the crop.

Even though Muthalamada mangoes are famous in both Indian and foreign markets, the mango cultivation in this area is facing various problems which is directly or indirectly resulting in lower yield and quality. During the recent past, the production of mangoes from this tract is following a decreasing pattern over the years. At present the major factors that are adversely affecting mango production in this area are increased atmospheric temperature, cloudy weather and high humidity leading to the incidence of pests such as mango hoppers and thrips. In addition to this, high humidity and cloudy weather during the flowering season are a nightmare to the farmers as they cause shedding of flowers. The infestation of mango thrips and hoppers adversely affect the developing inflorescence and causes drying off of the flowers and inflorescence axis which in turn results in yield reduction.

The quality of fruits is also affected by the changing climatic conditions and the incidence of pests and diseases. The fruit characters such as peel colour, blush colour, *etc.* increases the appeal of fruits in both global and local markets but physiological disorders such as spongy tissue is a major problem which deters the quality and palatability of the fruits, especially in Alphonso variety of mango.

Since the orchards in the Muthalamada tract are constantly prone to pest infestations, the farmers are resorting to intensive use of pesticides which is high than the recommended rates. The indiscriminate use of pesticides and growth promoters on one hand is increasing the cost of production and on the other hand it is resulting in huge loss to the farmers. Due to these reasons they are in desperate need of proper guidelines for getting good profit by reducing the cost to be incurred for the inputs used for production, coupled with the production of good quality safe to eat mangoes.

Only a few scientific studies have been conducted till date in this area and the difference in ecological and climatological conditions makes it necessary to study the ecophysiology of flowering and fruiting in Muthalamada region. The present study on

"Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area" was undertaken with the objective to understand the performance of different varieties of mango under agro-ecological conditions of this region and thereby identifying the most suitable variety for this tract so that the farmers can eliminate varieties with low performance while setting up new orchards and also to provide proper guidelines to the farmers for scheduling the management practices according to the responsive stages of the crop.

Review of Literature

2. REVIEW OF LITERATURE

Mango is a crop with complex flowering physiology and the crop interacts with the environment in such a way that it is reflected in the quantity and quality of the fruits produced. The flowering and fruiting in mango are highly influenced by the environmental factors and numerous studies have been conducted on this aspect all over the world across various agroclimatic conditions. Muthalamada is well known as the major mango growing tract in Kerala which produces early season mangoes with unique qualities such as colour, taste, flavour, *etc*., which make them the most sort after ones in the Indian market. Even though this region has been in the forefront of mango production, the mango growers are now facing the problems such as change in fruiting season, low yield, fruit drop, alternate bearing, pest and disease incidence and changes in climatic conditions.

The climatic parameters that mainly affect the quality and quantity of the produce are temperature, relative humidity and rainfall. High density planting is practiced in the orchard which helps in modifying the flowering and growth habits of the trees. Varietal characters of these varieties are also important since they are mainly export oriented. The effects of weather parameters on the physiological and biochemical characters of mango have been studied by various scientists across the world and abundant literature are available on the research work conducted on these aspects.

2.1 Varietal characters of varieties under study

An ideal mango variety should be regular bearing with dwarf stature and medium sized fruits which are having golden apricot yellow colour, preferably with red blush and high pulp to stone ratio. The fruits should have good keeping quality having firm, fibreless pulp with excellent sugar-acid blend and pleasant aroma (Mango DB, 2016).

Alphonso is a superior variety of mango in India which is extensively being exported. It is cultivated mainly in Ratnagiri district of Maharashtra, Gujarat and Karnataka. Fruits are having yellow to orange colour with attractive blush towards the basal end. Even though this variety is having good keeping quality, they are prone to alternate bearing and are highly susceptible to spongy tissue (Radha *et al*., 2019).

According to Hada and Singh (2017), the flowering in the mango variety Alphonso starts from the last week of February, with a mean flowering duration of 22.50 days.

Mango variety Imam Pasand which is also known as Himayuddin is a popular variety of Andhra Pradesh having very good eating quality. This variety has a low fruit bearing intensity and usually flowers from January to February (Mango DB,2016).

Bennet Alphonso, locally known as Sindhooram is a mango variety which is highly adapted to Kerala conditions and flowers from mid-January to the first week of February (Mango DB,2016).

2.2 Effect of High-Density Planting system on yield and quality of mango

According to Dalvi *et al*. (2010) higher fruit yield was obtained under high density planting when compared to normal spacing out of which maximum yield was recorded in 5 m × 5 m spacing for the mango variety Alphonso.

According to Adak *et al*. (2019) maximum fruit yield was recorded for medium density planting at 5 m × 5 m spacing with a plant density of 400 trees ha^{-1} when compared to traditional spacing of 10 m × 10 m in the mango cultivar Dashehari.

According to Aswini (2019) mango genotypes Mallika, Ratna, Muvandan, Vellaikolumban and Prior are best suited for high density planting under the scenario of climate change.

Kumar (2019) reported that technology such as formative pruning and annual canopy management should be followed under high density planting or ultra-high-density planting for better yield and pest and disease management.

According to Sagar *et al*. (2019) maximum plant height, plant girth and canopy volume was recorded in the variety Alphonso under 5 m × 5 m spacing whereas maximum per hectare yield was obtained in 2.5 m × 2.5 m spacing under high density planting system.

According to Senthivel and Kaleeswaran (2019) the mango variety Banganapalli was found to be the best suitable variety for ultra-high-density planting

system, both in terms of yield and benefit-cost ratio. It was also observed that the best quality fruits in terms of TSS were obtained from the variety Banganapalli under ultra-high-density planting system.

2.3 Effect of weather parameters on flowering and fruit set in mango

2.3.1 Effect of temperature on flowering

According to Lakshminarayana and Aguilar (1975) field temperatures not less than 10ºC during fruit set and development period results in normal fruit production in the mango variety Haden.

de Wet *et al*. (1989) reported that a temperature range of 25 to 30 ºC is necessary for effective pollination in cross pollinated mango trees of the variety Haden using the variety Zill as the pollen donor.

According to Whiley (1992) day and night temperatures below 20 ºC and 15 ºC respectively result in floral induction. Nunez-Elisea *et. al* (1993) reported that vegetative growth flushes occur during warm temperatures, around 25 ºC or higher under subtropical conditions in mango.

According to Nunez-Elisea and Davenport (1994) water stress during both warm and cool temperatures did not induce floral morphogenesis in container grown mango trees of the variety Tommy Atkins. It was also observed that under cooler night temperatures of 15 ºC, the number of buds displaying floral morphogenesis was not increased by water stress but resulted in early bud break of around 40 per cent of the apical buds.

Shii (1999) reported that warm day and night temperatures of 31ºC and 25ºC respectively hastens the growth rates of mango panicles and flowers and shortened flowering duration and life span of individual flowers. Warmer temperatures also resulted in higher rates of anther dehiscence and fertilisation.

According to Davenport (2000) mango passes through different phenological stages that start with cell division of apical and lateral meristems and reproductive flushes are developed after a period of stem rest or after a period with cool night temperatures. Individual stems are dormant most of the time and periods of dormancy

are short in young plants but can last for more than eight months between flushing episodes in mature trees. Flushes occurring during low temperatures of 5- 15ºC usually produce flowering panicles and frequency of flushes generally depends upon cultivar, size of the tree, and growing conditions.

According to Davenport (2007) the effect of temperature is more evident under subtropical conditions where flower formation occurs after or during exposure to floral inductive cool temperatures. Mangoes grown in the low- latitude tropics rely less on low temperature for floral induction than trees grown in the upper- latitude tropics and subtropics.

According to Parmar *et al.* (2012) relatively higher temperature regimes during flower induction period adversely affects the flowering and fruit set in the mango varieties Kesar and Alphonso in Gujarat. It was also observed that temperatures below 17º C are optimal for better flowering.

A study conducted by Kumar *et al.* (2014) in Kanyakumari and Tenkasi regions of Tamil Nadu revealed that flowering of mango during both main season and off-season is positively correlated to the maximum temperature of 32 ºC, minimum temperature of 20.30 ºC, relative humidity of 84.50 per cent and an average rainfall of 130 mm prevailing in the area.

Normand *et al.* (2015) reported that higher temperatures increases the photosynthetic assimilation and respiratory loss in mango trees whereas extremely high temperatures results in damaging the photosynthetic mechanism. They reported that when water and nutrients are not limiting, the increase in ambient temperature results in rapid growth rhythm which in turn reduces the time lag between successful vegetative flushes. It was also reported that floral induction in mango is driven by cooler temperatures and higher temperatures during this period negatively affects the floral induction process.

The fruit set percentage is directly related to the sex ratio and temperature during flowering where higher temperatures favored higher fruit set percentage in mango varieties. Maximum fruit set was observed during the month of March in most of the

cultivars regardless of the hermaphrodite flower proportion indicating that the fruit set was influenced by the temperature during flower anthesis (Geetha *et al.,* 2016).

According to Kaviarasu *et al.* (2017) a maximum temperature of 29.90 to 32.90°C with a diurnal variation of 6.90°C is found to be highly conducive for off-season flowering of mango in Kanyakumari. It was also noted that an average relative humidity of 76.60 per cent and an average rainfall of 159.53 mm contributed to the early flowering of mango trees.

The daily maximum and minimum temperatures and bright sunshine hours are found to have significant negative correlation with days to flower initiation, fruit set and male flower (%) and significant positive correlation with width of panicle, number of panicle/tree and perfect flower (%). It was also observed that the relative humidity had highly significant positive correlation with days to flower initiation, fruit set and male flower (%) and showed highly significant negative correlation with number of panicles/tree and perfect flowers (%) (Rajatiya *et al*., 2018).

According to Aswini (2019) changes in the climatic conditions such as temperature and rainfall had a significant impact on mango genotypes since the flower initiation, fruit initiation and fruit maturation phenophases are strongly influenced by the environment.

Mandal and Verma (2020) reported that the bud morphogenesis in mango is temperature dependent. They also reported that flower bud initiation and growth of the buds were favoured by cool and warm temperatures respectively.

2.3.2 Effect of rainfall on growth, flowering and yield

According to Yaacob *et al.* (1979) the nitrogen and potassium content in the young leaves were higher in dry months when compared to rainy season and the younger leaves had significantly higher nitrogen, phosphorus and potassium content when compared to the older leaves in cashew.

According to Lobell *et al.* (2007) higher rainfall in June had a positive effect on yield in wine grapes whereas rains during October were favourable for table grapes in California.

Jedrszczyk *et al.* (2016) reported that the fruit weight, fruit length and fruit width were negatively correlated to the precipitation received during the various stages of fruit growth in tomato.

According to Singh *et al.* (2016) rainfall and hails during flowering adversely affects the fruit set, whereas moderate temperature of 20 °C with relatively low rains during flowering results in the good fruit set in apple. rains accompanied by low temperature adversely affect the transfer of pollen by restricting bee activity, washing off of pollen and by retarding the pollen tube growth in apple.

2.3.3 Effect of relative humidity on flowering

According to Baer and Smeets (1978) relative humidity had a significant effect on flower drop but had a positive effect on seed set in pepper (*Capsicum annuum* L.).

Lyrene and Williamson (2003) reported that high relative humidity during the time of flowering adversely affected the fruit set of highbush varieties of blueberry in north Florida and south east Georgia.

According to Navjot *et al.* (2012) low humidity and high temperature adversely affect the photosynthetic efficiency and carbon accumulation thereby reducing the ability of the tree to maintain heavy crop loads.

According to Kumari *et al*. (2014) the population of pollinators is negatively correlated with relative humidity which implied that lower relative humidity during flowering season results in better fruit set due to higher population of pollinators.

Makhmale *et al*. (2016) reported that lower relative humidity is favourable for flowering and fruit set in mango whereas high humidity will result in vegetative growth.

According to Mavuso and Yapwattanaphun (2017) relative humidity does not have a significant effect on flower induction of marian plum.

According to Leopold *et al*. (2018) a positive correlation occurs between relative humidity and the time required for inflorescence appearance and first flower opening. Shorter duration was observed from inflorescence appearance to first flower opening under low relative humidity.

Meghwal *et al*. (2018) reported that relative humidity lower than 30 per cent adversely affects the flowering and fruit set in ber.

Sinha *et al*. (2020) reported that mango requires low relative humidity during fruit development when compared to that of flowering and fruit setting in the Central Plain Zone of Uttar Pradesh.

2.4 Effect of pruning on flowering and yield

2.4.1 Effect of pruning on flowering

Tip pruning in mango trees results in quick lateral shoot growth if the leaf nitrogen content is in the range of 1.10 % to 1.40 %. These lateral shoots will flower after a period of rest for four to five months, by stimulus such as cool temperatures or foliar application of ethephon or any nitrate salts (Davenport, 2000).

Increase in photosynthetic rate and light penetration was observed with the extend of pruning and chlorophyll content in leaves was higher in the unpruned and tipped shoots in the mango variety Amrapali grown under high density planting system (Sharma *et al*., 2006).

According to Davenport (2007) tip pruning is instrumental in flowering management and thereby improving the productivity of mango trees by increasing the number of bearing stems.

According to Ghavale *et al.* (2016) pruning of current season shoots during the first and third week of October resulted in the early inflorescence emergence and flowering and also resulted in better fruit set and yield in mango.

Post-harvest tip pruning of the whole tree during the ‘on’ year followed by soil drenching with paclobutrazol, one month before flower bud differentiation helps in regulating flowering and fruiting during ‘off’ year in the mango variety Dasheshari (Barman and Mishra, 2018).

Rani *et al.* (2020) reported that a combination of pruning, paclobutrazol application and Integrated Nutrient Management had an additive effect in enhancing the fruit yield in the variety Alphonso.

2.4.2 Effect of pruning on fruit yield and quality

According to Pratap *et al.* (2003) pruning at moderate levels of 20 cm from the apex were effective in maintaining optimum metabolic and photosynthetic rates and also in improving the yield in the mango variety Amrapali under high density planting.

According to Singh *et al*. (2010) the pruning intensities significantly influenced the fruit weight and severely pruned trees recorded the highest total soluble solids in the mango varieties Amrapali, Mallika and Dashehari grown under high density planting in sub-tropical conditions.

Gopu *et al.* (2014) reported that different levels of pruning influenced the fruit and yield characters of mango trees under ultra-high-density planting. It was also observed that light pruning by retaining 70 cm of the past season growth recorded the highest mean fruit rate, fruit length, fruit volume, pulp weight and stone weight.

According to Adhikari and Kandel (2015) pruning during early May at a 20 cm pruning level reduced the rainy season crop load and improved the yield and quality of winter season crop in guava.

Singh *et al.* (2016) reported maximum yield per tree as well as per hectare yield in the variety Amrapali grown under HDP system was reported in control trees which were treated with paclobutrazol without pruning. In the same study, the highest fruit weight and pulp percentage were recorded in the trees which were headed back at 20 cm length of the terminal shoots during the resting period before emergence of new growth.

According to Soudagar et al. (2018), tip pruning up to two leaves induced early flowering and early harvest and also improved the yield without affecting physio-chemical composition and sensory qualities in the mango variety Alphonso in Dapoli region of Maharashtra.

According to Kishore *et al.* (2019) paclobutrazol had a significant effect in early induction of floral bud break and in increasing flowering and fruit yield. It was also reported that vegetative growth, leaf area, leaf N and K contents and fruit set were affected negatively by paclobutrazol application in the mango variety Arka Neelachal Kesari.

According to Manohar (2019), the number of fruits per tree and fruit weight were found to be the highest in trees pruned at 20 cm length during the month of June followed by paclobutrazol application in the mango hybrids Mallika and Ratna maintained under high density planting system. It was also reported that fruit weight and fruit quality in both the hybrids were better in the trees which were pruned at 20 cm length during the month of September followed by paclobutrazol application.

According to Rani and Honnabyraiah (2020), a combination of pruning, nutrition and paclobutrazol application can be an effective method in increasing the fruit quality and reducing the incidence of spongy tissue in the mango variety Alphonso.

2.5 Effect of biochemical parameters on flowering and fruit set

Walton et al. (1991) reported that the concentration of the amino acid proline declined prior to bud break in kiwi fruit, which suggests its role in flowering of the crop.

According to Ennajeh *et al.* (2009) the proline content in both the roots and the leaves of olive trees increased with the increase in drought stress which indicates the role of proline in drought tolerance.

Mattioli *et al.* (2009) suggests that proline acts both as a metabolite as well as a signal molecule during flowering and development. It acts an energy source during development and facilitates rapid cell growth. The accumulation of proline imparts stress tolerance in plants which help them thrive under salt or drought stress conditions by maintaining the osmotic potential of the cells (Dar *et al.,* 2016).

The extend of flowering in 'Montenegrina' mandarin trees during the spring is positively correlated with leaf proline content in the previous winter which confirms the involvement of proline in floral induction in citrus (Arias-Sibillotte *et al*., 2019)

Most of the plants responds to water stress by accumulating compatible solvents such as the amino acid proline and the amphoteric quaternary amine glycine betaine. The Relative Water Content (RWC) in the leaves of chilly was found to be negatively correlated to the proline content whereas it was found that the glycine betaine content did not significantly affect the RWC (Escalante-Magana *et al*., 2019).

2.6 Effect of leaf nutrient status

2.6.1 Effect of leaf nutrient status on flowering

The initiation of off season bearing in mango depends upon the variety and may also be correlated with the macronutrient status of the shoots (Singh, 1960).

Garcia-Luis *et al*. (1995) reported that leaf carbohydrate levels were not limiting flower formation in Owari variety of satsuma mandarin (*Citrus unshiu* Marc.)

According to Ulger *et al.* (2004), the level of carbohydrates and mineral nutrients such as N, P, K, Ca, Mg, Fe, Zn, Mn and Cu does not have a direct effect on flower initiation in olive trees grown in the Mediterranean region,

According to Anusuya *et al.* (2011), off season flower bud initiation was observed during October to December, when the leaf nitrogen content was at its minimum. Shoots bearing flowering flush contained lower concentration of nitrogen compared to non-bearing trees.

According to Faria *et al*. (2016), the concentrations of mobile nutrients such as N, P, K and Mg decreased from flowering to fruiting whereas the concentration of nutrients with lower mobility such as Ca, B, Fe and Mn increased from flowering to fruiting in the leaves of Tommy Atkins mango trees.

2.6.2 Effect of leaf nutrient status on fruit development and yield

Ray and Mukherjee (1987) reported that the leaf nitrogen content before flowering and after harvest and phosphorus content before harvest were positively correlated to yield in mango.

According to Oosthuyse (1999) the concentration of the leaf nutrients N, P, K, Ca, Mg, Cu, Fe, Mn and Zn exhibit a flux during the month of November at the time of rapid fruit expansion in the mango cultivars Zill, Tommy Atkins, Sensation, Heidi and Kent.

According to Reddy *et al.* (2001) the fruit yield had a significant positive correlation with leaf nitrogen content before and during flowering, with leaf phosphorus content after harvest and leaf potassium content before flowering in the mango varieties Bamganapalli, Totapuri and Alphonso,

Ahmad *et al*. (2018) reported that a deficiency of boron and zinc in the leaves adversely affect the yield and quality of mango which can be rectified by foliar or soil application.

Khalasi *et al*. (2018) reported that the leaf nitrogen content was the highest during harvesting stage which can be accounted to storing nutrients which are to be mobilized during the subsequent season. It was also observed that the phosphorus content in the leaves were found to be highest when the fruits were in the egg stage of development.

2.7 Effect of paclobutrazol on flowering and yield

According to Ram and Tripathi (1993) cultar application induced flowering and fruiting on new shoots after pruning and suppressed the vegetative growth of trees in the mango variety Dashehari.

According to Junthasri *et al.* (2000) application of paclobutrazol followed by 0.50 per cent thiourea spray after 120 days resulted in flowering within 2.50 to 4.00 months after application depending on cultivar.

Yeshitela *et al*. (2004) reported that paclobutrazol treatment improved the fruit set and the number of fruits per tree when compared to untreated trees of Tommy Atkins mango variety.

According to Kotur (2012) a mean increase of fruit yield of 54 per cent was observed in paclobutrazol treated trees of the mango variety Alphonso.

According to Randeep (2012) paclobutrazol application resulted in early and profuse flowering with a greater number of hermaphrodite flowers in the varieties Alphonso and Prior.

According to Gopu *et al*. (2017) mango trees treated with paclobutrazol at a rate of 1.00 g a.i /m of canopy diameter along with two percent potassium nitrate foliar spray recorded the highest number of fruits per tree and was on par with the trees treated with uniconazole foliar spray at a rate of 1.50 g/l.

According to Kishore et al (2019), application of paclobutrazol during mid-September advanced floral bud break and increased flowering intensity, percentage of

bisexual flowers, fruit yield, TSS and yield efficiency under tropical hot-humid climatic conditions of eastern India in the mango var. Arka Neelachal Kesari.

Kumar *et al.* (2019) reported that soil drench application of paclobutrazol at 5000 ppm or 10000 ppm resulted in earlier panicle emergence and harvest of the crop and resulted in better fruit weight and quality in the mango cultivar Amrapali.

Materials and Methods

3. MATERIALS AND METHODS

3.1 Experimental site

The present study was carried out during the period 2018-2020 in the mango orchard of a farmer in Muthalamada region of Palakkad district which is well known for extensive commercial mango cultivation.

3.1.1 Location

The experimental orchard is situated in Muthalamada region in Palakkad district of Kerala. The orchard is situated between 10°37'03.1"N and 10°37'08.1"N latitudes and 76°42'56.3"E and 76°42'55.1"E longitudes. This area comes under the jurisdiction of Kollengode block panchayat of Chittore taluk, located towards the eastern region of Palakkad district.

3.1.2 Climate

This region has a tropical climate but has a comparatively lower relative humidity. This region receives an annual rainfall around 1400-1600 mm and has an average temperature of 32.45 ºC. The average relative humidity recorded in this region is 70.96 per cent. The warmest month of the year is May with a mean maximum temperature of 37.13 ºC and the average maximum temperature was the least in the month of August with an average temperature of 29.13 ºC.

3.2 Materials

3.2.1 Varieties

Four mango varieties namely, Alphonso, Banganapalli, Bennet Alphonso (Sindhooram) and Imam Pasand which are in extensive cultivation in Muthalamada region were selected for the study. These varieties are in high demand both locally and globally. The trees in the selected orchard were four years of age and maintained under good management.

3.2.2 System of growing

The trees were planted under high density planting system with a spacing of 4m × 3m and the tree canopy was maintained by selective pruning. Irrigation was provided by drip irrigation system.

Tip pruning at a length of 20 cm was carried out from 4th to 7th of July 2019 on all the four varieties. Goat manure was applied immediately after pruning at a rate of 10 kg per tree and the basins around the trees were earthed up.

Paclobutrazol application was carried out one month after pruning on 2nd August 2019. Paclobutrazol solution was prepared by diluting 4 ml of the formulation in 10 liters of water (KAU, 2016). This solution was drenched in the tree basins in small pits of 25 cm depth made around the tree base 60 cm away from the trunk (Plate 1).

3.3 Methods

3.3.1 Design of experiment

The study aimed at observing the response of the trees in the current changing climatic conditions under the commonly followed management practices prevailing in this area. Random sampling techniques were involved in selecting the experimental units and correlation studies were carried out. Five trees each from the four selected varieties of comparable age and stature were selected for the study and their vegetative, floral and yield characters were studied during the period from June 2019 to May 2020. The study was conducted under the existing cultural activities followed in the orchard during the previous seasons. The cultural activities followed in the orchard were paclobutrazol application, selective tip pruning and application of organic manure and plant protection chemicals.

3.4 Observations

3.4.1 Tree characters

3.4.1.1 Tree height

The tree height was recorded by measuring the distance from the ground level up to the topmost or tallest portion of the tree using a meter scale and was expressed in meters (Plate 2).

3.4.1.2 Trunk circumference

The trunk circumference was measured by measuring the girth of the tree at 50 cm height from the ground level using a measuring tape and was expressed in centimeters.

3.4.1.3 Crown diameter

The crown diameter was recorded by measuring the tree spread in East-West and North-South directions using a measuring tape and averages were worked out and expressed in meters.

3.4.1.4 Crown shape

The crown shape was determined by using mango descriptor (IPGRI, 2006) and was categorized into various shapes such as oblong, broadly pyramidal, semi-circular, spherical and other shapes.

3.4.1.5 Foliage density

Foliage density of the tree was determined by using mango descriptor (IPGRI, 2006) and was categorized into sparse, intermediate and dense.

3.4.2 Inflorescence characters

3.4.2.1 Flowering duration

Flowering duration was recorded by counting the number of days between the first instance of flowering and date of last flowering.

3.4.2.2 Date of first flowering

Date of first flowering was recorded by noting the date on which the first flower opened after the emergence and development of the inflorescence.

3.4.2.3 Secondary or off-season flowering

Secondary or off-season flowering was recorded by noting flowering before or after the normal flowering season.

3.4.2.4 Inflorescence position

The position of inflorescence on the tree was determined by using mango descriptor (IPGRI, 2006) and were categorized into terminal, axillary and others.

3.4.2.5 Inflorescence length

Inflorescence length was recorded by measuring the length of 10 inflorescences on each observational tree using a meter scale and then averages were worked out and expressed in centimeters.

3.4.2.6 Inflorescence width

Inflorescence width was recorded by measuring the width of 10 inflorescences on each observational tree using a meter scale, averages worked out and expressed in centimeters.

3.4.3 Phenological characters

Landmark stages of vegetative shoot growth and generative shoot growth stages were photographically recorded according to Davenport scale (Ramirez *et al.*, 2014).

3.4.4 Leaf nutrient analysis

Leaf samples were collected by using the sampling techniques proposed by Bhargava and Chadda (1993). Four to seven-month-old leaves from the tertiary shoots were collected from all sides of the tree. The collected samples were dried using a hot air oven at 80 ± 5 ^{o}C and were powdered using a mixer grinder. This powdered sample was used for leaf nutrient analysis.

3.4.4.1 Total carbohydrate content

Total carbohydrate content in the leaves were estimated by Anthrone method (Yemm and Willis, 1954). Leaf sample (100 mg) was hydrolyzed by keeping in boiling water bath for three hours with 5 ml of 2.5 N HCl and was cooled to room temperature. The sample was neutralized with solid sodium carbonate until the effervescence stops and the volume was made up to 100 ml. The supernatant was collected and 1 ml aliquot was taken from it. Standards of 0, 20, 40, 60 and 100 ppm concentrations were prepared. Anthrone reagent (4 ml) was added to the sample and was heated for eight minutes in a

boiling water bath. The sample was cooled rapidly and the colour intensity was read at 630 nm in a spectrophotometer. A standard curve was drawn and the total carbohydrate present in the sample was calculated.

3.4.4.2 Total nitrogen content

Total nitrogen content in the leaf samples was estimated by micro-Kjeldahl method.

The oven dried leaf sample (0.2 g) was digested with 20 ml of sulphuric acid and a pinch of digestion mixture in a block digester after overnight predigestion. The contents were cooled and the volume was made up to 100 ml. From the sample 50 ml was distilled after adding 50 ml of 40 per cent sodium hydroxide solution and 20 ml of two per cent boric acid was placed at the delivery end. The sample was titrated against 0.1 N hydrochloric acid along with a blank titration.

The percentage of nitrogen present in the sample was calculated by the formula:

$$\text{Total nitrogen (\%)} = \frac{(\text{Titre value} - \text{Blank value}) \times N_{acid} \times 0.014 \times 100}{\text{Weight of the sample}}$$

3.4.4.3 Leaf nutrient analysis

For analyzing the leaf nutrients such as phosphorus, potassium, calcium, magnesium and boron, diacid digestion of the sample was carried out to prepare the leaf extract.

The dried and powdered leaf sample (0.2 g) was taken in a digestion tube by adding 20 ml of diacid mixture prepared by mixing nitric acid and perchloric acid in 9:4 ratio. This was kept overnight for predigestion. On the next day the sample was digested in a block digester until the sample turns clear. The contents were cooled and filtered and the volume was made up to 100 ml.

3.4.4.3.1 Phosphorus content

The phosphorus content in the leaves was estimated by spectrophotometry. The leaf sample (0.2 g) was digested with 20 ml of diacid mixture after overnight

predigestion. The contents were cooled and made-up to 100 ml. From this extract, 5 ml pipetted out to a 25 ml volumetric flask and 4 ml of Barton's reagent was added to it.

The volume was made up to 25 ml and standards of 0, 1, 2, 3, 4 and 5 ppm concentrations were prepared. The colour intensity of both the standards and samples were read at 420 nm using a spectrophotometer.

3.4.4.3.2 Potassium content

The leaf potassium content was estimated by using flame photometry. Standards of 0, 20, 40, 60, 80 and 100 ppm concentrations were prepared and readings were taken using flame photometer. The diacid extract prepared was fed to the flame photometer and the potassium content in the sample was red.

3.4.4.3.3 Calcium content

The leaf calcium content was estimated by using Atomic Absorption Spectrophotometry. The diacid extract (10 ml) was taken in a 50 ml standard flask and the volume was made up. The diluted diacid extract prepared was fed to the Atomic Absorption Spectrophotometer and the readings were taken after calibrating the equipment.

3.4.4.3.4 Magnesium content

The magnesium content in the leaf diacid extract was estimated by using Atomic Absorption Spectrophotometry. The diacid extract (10 ml) was taken in a 50 ml standard flask and the volume was made up. The diluted diacid extract prepared was fed to the Atomic Absorption Spectrophotometer and the readings were taken after calibrating the equipment.

3.4.4.3.5 Boron content

Boron content in the leaf samples were estimated spectrophotometrically using Azomethine-H Method. The diacid extract or sample aliquot (5 ml), 2 ml of ammonium acetate buffer (pH 5.5) and 2 ml of 0.02 M EDTA were added to a 20 ml Boron free test tube and vortexed. After adding 1 mL of Azomethine-H reagent (0.9% Azomethine-H + 2% ascorbic acid solution) the tube was again vortexed, allowed to stand for 1 hour

at approximately 25 °C, and was vortexed again. The absorbance readings were taken at 420 nm using the spectrophotometer.

3.4.5 Physiological characters

Physiological characters such as stomatal conductance, photosynthetic rate, transpiration rate and leaf temperature were recorded using Infra-Red Gas Analyzer. Physiologically active leaves were selected and the readings were taken during the morning hours.

3.4.5.1 Relative water content (RWC)

Relative water content in the plant tissue gives an estimate of plant water stress. Twenty leaf discs of 1 cm diameter were cut out from fresh leaf sample and the weight was recorded. Later turgid weight was recorded after placing the discs in petri plates filled with water for four hours at ambient temperature. After taking the turgid weight the leaf discs were dried in a hot air oven at 80°C and the dry weight was recorded. The Relative Water Content (RWC) was calculated by the formula:

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.4.5.2 Stomatal index

Stomatal index is the percentage of the number of stomata to the total number of epidermal cells per unit area of leaf. It was calculated by the formula:

$$\text{Stomatal index (\%)} = \frac{\text{Number of stomata present per unit area of leaf}}{\text{No. of stomata + No. of epidermal cells within unit area of leaf}} \times 100$$

3.4.5.3 Stomatal frequency

Stomatal frequency is defined as the number of stomata present per unit area of a leaf and was expressed in terms of number of stomata per square millimetre.

3.4.5.4 Leaf Area Index

Leaf Area Index is the ratio between leaf area of the plant to the ground area occupied by it and it was calculated by using the formula:

$$LAI = \frac{\text{Leaf area of the plant}}{\text{Ground area occupied by the plant}}$$

3.4.5.5 Chlorophyll content

The chlorophyll content in the leaves was estimated by spectrophotometry method. Fresh leaf sample (1g) was ground into a fine pulp using 20 ml of 80 per cent acetone. The sample was centrifuged and the supernatant was transferred into a 100 ml volumetric flask. Grinding of the sample was repeated until it turns colourless and the volume of sample was made up to 100 ml using 80 per cent acetone. The absorbance of the sample solutions was red at 645 nm, 663 nm and 652 nm against 80 per cent acetone as blank. The amount of chlorophyll present in the extract was calculated by the formula:

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

$$\text{Chlorophyll b (mg/ g of tissue)} = 22.9\ (A_{663}) - 4.68\ (A_{645}) \times \frac{V}{1000 \times W}$$

$$\text{Total chlorophyll (mg/ g of tissue)} = 20.2\ (A_{663}) + 8.02\ (A_{645}) \times \frac{V}{1000 \times W}$$

3.4.6 Biochemical analysis

3.4.6.1 Proline content

Proline is an amino acid which is synthesized by glutamic acid pathway in plants. Proline content in leaf sample was estimated by spectrophotometry after selective extraction of proline in the sample using three per cent aqueous sulphosalicylic acid solution.

Procedure:

Leaf sample (0.5g) was extracted by homogenizing using 10 ml of three per cent sulphosalicylic acid. The extract was filtered using a Whatman No. 2 filter paper. The filtrate (2 ml) was taken in a test tube and 2 ml of glacial acetic acid was added to it. The sample was heated in a boiling water bath for 1 hour after adding acid ninhydrin. The reaction was terminated by placing the tube in an ice bath. Toluene (4 ml) was

added to the reaction mixture and was stirred well for 20 to 30 seconds. The toluene layer was separated and the sample was warmed to room temperature. The red colour intensity was measured at 520 nm along with a series of standards. The concentration of proline present in the sample is calculated from the standard curve and expressed on fresh weight basis using the formula:

$$\text{Proline (}\mu\text{ moles g}^{-1}\text{ tissue)} = \frac{\mu\text{g proline/ml} \times \text{ml toluene}}{\text{Weight of sample}}$$

3.4.6.2 Glycine betaine

Glycine betaine is a quaternary amine which is accumulated during stress conditions in stress tolerant plants which protects the enzymes from heat and drought damage.

Procedure:

Finely ground dry leaf material (500 mg) was mechanically shaken with 20 ml of deionized water for 24 h at 25ºC. The samples were then filtered through Whatman No. 1 filter paper and the filtrates were used for analysis.

The filtrate was made up to 20 ml with deionized water and used for estimation immediately. One ml of the extract was acidified with one ml of 2N H_2SO_4 and was cooled in ice bath for one hour. 0.5 ml of cooled acidified extract was pipetted out and 0.2 ml of cold potassium tri-iodide solution was added to it. The extract was mixed gently using a vortex mixture and the sample was centrifuged for 15 minutes at 10,000 rpm. The supernatant was collected using a fine tipped glass tube. The per iodide crystals were dissolved in 9 ml of 1,2-dichloroethane with vigorous shaking. After 2.5 h, the absorbance was measured at 365 nm in a spectrophotometer. The glycine betaine content was determined from a standard curve prepared with glycine betaine in 1 N H_2SO_4 and expressed in µ mol/ g dry weight.

3.4.7 Meteorological data

Meteorological data including maximum temperature (ºC), minimum temperature (ºC), rainfall (mm) and relative humidity (%) were recorded on a daily

basis. The total number of rainy days was also recorded from 26th June 2019 to 31st May 2020.

3.4.8 Yield characters

3.4.8.1 Fruiting duration

Fruiting duration was calculated by counting the number of days from the first fruit set to the end of fruiting.

3.4.8.2 Fruit bearing intensity

Fruit bearing intensity was determined by using mango descriptor (IPGRI, 2006) and was categorized into low, medium and high categories.

3.4.8.3 Fruit weight

Fruit weight was estimated by calculating the average fruit weight of 20 fruits and was expressed in terms of grams per fruit.

3.4.8.4 Fruit peel colour

Peel colour of ripe fruit were determined by using mango descriptor (IPGRI, 2006) and was categorized into green, greenish yellow, yellow, green with red blush, green with purple patches.

3.4.8.5 Yield per tree

The total weight of fruits produced by the tree during the season, expressed in terms of kilograms per year represents the yield per tree.

3.4.9 Soil analysis

3.4.9.1 Soil pH

Soil pH was estimated potentiometrically using a pH meter from a soil water suspension of 1:2.5 ratio.

Procedure:

The pH meter was calibrated with the help of buffer solutions. Soil sample (10 g) was taken in a beaker and 25 mL of distilled water was added to it. This suspension was stirred well for about five minutes and kept for half an hour. Just before immersing the electrode the suspension was stirred well and the reading was taken.

3.4.9.2 Electrical conductivity

Electrical conductivity is a measure of the concentration of soluble salts and extent of soil salinity. It was measured using a conductivity meter.

Procedure:

The conductivity meter was calibrated with the help of KI solution and the cell constant was determined. A soil- water suspension of 1:2.5 ratio was prepared and allowed to settle down to form a clear supernatant. This supernatant was used for obtaining electrical conductivity reading.

3.4.9.3 Organic carbon content

Organic carbon content in soil was estimated by Walkley and Black wet digestion method. Organic matter in soil was oxidized with standard potassium dichromate ($K_2Cr_2O_7$) solution and concentrated sulphuric acid. The unreacted $K_2Cr_2O_7$ was back titrated with ferrous sulphate ($FeSO_4.7H_2O$) or ferrous ammonium sulphate ($FeSO_4(NH_4)_2SO_4.6H_2O$).

Procedure:

The soil sample ground in a mortar and pestle to pass through a 0.5 mm sieve. From this sieved sample 1 g was weighed and transferred to a 500 ml conical flask. The flask was swirled gently after adding 10 ml 1N $K_2Cr_2O_7$ to disperse soil in the solution. 20 ml of concentrated H_2SO_4 was rapidly added to this solution and the flask was swirled and shaken for about one minute. The flask was allowed to stand on a sheet of asbestos for 30 minutes and then 200 ml of distilled water was added to the flask. To the solution three to four drops of ferroin indicator was added and titrated with 0.5 N Ferrous ammonium sulphate. The end point was indicated by the colour change of the solution to a greenish colour and solution changed sharply to blue or red when it reached the end point. The organic carbon content in the soil was given by the formula:

$$\text{Organic Carbon (\%)} = \frac{[\text{meq } K_2Cr_2O_7 - \text{meq } Fe(NH_4)_2SO_4]\times 0.003\times 100\times 1.32}{\text{Weight of the sample}}$$

$$= \frac{[10\times 1 - \text{titre value (ml)}\times \text{Normality of } Fe(NH_4)_2SO_4\times 0.39]}{\text{Weight of the sample}}$$

3.4.9.4 Total nitrogen

The total nitrogen content in the soil sample was estimated by micro-Kjeldahl method by using 0.32 per cent potassium permanganate solution.

Procedure:

Soil sample (5 g) was taken in a distillation tube and 25 ml of 0.32 per cent potassium permanganate solution was added to it. Micro-Kjeldal distillation was immediately carried out for 12 minutes after swirling the tube and adding 25 ml 2.5 per cent sodium hydroxide solution. The evolved ammonia gas was collected at the delivery end using 25 ml four per cent boric acid solution with mixed indicator. The indicator solution turned from wine red to bluish green after distillation. The distillate was titrated using 0.01 N sulphuric acid and the end point was indicated by the changing of bluish green colour to pink.

3.4.9.5 Soil C:N ratio

The ratio between soil organic carbon and total nitrogen content in the soil was expressed as soil C:N ratio.

3.4.9.6 Available phosphorus

Available phosphorus was extracted using Bray No. 1 reagent and it was estimated colorimetrically using a spectrophotometer.

Procedure:

The soil sample (5 g) was taken in a 100 ml conical flask and 50 ml Bray No. 1 reagent was added and shaken for exactly 5 minutes. The extract was filtered through a Whatmann No. 42 filter paper and the phosphorus content was estimated colorimetrically by ascorbic acid method.

A volume of 5 ml of the extract was pipetted out into a 25 ml volumetric flask and 4 ml of Reagent B was added. The volume was made up to the mark and the contents were shaken well. The colour intensity was red at 660 nm after resting the sample for 10 minutes. The concentration of phosphorus in the sample was calculated from the standard curve by using the formula:

$$\text{Available P} = \frac{\text{Absorbance of the sample}}{\text{Slope of the curve}} \times 50$$

3.4.9.7 Available potassium

Available potassium content in the soil sample was estimated calorimetically by using a flame photometer.

Procedure:

Soil sample (5 g) was shaken with 25 ml neutral normal ammonium acetate solution for about 5 minutes and it was filtered immediately using a dry Whatmann No. 42 filter paper. The first few milliliters of the filtrate were discarded and the potassium concentration was read using a flame photometer after calibrating the equipment with the standard solutions. Available potassium content in the sample is calculated by the formula:

$$\text{Available K (mg kg}^{-1}\text{ soil)} = \mu\text{g K mL}^{-1}\text{ of the aliquot} \times \frac{25}{5}$$

3.4.9.8 Calcium content

Calcium content in the soil sample was estimated by extracting exchangeable Ca^{2+} cations by using neutral normal ammonium acetate followed by Atomic Absorption Spectrophotometry.

Procedure:

Soil sample (5 g) was shaken with 25 ml neutral normal ammonium acetate solution for about 5 minutes and it was filtered immediately using a dry Whatmann No. 42 filter paper. The first few milliliters of the filtrate were discarded and the calcium content in the soil extract was estimated by Atomic Absorption Spectrophotometry.

3.4.9.9 Magnesium content

Magnesium content in the soil sample was estimated by extracting exchangeable Mg^{2+} cations by using neutral normal ammonium acetate followed by Atomic Absorption Spectrophotometry.

Procedure:

Soil sample (5 g) was shaken with 25 ml neutral normal ammonium acetate solution for about 5 minutes and it was filtered immediately using a dry Whatmann No.

42 filter paper. The first few milliliters of the filtrate were discarded and the magnsium content in the soil extract was estimated by Atomic Absorption Spectrophotometry.

3.4.9.10 Boron content

The available boron content in the soil was estimated by hot water extraction method developed by Gupta (1967).

Procedure:

The processed soil sample (20 g) was weighed in a 250 ml quartz or other boron free containers and 40 ml distilled water was added to it. The sample was boiled for 5 minutes after adding 0.5 g of activated charcoal and was filtered immediately through a Whatmann No. 42 filter paper. The contents were cooled to room temperature and 1 ml aliquot of blank diluted boron standard or sample solution was transferred in to 10 ml polypropylene tubes. Buffer solution (2 ml) was added to it and mixed well. 2 ml of azomethene – H reagent was added to the sample and mixed well. The absorbance readings were taken at 420 nm in a spectrophotometer after 30 minutes. A standard curve was prepared and the boron content was calculated by using the formula:

$$\text{Available boron (mg kg}^{-1}\text{ soil)} = \frac{\text{Absorbance reading} \times 40}{\text{Slope of standard curve} \quad 20}$$

3.4.10 Pest and disease incidence

The pest population in the orchard was constantly monitored throughout the cropping season. Ten panicles per observational tree were selected for observation and the number of pests present on the panicle was counted by visual counting method. When the number of pests were more than ten, those pests were denoted as major pests and when the number of pests were less than ten, those pests were denoted as minor pests (Munj *et al.*, 2018).

3.4.11. Statistical analysis

Correlation analysis was carried out among the observational parameters by Spearman's correlation matrix method by using the software OPSTAT.

Plate 1. Overview of experimental orchard

Taking channels for paclobutrazol application

Application of paclobutrazol

Plate 2. Application of paclobutrazol in experimental orchard

Plate 3. Collection of observational data from the experimental orchard

Plate 4. Recording physiological parameters using Infra-Red Gas Analyzer

Results

4. RESULTS

The ecophysiology of mango under High Density Planting System in Muthalamada area was studied in a farmer's orchard located in Muthalamada during the period 2019-2020. The varieties Alphonso, Banganapalli, Bennet Alphonso (Sindhooram) and Imam Pasand were used for the study and the results of this study are furnished in this chapter.

4.1 Tree characters

4.1.1 Age of the tree

The trees selected from the experimental varieties under study were four years of age during the beginning of the study.

4.1.2 Height of the tree

The variety Imam Pasand recorded the lowest mean height of 3.06 m whereas the variety Alphonso recorded the highest mean height of 3.27 m. A mean tree height of 3.20 m and 3.17 m were recorded in the varieties Banganapalli and Sindhooram (Table 1).

4.1.3 Trunk circumference

The variety Alphonso recorded the highest mean trunk circumference of 30.20 cm and the variety Imam Pasand recorded the lowest mean trunk circumference of 21.00 cm. The varieties Banganapalli and Sindhooram recorded a stem girth of 29.40 cm and 27.60 cm respectively (Table 1).

4.1.4 Crown diameter

The variety Banganapalli recorded the highest mean crown diameter of 3.54 m and the variety Alphonso recorded the lowest mean crown diameter of 3.35 m. The varieties Sindhooram and Imam Pasand recorded mean crown diameter of 3.39 m and 3.44 m respectively (Table 1).

4.1.5 Crown shape

Three varieties under study namely, Alphonso, Banganapalli and Sindhooram exhibited semi-circular canopy shape whereas the variety Imam Pasand exhibited drooping canopy.

4.1.6 Foliage density

The varieties Alphonso, Banganapalli and Imam Pasand recorded intermediate foliage density and the variety Sindhooram had dense canopy.

4.2 Inflorescence characters

4.2.1 Flowering duration

The longest flowering duration was observed in the variety Sindhooram with 29.60 days, followed by the varieties Banganapalli with 25.80 days and Alphonso with 25.40 days. The shortest flowering duration was observed in the variety Imam Pasand where the flowering duration started from mid-September and continued for 15.80 days (Table 2).

4.2.2 Date of first flowering

The variety Banganapalli was the earliest among the four varieties in which first flowering was observed on 14th September 2019. First flowering was observed on 17th September 2019 in the variety Imam Pasand. In the variety Alphonso, first flowering was observed on 21st November 2019. The variety Sindhooram was the last variety to flower among the four varieties under study and first flowering was observed on 2nd December 2019 in this variety.

4.2.3 Secondary or off-season flowering

Secondary flowering was observed in the variety Imam Pasand following flower drop due to the attack of mango thrips. Secondary flowering was observed on 8th December 2019, but no fruit set was observed.

Table 1: Tree growth characters of the selected mango varieties

Variety	Tree characters		
	Tree height (m)	Crown diameter (m)	Stem girth (cm)
Alphonso	3.27	3.35	30.20
Banganapalli	3.20	3.54	29.40
Imam Pasand	3.06	3.44	21.00
Sindhooram	3.17	3.39	27.60
SD	0.09	0.08	4.78
CV	2.75	2.39	15.44

Table 2: Inflorescence characters of the selected varieties

Variety	Inflorescence characters		
	Flowering duration (Days)	Inflorescence length (cm)	Inflorescence width (cm)
Alphonso	25.40	29.20	19.80
Banganapalli	25.80	20.40	13.40
Imam Pasand	15.80	39.60	23.80
Sindhooram	29.60	35.60	19.20
SD	5.88	8.38	4.28
CV	24.35	26.85	22.49

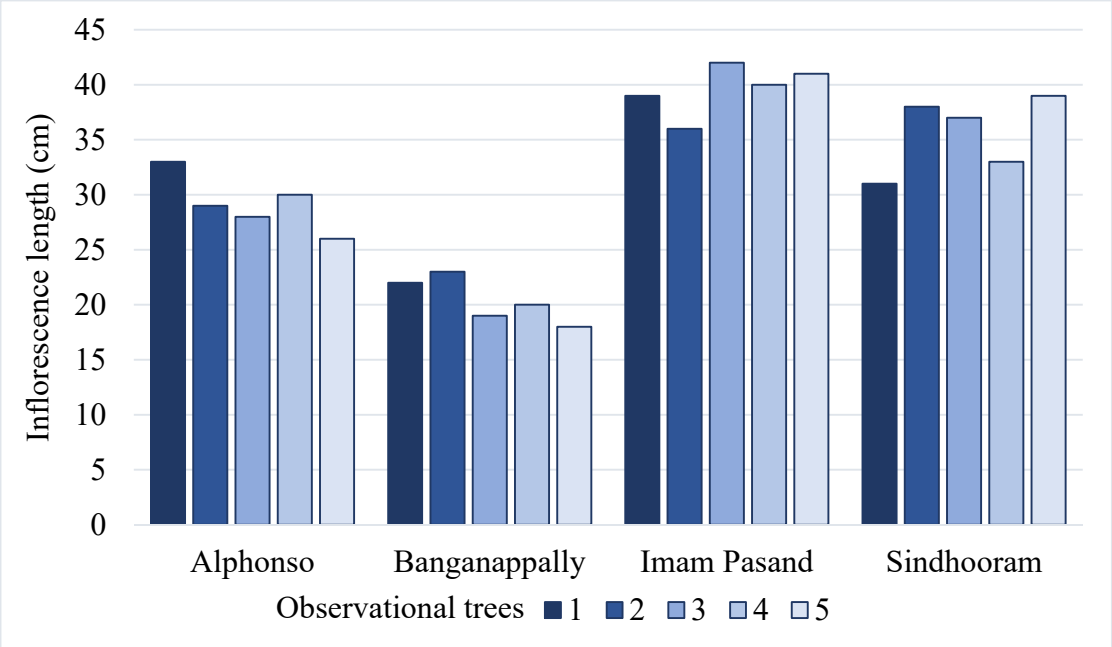


Fig. 1. Length of inflorescence in the varieties under study

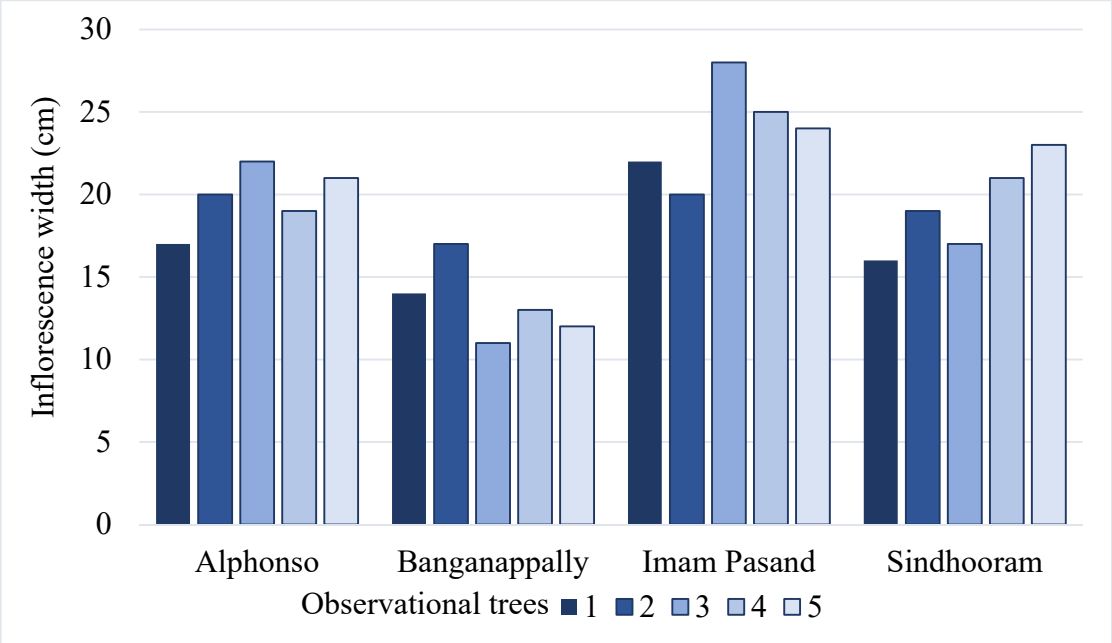


Fig. 2. Width of inflorescence in the varieties under study

4.2.4 Inflorescence position

Inflorescence position of the three varieties namely, Alphonso, Banganapalli and Imam Pasand were found to be terminal whereas, in the variety Sindhooram the position of the inflorescence was found to be both terminal and axillary (Plate 4).

4.2.5 Inflorescence length

The inflorescence length was found to be maximum in the variety Imam Pasand with a mean inflorescence length of 39.60 cm (Fig. 1). The variety Banganapalli recorded the minimum mean inflorescence length of 20.40 cm. The varieties Alphonso and Sindhooram recorded a mean inflorescence length of 29.20 cm and 35.60 cm respectively (Table 2).

4.2.6 Inflorescence width

The maximum inflorescence width of 23.80 cm was observed in the variety Imam Pasand whereas the minimum inflorescence width of 13.40 cm was observed in the variety Banganapalli (Fig. 2). The varieties Alphonso and Sindhooram recorded a mean inflorescence width of 19.80 cm and 19.20 cm respectively (Table 2).

4.3 Phenological stages

The phenological stages of the trees were observed starting from pruning to fruit set. The landmark stages of vegetative shoot growth were Vegetative Bud Break (VBB), Elongating Green Leaf Stage (EGL), Limp Red Leaf Stage (LRL), Immature Green Leaf Stage (IGL) and Mature Green Leaf Stage (MGL). and the landmark stages of generative shoot growth were Floral Bud Break (FBB), Floral Bud Expansion Stage (FBE), Early Panicle Elongation Stage (EPE), Mid-Size Panicle Early Anthesis Stage (MPEA) and Full Size Panicle Maximum Anthesis Stage (FSPMA) (Ramírez *et al*., 2014). These stages were photographically recorded in all the four varieties namely Alphonso (Plate 4a and 4b), Banganapalli (Plate 5a and 5b), Imam Pasand (Plate 6a and 6b) and Sindhooram (Plate 7a and 7b). The time required to attain flowering from staring from pruning was minimum in the variety Baganapalli which required 138.80 days and maximum in the variety Sindhooram which required 150 days (Table 3).

Table 3: Time requirement of varieties from pruning to the onset of flowering

Observational tree	No. of days from pruning to first flowering			
	Alphonso	Banganapalli	Imam Pasand	Sindhooram
1	141.00	72.00	76.00	150.00
2	138.00	74.00	75.00	149.00
3	137.00	75.00	77.00	152.00
4	140.00	70.00	79.00	151.00
5	138.00	71.00	74.00	148.00
Mean	138.80	72.40	76.20	150.00
SD	1.64	2.07	1.92	1.58
CV	1.18	2.86	2.52	1.05

Variety- Alphonso

Variety- Banganapalli

Variety- Imam Pasand

Variety- Sindhooram

Plate 5. Inflorescence position of the varieties under study

Resting stage

Vegetative Bud Break stage

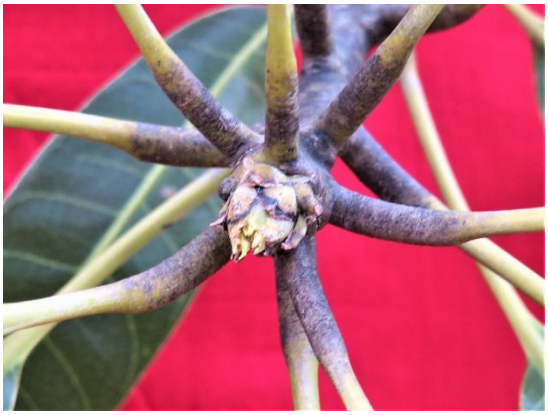
Elongating Green Leaf stage

Limp Red Leaf stage

Immature Green Leaf stage

Mature Green Leaf stage

Plate 6a: Landmark stages of vegetative growth in variety Alphonso



Resting stage

Floral Bud Break

Floral Bud Expansion stage

Early Panicle Elongation stage

Mid-size Panicle Early Anthesis stage

Full-size Panicle Maximum Anthesis stage

Plate 6b: Landmark stages of flowering in variety Alphonso

Resting stage

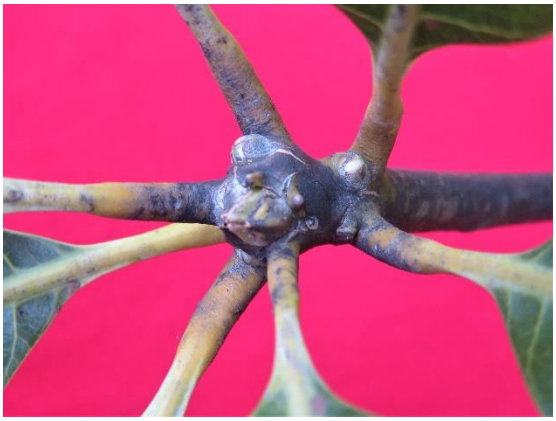
Vegetative Bud Break stage

Elongating Green Leaf stage

Limp Red Leaf stage

Mature Green Leaf stage

Plate 7a: Landmark stages of vegetative growth in variety Banganapalli



Resting stage

Floral Bud Break

Floral Bud Expansion stage

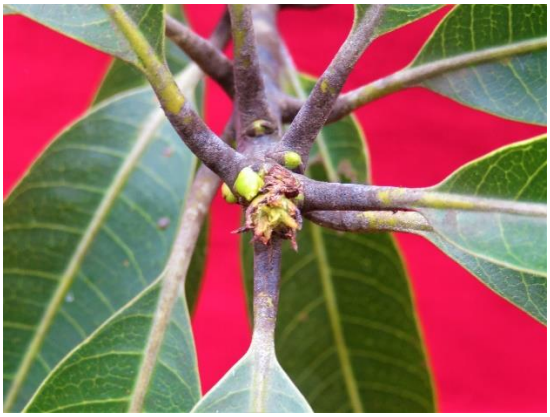
Early Panicle Elongation stage

Mid-size Panicle Early Anthesis stage

Full-size Panicle Maximum Anthesis stage

Plate 7b: Landmark stages of flowering in variety Banganapalli

Resting stage



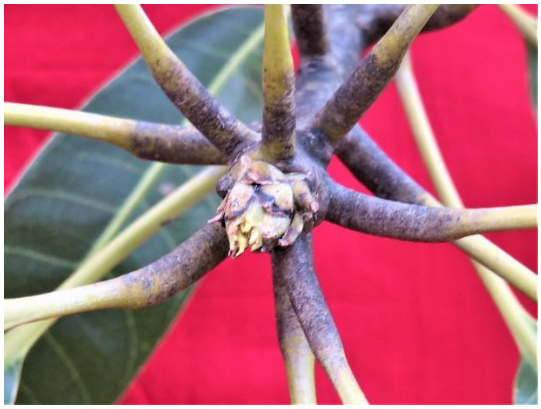
Vegetative Bud Break stage

Elongating Green Leaf stage

Limp Red Leaf stage

Mature Green Leaf stage

Plate 8a: Landmark stages of vegetative growth in variety Imam Pasand



Resting stage

Floral Bud Break

Floral Bud Expansion stage

Early Panicle Elongation stage

Mid-size Panicle Early Anthesis stage

Full-size Panicle Maximum Anthesis stage

Plate 8b: Landmark stages of flowering in variety Imam Pasand

Resting stage

Vegetative Bud Break stage

Elongating Green Leaf stage

Limp Red Leaf stage

Immature Green Leaf stage

Mature Green Leaf stage

Plate 9a: Landmark stages of vegetative growth in variety Sindhooram

Resting stage

Floral Bud Break

Flower Bud Expansion stage

Early Panicle Elongation stage

Mid-size Panicle Early Anthesis stage

Full-size Panicle Maximum Anthesis stage

Plate 9b: Landmark stages of flowering in variety Sindhooram

4.4 Leaf nutrient status

Leaf nutrient analysis was carried out in the observational trees before the onset of flowering and after fruit harvest by using the index leaves for carrying out the analysis.

4.4.1 Total nitrogen

Total nitrogen content in the leaf samples of the observational trees were estimated before flowering and after harvest. The variety Imam Pasand recorded the highest total leaf nitrogen content of 1.75 per cent before flowering. The variety Banganapalli recorded the lowest total nitrogen content of 1.29 per cent and the varieties Imam Pasand and Sindhooram recorded 1.63 per cent and 1.50 per cent respectively.

The highest leaf nitrogen content of 1.92 per cent was recorded in the variety Alphonso after harvest and the lowest nitrogen content of 1.38 per cent was recorded in the variety Banganapalli. The varieties Imam Pasand and Sindhooram recorded a mean leaf nitrogen content of 1.67 per cent and 1.64 per cent respectively (Table 4).

4.4.2 Leaf carbohydrate content

The carbohydrate content in the leaves of the observational trees were estimated before the onset of flowering and after fruit harvest. The variety Alphonso recorded the highest leaf carbohydrate content of 11.42 per cent and the variety Imam Pasand recorded the lowest leaf carbohydrate content of 10.42 per cent before the onset of flowering. The variety Banganapalli recorded a mean pre-flowering leaf carbohydrate content of 11.17 per cent and the variety Sindhooram recorded a mean pre-flowering leaf carbohydrate content of 11.19 per cent respectively (Table 4).

The highest post-harvest leaf carbohydrate content of 10.90 per cent was recorded in the variety Alphonso and the lowest carbohydrate concentration was recorded in the variety Imam Pasand with 10.16 per cent. Both the varieties Banganapalli and Sindhooram recorded a mean leaf carbohydrate content of 10.68 per cent after harvest.

4.4.3 Carbohydrate: Nitrogen ratio

The carbohydrate: nitrogen ratio (C:N ratio) in the leaves of the observational trees were estimated before the onset of flowering and after fruit harvest. The highest pre flowering C:N ratio of 8.70 was observed in the variety Banganapalli, followed by the varieties Sindhooram, Alphonso and Imam Pasand with C:N ratios of 7.23, 7.02 and 5.98 respectively. The variety Banganapalli also recorded the highest post-harvest C:N ratio 7.74 of after harvest. The lowest C:N ratio of 5.63 was recorded in the variety Alphonso. The variety Imam Pasand recorded a leaf C:N ratio of 6.17 and the variety Sindhooram recorded a leaf C:N ratio of 6.55 after fruit harvest (Table 4).

4.4.3 Phosphorus

Phosphorus content in the leaves of the observational trees were estimated before the onset of flowering. The variety Alphonso recorded the highest mean leaf phosphorus content of 0.93 mg g^{-1} and the variety Sindhooram recorded the lowest content of 0.72 mg g^{-1} (Table 5). The variety Banganapalli recorded a mean leaf phosphorus content of 0.74 mg g^{-1} and the variety Imam Pasand recorded a mean leaf phosphorus content of 0.80 mg g^{-1} respectively.

4.4.4 Potassium

Leaf potassium content was estimated in the observational trees before flowering and the variety Imam Pasand recorded the highest leaf potassium content of 18.15 mg g^{-1} weight of leaf sample whereas, the variety Sindhooram recorded the lowest mean content of 11.96 mg g^{-1} (Table 5). A mean leaf potassium content of 15.03 mg g^{-1} and 15.93 mg g^{-1} were recorded in the varieties Alphonso and Banganapalli respectively.

4.4.5 Calcium

Calcium content in the leaves of the observational trees were estimated before the onset of flowering and the variety Imam Pasand recorded the highest leaf calcium content of 3.52 mg g^{-1} weight of leaf sample and the variety Sindhooram recorded the lowest content of 2.43 mg g^{-1}. The varieties Alphonso and Banganapalli recorded a mean leaf calcium content of 3.31 mg g^{-1} and 2.91 mg g^{-1} of leaf sample respectively (Table 5).

4.4.6 Magnesium

The leaf magnesium content in the observational trees were estimated during the pre-flowering period and the variety Banganapalli recorded the highest mean leaf magnesium content of 0.79 mg g^{-1} of leaf sample and the variety Imam Pasand recorded the lowest magnesium content of 0.50 mg g^{-1} (Table 5). The varieties Alphonso and Sindhooram recorded leaf magnesium content 0.56 mg g^{-1} and 0.55 mg g^{-1} of leaf sample.

4.4.7 Boron

Boron content in the leaf samples of the observational trees were estimated before flowering and the highest boron content of 0.69 mg kg^{-1} was recorded in the variety Banganapalli and the lowest mean boron content of 0.17 mg kg^{-1} was recorded in the variety Imam Pasand. The varieties Alphonso and Sindhooram recorded a leaf boron content of 0.19 mg kg^{-1} and 0.25 mg kg^{-1} of leaf sample respectively (Table 5).

4.5 Physiological characters

4.5.1 Stomatal index

The stomatal index in the variety Alphonso ranged from 19.45 to 20.39 per cent with an average value of 19.93 per cent whereas the in the variety Banganapalli, the value ranged from 18.36 to 19.24 per cent with an average value of 18.73 per cent (Table 6a). The variety Imam Pasand recorded the lowest average stomatal index value of 16.03 with the individual values ranging from 15.85 to 16.23 per cent. The variety Sindhooram recorded the highest average stomatal index value of 20.19 per cent, with the values ranging from 19.86 to 20.57 per cent.

4.5.2 Stomatal frequency

The highest stomatal frequency of 707.80 stomata mm^{-1} was recorded in the variety Alphonso, followed by Banganapalli with 617.00 stomata mm^{-1} and Imam Pasand with 554.20 stomata mm^{-1}. The lowest stomatal frequency of 533.60 stomata mm^{-1} was recorded in the variety Sindhooram (Table 6a).

4.5.3 Stomatal conductance

The variety Imam Pasand recorded the highest average stomatal conductance value of 0.492 µS whereas, the variety Alphonso recorded the lowest average value of 0.062 µS (Table 6a). The varieties Banganapalli and Sindhooram recorded average stomatal conductance values of 0.202 µS and 0.078 µS respectively.

4.5.4 Photosynthetic rate

The highest mean photosynthetic rate of 2.01 µ mol CO_2 m^{-2} s^{-2} was recorded in the variety Banganapalli and the lowest photosynthetic rate of 0.41 µ mol CO_2 m^{-2} s^{-2} was recorded in the variety Alphonso. The varieties Imam Pasand and Sindhooram recorded average photosynthetic rates of 1.09 µ mol CO_2 m^{-2} s^{-2} and 1.07 µ mol CO_2 m^{-2} s^{-2} respectively.

4.5.5 Transpiration rate

Highest mean transpiration rate of 2.55 m mol H_2O m^{-2} s^{-2} was recorded in the variety Banganapalli and the lowest rate of 1.29 m mol H_2O m^{-2} s^{-2} was recorded in the variety Alphonso (Table 6b). The variety Imam Pasand recorded a mean transpiration rate of 2.36 m mol H_2O m^{-2} s^{-2} and the variety Sindhooram recorded a mean of 1.46 m mol H_2O m^{-2} s^{-2}.

4.5.6 Leaf area index (LAI)

The variety Banganapalli recorded the highest mean leaf area index of 2.60 and the variety Alphonso recorded the lowest leaf area index of 2.42. The varieties Imam Pasand and Sindhooram recorded leaf area indices of 2.52 and 2.57 respectively (Table 6a).

4.5.7 Leaf temperature

The leaf temperature readings of the observational varieties range from 33.12 ºC to 34.83 ºC (Table 6b). The highest leaf temperature of 34.32 ºC was recorded in the variety Imam Pasand, followed by Alphonso with 33.56 ºC and Sindhooram with 33.42 ºC. The lowest mean temperature of 33.28 ºC was recorded in the variety Banganapalli.

4.5.8 Canopy air temperature (ºC)

The mean air temperature of the tree canopy of the observational trees varied from 33.02 ºC to 34.32 ºC, with the variety Banganapalli having the least mean canopy air temperature of 33.02 ºC and the variety Imam Pasand having the highest mean canopy air temperature of 34.32 ºC. The varieties Alphonso and Sindhooram had canopy air temperature of 33.66 ºC and 33.31 ºC respectively (Table 6b).

4.5.9 Chlorophyll content (mg g^{-1})

The highest total chlorophyll content was observed in the variety Imam Pasand with an average chlorophyll a content of 0.51 mg g^{-1}, an average chlorophyll b content of 0.92 mg g^{-1} and a total chlorophyll content of 1.20 mg g^{-1}. The varieties Banganapalli and Sindhooram recorded a total chlorophyll content of 1.09 mg g^{-1} and 1.15 mg g^{-1} of leaf sample respectively (Table 7). The chlorophyll a and b content in the variety Banganapalli was 0.44 mg g^{-1} and 0.80 mg g^{-1}, and that of the variety Sindhooram was 0.44 mg g^{-1} and 0.81 mg g^{-1} of leaf sample respectively.

4.6 Biochemical Analysis

4.6.1 Proline content

The proline content in the leaf samples were analysed before flowering and after harvest. The highest proline content of 13.92 µg g^{-1} was observed in the variety Sindhooram whereas the lowest proline content of 1.43 µg g^{-1} was recorded in the variety Banganapalli during the pre-flowering period (Fig. 4). The varieties Alphonso and Imam Pasand recorded a pre-flowering proline content of 5.85 µg g^{-1} and 9.72 µg g^{-1} respectively. The highest proline content after fruit harvest was recorded in the variety Sindhooram with a value of 16.92 µg g^{-1} and the lowest proline content of 4.98 µg g^{-1} was recorded in the variety Imam Pasand.

4.6.2 Glycine betaine (mol g^{-1})

Glycine betaine content in the dried leaf samples of the observational trees were analysed both before and after flowering but was unable to trace the presence of glycine betaine in the samples during both the stages.

Table 4: Leaf carbohydrate: nitrogen ratio before flowering and after harvest

Variety	Before flowering			After harvest		
	Nitrogen content (%)	Carbohydrate content (%)	Carbohydrate: Nitrogen Ratio	Nitrogen content (%)	Carbohydrate content (%)	Carbohydrate: Nitrogen Ratio
Alphonso	1.63	11.42	7.02	1.92	10.90	5.63
Banganapalli	1.29	11.17	8.70	1.38	10.68	7.74
Imam Pasand	1.75	10.42	5.98	1.67	10.16	6.17
Sindhooram	1.50	11.19	7.23	1.64	10.68	6.55
SD	0.20	0.44	1.21	0.22	0.31	0.90
CV	12.76	394	15.49	13.36	2.96	13.72

Table 5: Status of leaf nutrients in the varieties under study

Variety	Leaf nutrient status				
	Phosphorus content ($mg\ g^{-1}$)	Potassium content ($mg\ g^{-1}$)	Calcium content ($mg\ g^{-1}$)	Magnesium content ($mg\ g^{-1}$)	Boron content ($mg\ kg^{-1}$)
Alphonso	0.93	15.03	3.31	0.56	0.19
Banganapalli	0.74	15.93	2.91	0.79	0.69
Imam Pasand	0.80	18.15	3.52	0.50	0.17
Sindhooram	0.72	11.96	2.43	0.55	0.25
SD	0.10	2.57	0.48	0.13	0.25
CV	11.87	16.80	15.79	21.56	75.60

Table 6a: Observations on physiological characters of the varieties

Varieties	Physiological characters			
	Stomatal index (%)	Stomatal frequency (No. of stomata/ mm)	Leaf area index	Stomatal conductance (µ S)
Alphonso	19.93	707.80	2.42	0.062
Banganapalli	18.73	617.00	2.60	0.202
Imam Pasand	16.03	554.20	2.52	0.492
Sindhooram	20.19	533.60	2.57	0.078
SD	1.90	78.27	0.08	0.06
CV	10.16	12.98	3.12	57.34

Table 6b: Observations on physiological characters of the varieties

Varieties	Physiological characters				
	Photosynthetic rate (μ mol CO_2 m^{-2} s^{-2})	Transpiration rate (m mol H_2O m^{-2} s^{-2})	Leaf temperature (^oC)	Canopy air temperature (^oC)	Relative water content (%)
Alphonso	0.41	1.29	33.56	33.66	89.85
Banganapalli	2.01	2.55	33.28	33.02	88.82
Imam Pasand	1.09	2.36	34.32	34.32	85.56
Sindhooram	1.07	1.46	33.42	33.31	88.01
SD	0.66	0.63	0.46	0.56	1.83
CV	56.43	31.01	1.38	1.67	2.07

Table 7: Level of leaf chlorophyll pigments in the varieties

Variety	Chlorophyll content (mg g^{-1})		
	Chlorophyll a	Chlorophyll b	Total chlorophyll
Alphonso	0.38	0.70	1.05
Banganapalli	0.44	0.80	1.09
Imam Pasand	0.51	0.92	1.20
Sindhooram	0.44	0.81	1.15
SD	0.05	0.09	0.07
CV	12.01	11.14	5.88

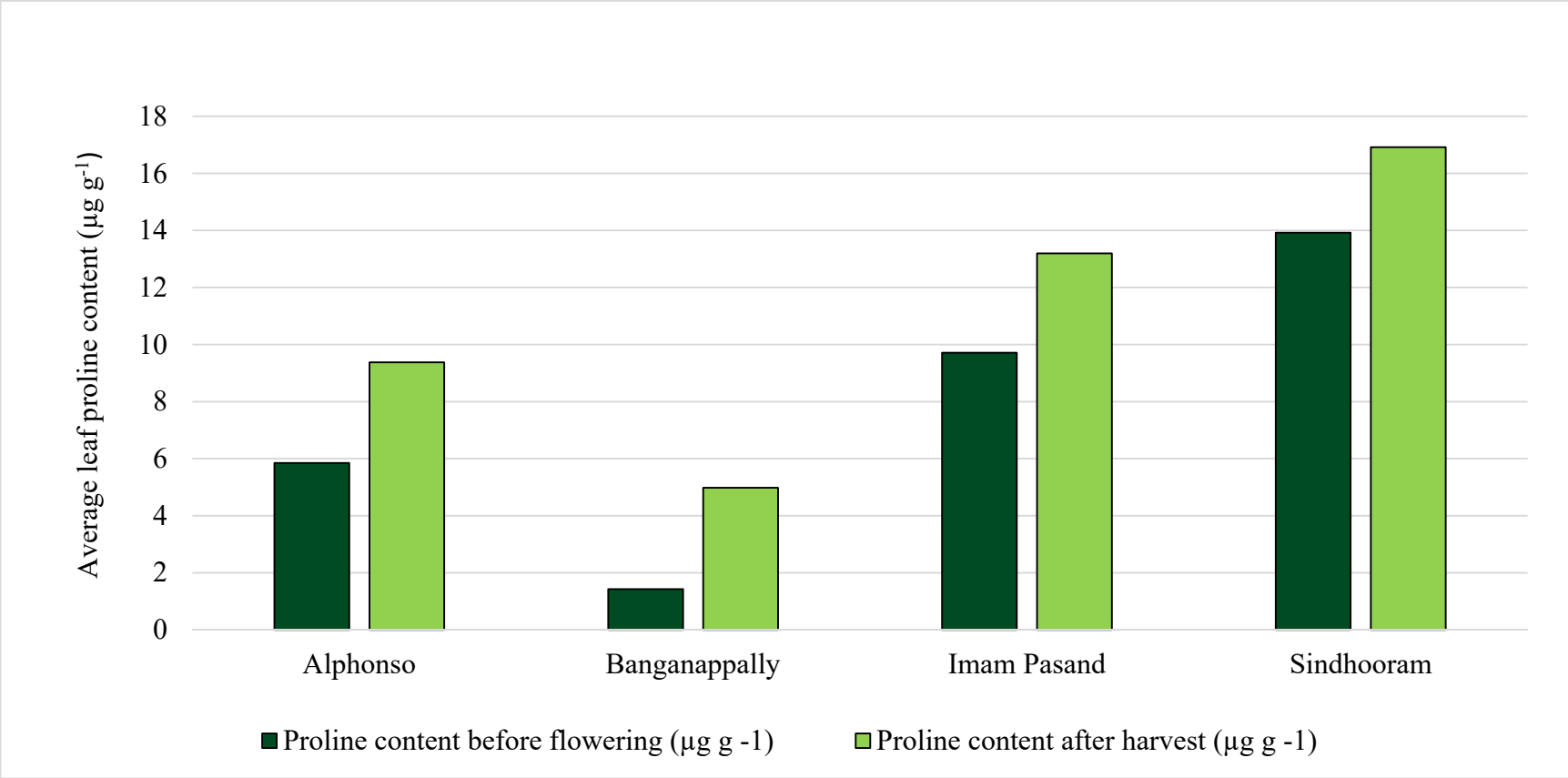


Fig. 3. Proline content in the leaves before flowering and after harvest

4.7 Meteorological data

4.7.1 Maximum temperature

The maximum temperature in the experimental location were recorded on a daily basis and the highest maximum temperature of 37.13 ºC was recorded in the month of May. The maximum temperature was found to be the lowest in the month of August, with a monthly average of 29.13 ºC. The mean maximum temperature from pruning to flowering was also calculated and it was maximum for the variety Sindhooram (30.41ºC) and minimum for the variety Imam Pasand (29.59 ºC) (Table 8).

4.7.2 Minimum temperature

The lowest minimum temperature was recorded in the month of August with a monthly average of 23.71 ºC whereas the daily minimum temperature was found to be the highest in the month of June, with a monthly average of 27.50 ºC. The average minimum temperature before flowering was maximum in the variety Banganapalli (25.71 ºC) and minimum in the variety Imam Pasand (24.06 ºC) (Table 8).

The heat units accumulated from pruning to flowering was minimum in the variety Banganapalli (1252.90 ºC) and maximum in the variety Sindhooram (2629 ºC) (Table 9).

4.7.3 Rainfall

The region received a total rainfall of 1426.10 mm during the period from 25th June 2019 to 31st May 2020. August was the wettest month of the year which received a total rainfall of 347.10 mm. No rainfall was recorded during the months of January and February. The average rainfall received before flowering starting from pruning was maximum in the variety was maximum in the variety Banganapalli and minimum in the variety Sindhooram (Table 8).

4.7.4 Number of rainy days

A total of 152 rainy days were recorded in the observational orchard from 25th June 2019 to 31st May 2020. Maximum number of rainy days were obtained during the month of August and no rainfall was recorded during the months of January and February.

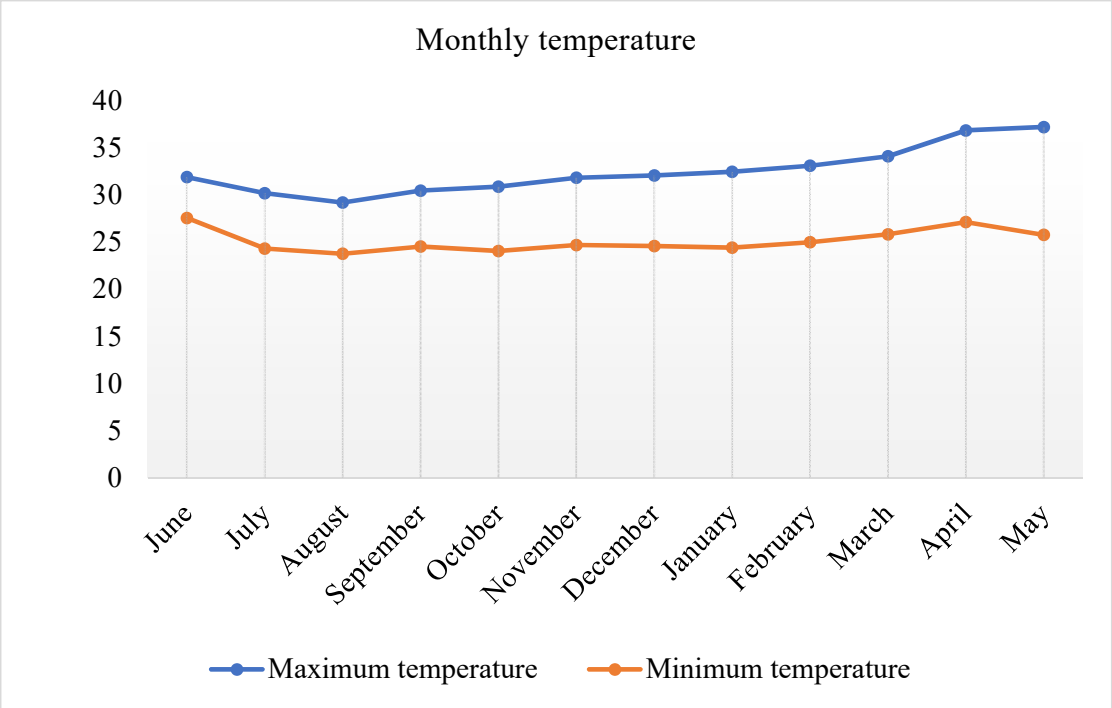


Fig. 4. Average monthly temperatures of Muthalamada region

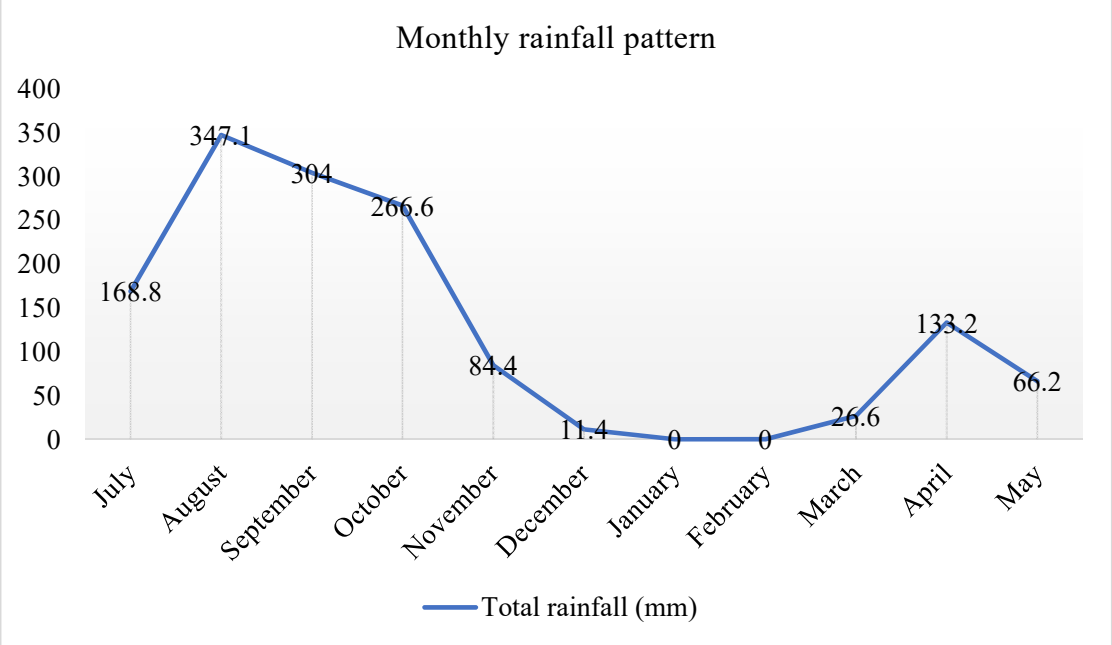


Fig. 5. Monthly rainfall pattern in Muthalamada region

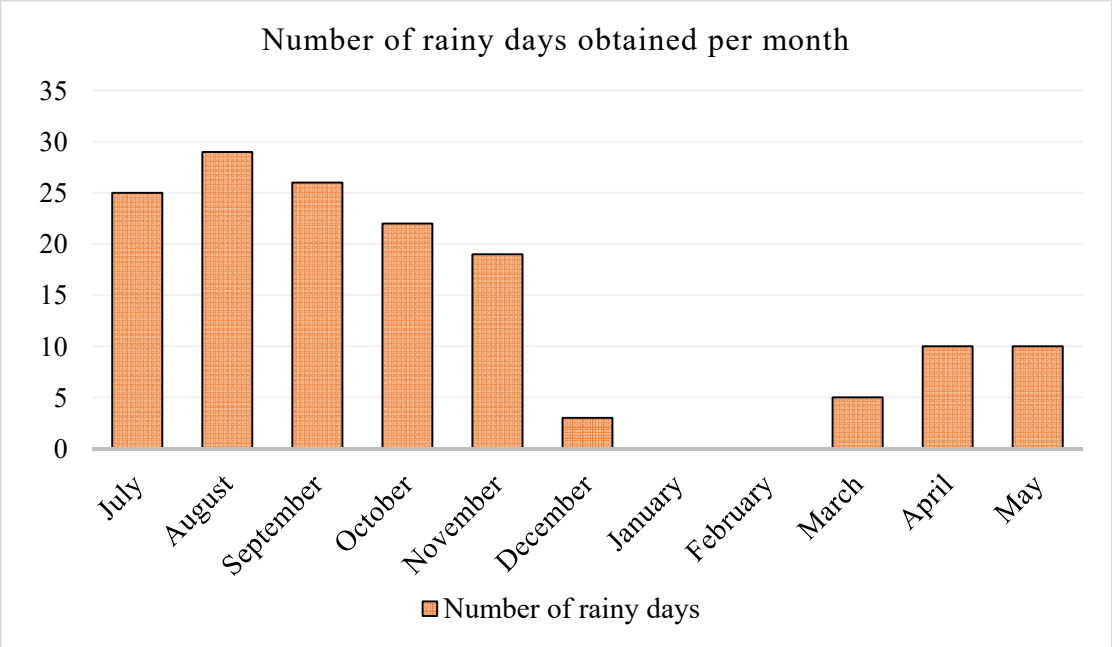


Figure 6: Number of rainy days obtained per month in Muthalamada region

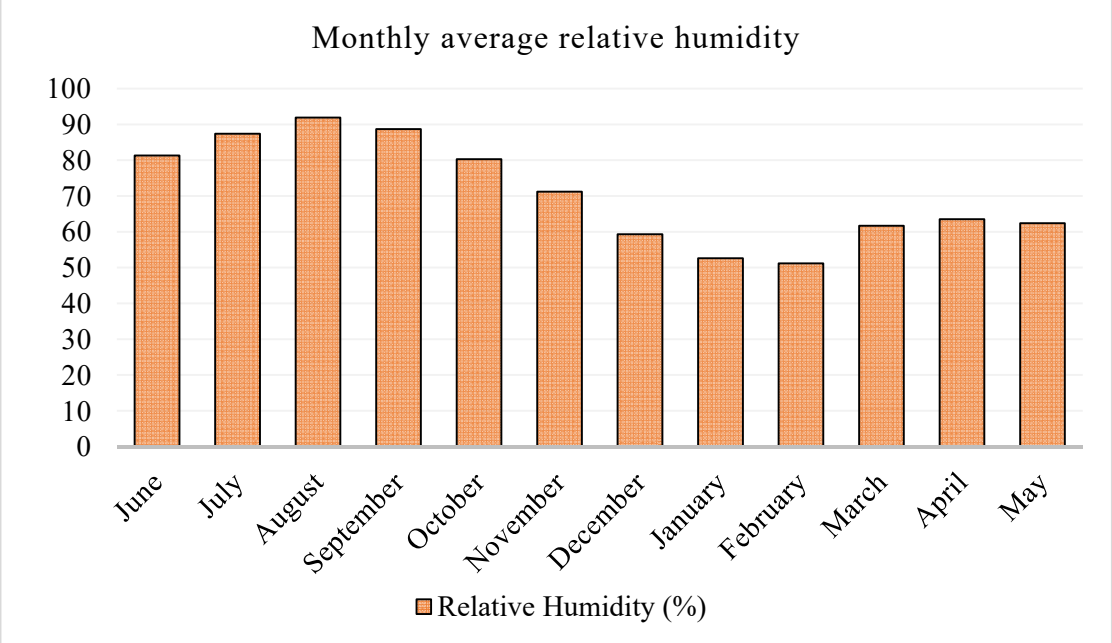


Fig. 7: Average monthly Relative Humidity in Muthalamada region

4.7.5 Relative humidity (%)

The relative humidity ranged from a maximum relative humidity of 91.90 per cent in the month of August to a minimum relative humidity of 51.20 per cent in the month of February.

4.8 Soil Analysis

4.8.1 Soil pH

Soil pH of the soil sample from the orchard was estimated by potentiometric method and the soil in the orchard was found to be strongly acidic (KAU, 2016) with a pH of 5.31.

4.8.2 Electrical conductivity

The electrical conductivity of the soil sample collected from the orchard was 0.085 µS.

4.8.3 Organic carbon content

Soil organic carbon content in the soil sample was estimated and the sample recorded a high organic carbon content of 1.01 per cent and the soil can be classified into the soil fertility class five (KAU, 2016).

4.8.4 Total nitrogen content

A soil nitrogen content of 198 kg ha^{-1} was recorded in the soil sample collected from the orchard and the nitrogen content was rated as low according to Dev (1997).

4.8.6 Available phosphorus

Available phosphorus content in the soil sample collected from the research orchard was 68.51 kg ha^{-1} and the soil phosphorus status could be rated as high according to Dev (1997).

4.8.7 Available potassium

Available potassium content in the soil sample collected from the orchard was recorded as 181.10 kg ha^{-1} and the soil potassium status was rated as medium according to Dev (1997).

4.8.8 Calcium

Calcium content in the soil sample collected from the orchard was 912.50 mg kg^{-1} and soil calcium content was found to be sufficient according to KAU (2016).

4.8.9 Magnesium

The magnesium content in the soil sample from the research orchard was 295.35 mg kg^{-1} and the soil magnesium status of the soil was found to be sufficient according to KAU (2016).

4.8.10 Boron

The soil sample collected from the research orchard recorded a boron content of 0.06 mg kg^{-1} and the sample was found to be deficient in soil boron content according to KAU (2016).

4.9 Yield characters

4.9.1 Fruiting duration

The longest fruiting duration of 109.00 days was observed in the variety Alphonso whereas the shortest duration of 81.60 days was observed in the variety Sindhooram. The variety Banganapalli recorded a fruiting duration of 86.40 days. Since there was no fruit set in the variety Imam Pasand, the fruiting duration was considered as zero days. The average time taken from flowering to fruit maturity was maximum for the variety Banganapalli, which required 161.60 days followed by the variety Alphonso, which required 142.60 days and the variety Sindhooram which required 130.80 days for fruit maturity. The variety Banganapalli accumulated the maximum heat units and the variety Sindhooram accumulated the lowest quantity of heat units from flowering to fruit maturity (Table 9).

4.9.2 Fruit bearing intensity

Medium fruit bearing intensity was observed in all the observational trees in the variety Banganapalli. Whereas in the case of both Alphonso and Sindhooram, two observational trees recorded medium fruit bearing intensity and the rest three recorded low fruit bearing intensity. No fruit set was observed in the variety Imam Pasand.

Table 8: Meteorological observations of Muthalamada from pruning to flowering

Variety	Meteorological observations from pruning to flowering			
	Average maximum temperature (ºC)	Average minimum temperature (ºC)	Heat units accumulated (ºC)	Average rainfall (mm)
Alphonso	30.27	24.10	2403.40	8.20
Banganapalli	29.65	25.71	1252.90	10.30
Imam Pasand	29.59	24.06	1274.90	9.85
Sindhooram	30.41	24.18	2629.00	7.74
SD	0.42	0.80	728.91	1.24
CV	1.40	3.26	38.57	13.78

Table 9: Yield characters and degree days requirement of the varieties

Variety	Yield characteristics of the varieties				
	Fruiting duration (days)	Fruit weight (g)	Yield per tree (kg year^{-1})	Days from flowering to fruit maturity (days)	Growing degree days (ºC)
Alphonso	109.00	274.62	9.89	142.60	2715.60
Banganapalli	86.40	260.05	11.02	161.60	2927.70
Sindhooram	81.60	191.44	11.27	130.80	2509.90
SD	14.63	44.42	0.74	15.54	208.91
CV	15.85	18.35	6.86	10.72	7.69

4.9.3 Fruit weight

The average fruit weight was found to be maximum in Alphonso with a mean weight of 274.62 g. The mean fruit weight in the variety Banganapalli was found to be 260.05 g. The variety Sindhooram was the one with the smallest fruits with a mean fruit weight of 191.44 g (Table 9).

4.9.4 Colour of fruits

The ground colour of fruit peel of ripe fruits in all the three varieties were found to be yellow out of which the varieties Alphonso and Sindhooram exhibited characteristic blushing on the skin with orange and red colours respectively.

4.9.5 Yield per tree

The highest per tree yield was observed in the variety Sindhooram with a mean yield of 11.27 kg. the varieties Alphonso and Banganapalli recorded a mean per tree yield of 9.89 kg and 11.02 kg respectively (Table 9).

4.10 Incidence of pests and diseases

The major pests found to infest the varieties, especially during flowering season were mango thrips (*Scirtothrips dorsalis)* and mango hoppers (*Idioscopus niveosparsus*). The attack of mango hoppers was found to be severe from the first week of November to the first week of December. The hopper infestation was severe in the variety Imam Pasand and the typical symptom of infestation was drying up of the flowers and honey dew excretion. The thrips infestation was found to be severe in the variety Imam Pasand, which caused the variety to be unfruitful. The typical symptom of thrips infestation was drying up of panicles and presence of thrips on the dried panicles. Since both the pests were sucking type pest, sooty mould development was observed in the varieties but was found to be a minor infection. From the pest population present on the panicle, the mango hopper (*Idioscopus niveosparsus*) and mango thrips (*Scirtothrips dorsalis)* can be classified as major pests according to Munj *et al.* (2019)

The infestation of mango hoppers and thrips started from early October and reached a peak level by late November. The phenological stages in the variety Imam Pasand which suffered maximum crop damage during which the infestation was severe

were Early Panicle Elongation Stage (EPE), Mid-Size Panicle Early Anthesis Stage (MPEA) and Full Size Panicle Maximum Anthesis Stage (FSPMA). The infestation during these stages resulted in no fruit set in the variety Imam Pasand.

A few fruits of the variety Alphonso were affected by the physiological disorder spongy tissue. The typical symptom of spongy tissue was observed in the mesocarp region of the fruits with no external symptoms. The occurrence of spongy tissue in the variety Alphonso was during the month of April which recorded an average maximum temperature of 36.77 ºC and an average minimum temperature of 27.07 ºC.

Table 10: Major pests which attacked the mango varieties under study during flowering season

Variety	Major pests attacking the varieties (No. of pests per panicle)	
	Mango hopper *(Idioscopus niveosparsus)*	Thrips *(Scirtothrips dorsalis)*
Alphonso	23.90	13.76
Banganapalli	12.02	10.28
Imam Pasand	45.18	17.56
Sindhooram	9.20	9.320
SD	16.36	3.74
CV	72.47	29.40

4.11 Correlation analysis

The average leaf nutrient content before flowering was correlated to the number of days taken from pruning to attain flowering. Parameters such as flowering duration, inflorescence length, inflorescence width, fruit weight and yield per tree were also correlated to the leaf nutrient status before flowering.

The number of days taken to attain flowering from pruning in all the four varieties was negatively correlated to the carbohydrate: nitrogen ratio. But the correlation is insignificant with a correlation coefficient of -0.225. The leaf nutrient status such as phosphorus, calcium, magnesium and boron content were not having any significant correlation to the number of days taken from pruning to flowering. Among all the nutrients, higher level of potassium content in the leaves was significantly correlated to the earliness in flowering with a correlation coefficient of -0.769.

Flowering duration was found to be positively correlated to the leaf carbohydrate: nitrogen ratio and boron content with a significant correlation coefficient of 0.509 and 0.530. The magnesium content in the leaves does not show any significant correlation with the flowering duration. The leaf nutrients phosphorus, potassium and calcium were significantly correlated to the flowering duration with a correlation coefficient of -0.458, -0.827 and -0.709, which implied that lesser the concentrations of these nutrients, longer the flowering duration (Table 11).

The inflorescence length was having a strong negative correlation with the leaf carbohydrate: nitrogen ratio, magnesium content and boron content with a correlation coefficient of -0.781, -0.795 and -0.694 respectively. The inflorescence width showed a significant negative correlation to the leaf carbohydrate: nitrogen ratio, magnesium and boron content with a correlation coefficient of -0.741, -0.713 and -0.714 respectively. The correlation of the leaf nutrients phosphorus, potassium and calcium to the width of the inflorescence were insignificant (Table 11).

The physiological parameters namely, photosynthetic and transpiration rates also exhibited a strong negative correlation with the number of days taken from pruning to flowering, which indicated that higher the photosynthetic and transpiration rates, earlier is the flowering.

The number of days taken to attain flowering showed a strong positive correlation with concentration of the amino acid proline in the leaves before flowering with a correlation coefficient of 0.713. This indicated that the flowering was delayed by the increase in the concentration of proline in the leaves (Table 11).

The correlation of leaf carbohydrate: nitrogen ratio to the photosynthetic rate and transpiration rate was non-significant.

The physiological characters such as stomatal conductance, photosynthetic rate, transpiration rate, leaf temperature, canopy air temperature, chlorophyll a, chlorophyll b and total chlorophyll content does not show any significant correlation with the parameters such as Flowering duration, Fruiting duration, Fruit weight and Yield/tree. The physiological character transpiration rate shows a significant negative correlation to the number of days taken from pruning to flowering and canopy air temperature is positively correlated to the same (Table 12).

The relative water content showed a negative correlation with the fruit weight with a significant correlation coefficient of -0.549 and exhibited a positive correlation with the per tree yield with a significant correlation coefficient of 0.517 (Table 12).

The earliness in flowering and flowering duration were positively correlated to the average maximum temperature before flowering and the heat units accumulated by the resting bud till flowering with a significant correlation coefficient of 0.869 and 0.973 respectively. It was also observed that there was a significant positive correlation among flowering duration and average maximum and minimum temperatures and heat units accumulated (Table 13). A significant negative correlation was observed between the inflorescence characters such as days required for flowering, inflorescence length and width with the average rainfall in the Muthalamada region. The inflorescence length and width exhibited a strong negative correlation with the minimum temperatures prevailing during the period from pruning to flowering (Table 13).

The accumulation of the amino acid proline during the pre-flowering period was positively correlated to the average maximum temperature and heat units accumulated during that period. The proline content was negatively correlated to the average rainfall with a significant correlation coefficient of -0.835 (Table 13).

Table 11: Correlation analysis of leaf nutrient status with inflorescence and yield characteristics

Leaf nutrient status	No. of days from pruning to flowering	Flowering duration	Inflorescence length	Inflorescence width	Fruiting duration	Fruit weight	Yield/tree
Carbohydrate content	0.348	0.386	-0.484*	-0.318	0.783**	0.345	-0.586*
Nitrogen	0.217	-0.431	0.727**	0.656**	0.396	0.156	-0.410
C:N ratio	-0.225	0.509*	-0.781**	-0.741**	-0.346	-0.007	0.168
Phosphorus	-0.008	-0.458*	-0.005	0.196	0.803**	0.613*	-0.697**
Potassium	-0.769**	-0.827**	0.128	0.195	0.306	0.536*	-0.482
Calcium	-0.342	-0.709**	0.234	0.443	0.747**	0.757**	-0.946**
Magnesium	-0.262	0.320	-0.795**	0.713**	0.045	0.393	-0.172
Boron	-0.215	0.530*	-0.694**	-0.714**	-0.512	0.243	0.421
Proline	0.713**	0.144	0.783**	0.528*	-0.239	-0.639*	0.433

[** Significant at 1 %, * Significant at 5 %]

Table 12: Correlation analysis of physiological characters with inflorescence and yield characteristics

Physiological character	No. of days from pruning to flowering	Flowering duration	Fruiting duration	Fruit weight	Yield/tree
Stomatal conductance	-0.231	0.040	0.051	-0.052	0.111
Photosynthetic rate	-0.030	0.155	0.081	-0.054	0.289
Transpiration rate	-0.520*	-0.244	0.038	0.161	-0.014
Leaf temperature	0.386	0.149	0.239	0.050	-0.179
Canopy air temperature	0.525*	0.125	0.401	0.091	-0.199
Relative water content	-0.168	-0.098	0.198	-0.549*	0.517*
Chlorophyll a	-0.147	-0.014	-0.458	-0.193	0.257
Chlorophyll b	-0.098	-0.005	-0.378	-0.218	0.220
Total chlorophyll	0.239	0.081	-0.285	-0.332	0.282

[** Significant at 1 %, * Significant at 5 %]

Table 13: Correlation analysis of weather parameters with inflorescence, yield and biochemical characteristics

Weather parameter	No. of days from pruning to flowering	Flowering duration	Inflorescence length	Inflorescence width	Proline content before flowering
Average maximum temperature	0.869**	0.712**	0.158	0.004	0.571**
Average minimum temperature	*0.125	0.559*	-0.690**	-0.775**	-0.377
Heat units accumulated	0.973**	0.634**	0.323	0.185	0.643**
Average rain fall	-0.583**	-0.167	-0.685**	-0.432	-0.835**

[** Significant at 1 %, * Significant at 5 %]

Variety- Alphonso

Variety- Banganapalli

Variety- Sindhooram

Plate 10. Fruit characteristics of the varieties Alphonso, Banganapalli and Sindhooram

Mango hopper attack on var. Alphonso

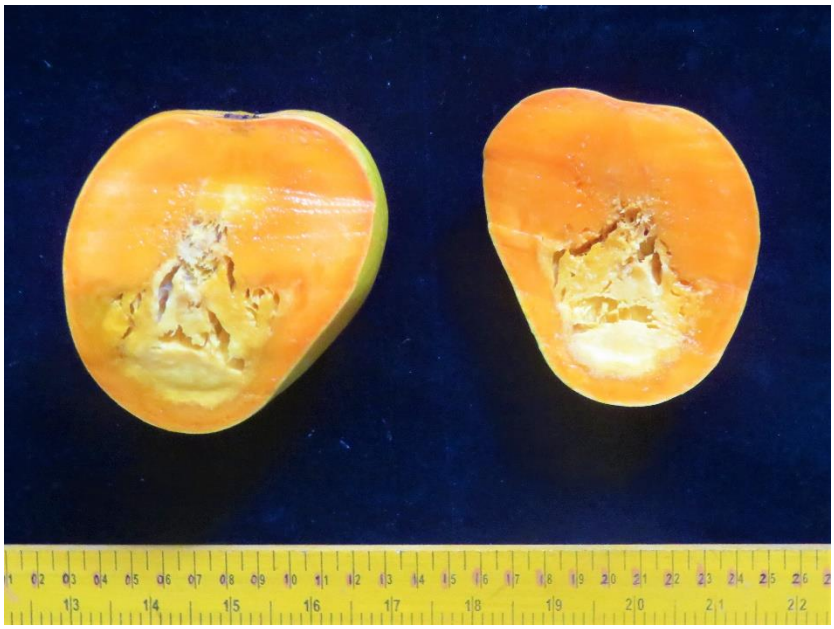
Mango hopper attack on var. Banganappally

Mango hopper attack on var. Imam Pasand

Thrips attack on var. Imam Pasand

Plate 11: Symptoms of pest infestation in the varieties

External appearance of fruit affected with spongy tissue



Internal fruit damage due to spongy tissue

Plate 12: Symptoms of the physiological disorder spongy tissue in var. Alphonso

Discussion

5. DISCUSSION

Mango production in Kerala is mainly concentrated in Muthalamada area and the produce from this region is the earliest in the market. Even though production is taking place in this region, the farmers here are in desperate need of advice regarding the most suitable variety and management practices. The present study on 'The ecophysiology of mango under High Density Planting System in Muthalamada area' was taken up to identify the best suitable mango variety and the factors which affect the mango production in Muthalamada region and the results of this study is discussed in this chapter.

5.1 Uniqueness of the study site

Muthalamada is located in Kollengode block panchayat of Chittur Taluk in Palakkad district. This region is known as the 'mango city of Kerala' and is famous for early season export quality mangoes. This region is situated in the eastern part of Palakkad district and is in close proximity with the Western Ghats mountain range. Extensive mango cultivation is practiced in this region, mostly on contract basis where a fixed amount is paid to the owner and all the inputs for cultivation is provided by the contractor. The flowering of mango in this region starts from September and extends till the month of December. Fruits mature by the month of January and the harvest extends till the month of April. The earliness in flowering and fruit maturity confers a unique status to Muthalamada mangoes in both local and foreign markets

5.2 Tree characters

The tree height and crown diameter were maintained by pruning during the month of August in all the four varieties to avoid overcrowding of branches and to improve light penetration. Trunk circumference was maximum in the variety Alphonso which represented four years of growth attained by assimilation of photosynthates.

The crown shape of the varieties Alphonso and Banganapalli was semi-circular, which is in agreement with the mango database (Mango DB, 2016). The canopy of the variety Sindhooram was semi-circular and that of the variety Imam Pasand was drooping. This is not in agreement with the normal canopy shape of both the varieties. The foliage density of the varieties Alphonso, Banganapalli and Imam Pasand were

intermediate which is in agreement with the general character whereas dense canopy was observed in the variety Sindhooram which is not in agreement with the general character of the variety.

5.2 Inflorescence characters

The flowering duration was maximum in the variety Sindhooram and minimum in the variety Imam Pasand. All the four varieties exhibited early flowering in Muthalamada region when compared to their normal flowering season. The variety Alphonso started flowering from late November to mid-December, which is comparatively earlier than the normal flowering season of January to February. Flowering in the variety Banganapalli started by mid-September, which is significantly earlier than the actual flowering period of mid-December to early January. The variety Imam Pasand flowered during the third week of September, which is not in agreement with the actual flowering season of January to February (Mango DB, 2016). Sindhooram, which is a relatively late variety with a normal flowering period from mid-January to early February flowered during the first week of December. Secondary flowering in the variety Imam Pasand could be due to the destruction of panicles during the critical stages of flower bud development. The inflorescence position of the varieties were found to be in agreement with the general varietal character as recorded in the mango database by KAU.

The gross carbohydrate content in the leaves of satsuma mandarin was not having any significant effect on flower formation (Garcia-Luis *et al.,* 1995). The present study also showed similar results were the number of days taken to attain flowering from pruning in all the four varieties did not exihibit any significant correlation with the leaf carbohydrate content and carbohydrate: nitrogen ratio. The leaf nutrient status such as phosphorus, calcium, magnesium and boron content did not have any significant correlation to the earliness in flowering. Similar results were reported by Ulger *et al.* (2004) on olive trees of the Mediterranean region were flowering was not directly influenced by the leaf carbohydrate content and nutrient status. Among the leaf nutrients the leaf potassium content was significantly correlated to the earliness in flowering with a correlation coefficient of -0.769.

The flowering duration was found to be positively correlated to the leaf carbohydrate: nitrogen ratio and boron content with a significant correlation coefficient of 0.509 and 0.530. Since the soil boron content is deficient, it would be advisable to give boron fertilization in order to improve flowering duration. The leaf nutrients phosphorus, potassium and calcium were showing negative correlation with flowering duration which implied that the lesser the concentrations of these nutrients, longer the flowering duration.

The panicles were longer than the normal in the varieties Alphonso, Imam Pasand and Sindhooram and was shorter in the variety Banganapalli. The inflorescence width was found to be greater than the varietal character in the varieties Alphonso and Imam Pasand and was lower than the varietal character in the variety Banganapalli. The inflorescence width was more or less similar to the varietal character in the mango variety Sindhooram. The inflorescence length and width were negatively correlated to the average minimum temperature during the period from pruning to flowering. The inflorescence width showed a significant negative correlation to the leaf carbohydrate: nitrogen ratio, magnesium and boron content with a correlation coefficient of -0.741, -0.713 and -0.714 respectively. The correlation of the leaf nutrients phosphorus, potassium and calcium to the width of the inflorescence were insignificant.

5.4 Phenological stages

The phenological stages of mango were recorded according to Ramírez *et al.* (2014). The critical phenological stages of flowering were Early Panicle Elongation Stage (EPE), Mid-Size Panicle Early Anthesis Stage (MPEA) and Full Size Panicle Maximum Anthesis Stage (FSPMA), during which the varieties were the most susceptible to yield loss due to pest attack.

5.5 Leaf nutrient status

The leaf nitrogen and phosphorus content before flowering were positively correlated to the yield in mango (Ray and Mukherjee, 1987, Reddy *et al.*, 2001). The results of the present study were not in agreement with this study since both the leaf minerals were negatively correlated to the yield.

Off season flower bud initiation in mango was favoured by lower leaf nitrogen content (Anusuya *et al.,* 2011). Similar tendency of lower leaf nitrogen content before flowering was observed in the varieties during the study.

The per tree yield of the observational trees is having no significant correlation with the pre-flowering leaf nitrogen status and has a strong negative correlation with the leaf phosphorus status before flowering. This is contrary to the findings of Ray and Mukherjee (1987).

5.6 Physiological characters

The physiological characters which show significant correlation to flowering and yield characteristics were transpiration rate, canopy air temperature and relative water content. The decrease in transpiration rate was found to hasten flowering whereas the increase in canopy temperature had a positive correlation with the time required for flowering starting from pruning. The relative water content showed a significant negative correlation with the fruit weight and a significant positive correlation with the per tree yield.

5.7 Biochemical analysis

Biochemical analysis for the estimation of proline was done before flowering and after harvest. The leaf proline content in the varieties were comparatively lower before flowering and lower levels of proline were reported in kiwi fruit by Walton *et al.* (1991)

The floral induction in citrus was found to be correlated to the leaf proline content (Arias-Sibillotte *et al.,* 2019). In the present study, number of days required to attain flowering is showing a strong positive correlation with concentration of the amino acid proline in the leaves before flowering with a correlation coefficient of 0.713, which indicated that the flowering is delayed by the increase in the concentration of proline in the leaves.

5.8 Influence of weather on flowering and fruit development

Night temperatures less than 15 ºC influences flowering in mango (Whiley, 1992) and field temperatures not less than 10 ºC are favourable for fruit development

in mango (Lakshminarayana and Aguilar, 1975). During the present study, the average minimum and maximum temperatures of Muthalamada was greater than 24 ºC and 29 ºC. This result showed a similar pattern to the mango flowering in Kanyakumari, where the flowering wase positively correlated to a maximum temperature of 32 ºC and a minimum temperature of 20.30 ºC prevailing in that region (Kumar *et al.* 2014).

It was also observed that the average maximum temperature was having a positive correlation with the number of days required for flowering, which suggested that the flowering was delayed by the increase in the daily maximum temperatures. This is in agreement with the studies conducted by Mandal and Verma (2020) on the correlation of temperature with that of flower bud morphogenesis.

The total heat units accumulated from pruning to flowering had a significant positive correlation with the number of days required for flowering and the flowering duration. This suggests that with the increase in the daily maximum and minimum temperatures, the time required for flowering and the flowering duration would be longer when compared to lower temperature regimes.

Average rainfall in Muthalamada during the pre-flowering is found to have a negative correlation with the time required for flowering.

5.9 Soil characters

The soil in Muthalamada region is strongly acidic with a lime requirement of 350 kg $CaCO_3$. Since the soil organic carbon in the orchard is 1.01 per cent, it belongs to the soil fertility class five. A fertilizer recommendation of 84 g N, 25.56 g P_2O_5 and 71 g of K_2O can be given for this orchard which is 84 per cent of general fertilizer recommendation of three to five year old mango trees. Since the soil is deficient in boron, borax can be recommended at a rate of 10 kg ha^{-1} as soil application or as foliar spray at 0.5 per cent concentration.

5.10 Yield characters

A significantly higher average fruit weight of 274.62 g was recorded in the variety Alphonso than the general average weight of 230.00 g. But the average fruit weight of the varietes Banganapalli and Sindhooram was significantly lower than the

normal fruit weight (Mango DB, 2016). Even though the variety Sindhooram had the highest per tree yield, the yield of the variety Banganapalli is on par with that of Sindhooram.

5.11 Pest incidence and yield

The major pests found to attack the panicle during the flowering stage were mango hoppers (*Idioscopus niveosparsus*) and mango thrips (*Scirtothrips dorsalis).* The variety that was severely affected by these pests was Imam Pasand and the phenological stages which were affected were Early Panicle Elongation Stage (EPE), Mid-Size Panicle Early Anthesis Stage (MPEA) and Full Size Panicle Maximum Anthesis Stage (FSPMA). Since no fruit set was obtained in Imam Pasand, it suggested the need of prophylactic plant protection measures before the panicles attain Early Panicle Elongation Stage (EPE) to control the pest damage.

It was observed that the varieties Banganapalli, Alphonso and Sindhooram suffered lesser pest damage when compared to the variety Imam Pasand since the pest attack in these varieties were not during the critical stages of panicle development.

5.12 Suitability of vareities in Muthalamada

Even though the variety Sindhooram was superior in terms of yield, the flowering and fruit set is late compared to the other varieties. The variety Imam Pasand generally has a low fruit bearing intensity and is highly susceptible to yield loss due to pest infestation in Muthalamada region. Considering the earliness in fruit maturity, the variety Banganapalli fetches maximum price and is the most profitable variety for this region when monetary profit is considered.

Summary

6. SUMMARY

The present study on "Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area" was conducted to evaluate the response of the mango varieties Alphonso, Banganapalli, Imam Pasand and Sindhooram to climatic conditions prevailing in Muthalamada area and the phenological cycles of growth and flowering were studied. The study was done in Muthalamada region, located in the Kollengode block panchayat of Chittur taluk in Palakkad district, Kerala during the period 2018- 2020. The observations were recorded on four year old trees of the varieties under study, maintained under high density planting at a spacing of 4m × 3m in a farmer's orchard in Muthalamada.

The phenological stages and the relationship between the leaf nutrient status, biochemical parameters, physiological parameters, weather data, pest incidence, flowering and yield were studied in detail and the important findings are summarized below.

1. The tree height was maximum in the variety Alphonso and minimum in the variety Imam Pasand.
2. Trunk circumference was maximum in the Alphonso and minimum in the variety Imam Pasand.
3. The variety Banganapalli recorded maximum crown diameter and the variety Alphonso recorded the lowest crown diameter.
4. Crow shape was semi-circular in Alphonso, Banganapalli and Sindhooram and was drooping in the variety Imam Pasand. Foliage density was intermediate in Alphonso, Banganapalli and Imam Pasand and the variety Sindhooram had dense foliage.
5. The variety Banganapalli was the earliest flower among the four varieties and late flowering was observed in Sindhooram. Longest flowering duration was recorded in the variety Sindhooram.
6. Highest pre flowering and post harvest leaf nitrogen content was observed in the variety Alphonso and lowest content was recorded in the variety Banganapalli.
7. Highest pre flowering and post harvest leaf carbohydrate content was observed in the variety Alphonso and lowest content was recorded in the variety Imam Pasand.

8. The variety Banganapalli recorded the highest carbohydrate: nitrogen ratio during pre-flowering and post-harvest periods. The variety Imam Pasand had the lowest leaf carbohydrate: nitrogen ratio before flowering and the variety Alphonso had the lowest carbohydrate: nitrogen ratio after harvest.
9. The phosphorus content in the leaves were maximum in the variety Alphonso and minimum in the variety Sindhooram.
10. The potassium and calcium content in the leaves were maximum in the variety Imam Pasand and minimum in the variety Sindhooram.
11. Leaf magnesium content was maximum in the variety Banganapalli and minimum in Imam Pasand.
12. Highest leaf boron content was recorded in the variety Banganapalli and the lowest content was recorded in Imam Pasand.
13. The variety Imam Pasand had the lowest stomatal index whereas the variety Sindhooram had the highest stomatal index. Stomatal frequency was maximum in Alphonso and minimum in Sindhooram.
14. The highest values of stomatal conductance and photosynthetic and transpiration rates were recorded in the varieties Imam Pasand and Banganapalli respectively and the lowest values were recorded in the varieties Banganapalli and Alphonso respectively.
15. The canopy air temperature and leaf temperature were maximum in the variety Imam Pasand and were minimum in the variety Banganapalli.
16. The proline assay in the leaves of the varieties under study revealed that the variety Sindhooram had the highest proline content both before flowering and after harvest. The lowest proline content was recorded in the variety Banganapalli before flowering and in the variety Imam Pasand after harvest.
17. The daily maximum and minimum temperatures were minimum during the month of August. The daily maximum temperature was highest during the month of May and the daily minimum temperature was highest during the month of June.
18. A total rainfall of 1426.10 mm was received from 25th July 2019 to 31st May 2020 and the maximum rain was recorded in the month of August.
19. Relative humidity was maximum in the month of August and minimum in the month of February.

20. The soil in the experimental orchard was strongly acidic and falls under the fifth soil fertility class.
21. The level of soil phosphorus and potassium were rated as high and medium respectively according to the ratings by Dev (1997).
22. Both calcium and magnesium content in the soil was found to be sufficient, whereas the boron content in the soil was deficient.
23. Fruiting duration was longest in the variety Alphonso and shortest in the variety Sindhooram.
24. No fruitset was observed in the variety Imam Pasand.
25. Maximum fruit weight and minimum per tree yield were recorded in the variety Alphonso and minimum fruit weight and maximum per tree yield were recorded in Sindhooram.
26. The fruits of Alphonso, Banganapalli and Sindhooram were having yellow peel colour and the varieties Alphonso and Sindhooram had a characteristic blushing with orange and red colour respectively.
27. The major pests attacking the mango varieties under study are mango thrips (*Scirtothrips dorsalis)* and mango hoppers (*Idioscopus niveosparsus*).
28. The important phenological stages of generative shoot growth which were severely affected by the attack of mango hoppers and thrips were Early Panicle Elongation Stage (EPE), Mid-Size Panicle Early Anthesis Stage (MPEA) and Full Size Panicle Maximum Anthesis Stage (FSPMA).
29. Incidence of the physiological disorder spongy tissue was observed in the variety Alphonso.
30. The number of days required by the varieties to flower starting from pruning had a significant positive correlation with leaf proline content, canopy air temperature, average maximum temperature and heat units accumulated. It is having a significant negative correlation with leaf potassium content, transpiration rate and average rainfall.
31. Flowering duration is positively correlated to leaf carbohydrate: nitrogen ratio, boron content, average maximum temperature, average minimum temperature and heat units accumulated. A significant negative correlation if observed between the

levels of leaf phosphorus, potassium and calcium content with the flowering duration of the varieties under study.

32. The inflorescence length is having a significant positive correlation with leaf nitrogen content and proline content and a strong negative correlation with leaf carbohydrate content, C:N ratio, magnesium content, boron content, average minimum temperature and average rainfall.
33. A significant positive correlation is exhibited by leaf nitrogen content, magnesium content and proline content with inflorescence width and a significant negative correlation exists between the inflorescence width and average minimum temperature.
34. The fruit weight is positively correlated with leaf phosphorus, potassium and calcium content and is negatively correlated with the leaf proline content.
35. The average yield per tree is negatively correlated with the leaf carbohydrate content, phosphorus content and calcium content.

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Appendices

APPENDIX

Monthly average of weather data

Month	Daily maximum temperature (ºC)	Daily minimum temperature (ºC)	Total rainfall (mm)	Number of rainy days	Relative humidity
July	30.13	24.26	168.80	25.00	87.40
August	29.13	23.71	347.10	29.00	91.90
September	30.40	24.47	304.00	26.00	88.70
October	30.81	24.00	266.60	22.00	80.30
November	31.76	24.63	84.40	19.00	71.20
December	32.00	24.52	11.40	3.00	59.30
January	32.39	24.35	0.00	0.00	52.60
February	33.03	24.93	0.00	0.00	51.20
March	34.03	25.77	20.60	5.00	61.70
April	36.77	27.07	138.20	10.00	63.50
May	37.13	25.71	66.20	10.00	62.40

Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area

by

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(2018-12-006)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the

requirement for the degree of

Master of Science in horticulture

(FRUIT SCIENCE)

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF FRUIT SCIENCE

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area

Abstract

The experiment on "Ecophysiology of mango (*Mangifera indica* L.) under High Density Planting System in Muthalamada area" was conducted in a farmer's orchard in Muthalamada located in Kollengode block panchayath of Palakkad district during October 2018 to May 2020.

The objective of the study was to evaluate the response of different varieties of mango to climatic conditions prevailing in Muthalamada area and study the phenological cycles of growth and production. Four varieties namely, Alphonso, Banganapalli, Imam Pasand and Sindhooram, which were extensively cultivated by the farmers of Muthalamada were selected as the material for study for the study.

Five trees each from the four varieties under study, maintained under high density planting system were selected at random for the study. The varieties in the orchard were of four years of age and were maintained under good management practices. Observations on tree characters, inflorescence characters, phenological stages, leaf nutrient status, physiological and biochemical characters and yield were recorded. In addition to these, observations on meteorological data, soil nutrient status and incidence of pests and diseases were recorded during the period under study and correlation studies were done to evaluate the effects of parameters on the flowering and yield of the varieties.

Among the four varieties, early flowering was noticed in the variety Banganapalli, followed by the varieties Imam Pasand, Alphonso and Sindhooram. Fruit set was observed in all the varieties except Imam Pasand. Among the three varieties which had fruited, the variety Alphonso recorded the maximum fruit weight (274.62 g) and the variety Sindhooram recorded the maximum fruit yield (11.27 kg).

Correlation coefficient analysis was carried out to identify the factors which influenced the flowering and fruiting behaviour in Muthalamada region. The level of potassium content in the leaves was significantly correlated with earliness in flowering with a correlation coefficient of -0.769 and flowering duration exhibited a positive correlation with leaf C:N ratio and boron content with a significant correlation coefficient of 0.509 and 0.530. The inflorescence length and width showed a significant negative correlation with the carbohydrate: nitrogen ratio, magnesium content and boron content in the leaves.

The physiological parameter transpiration rate was negatively correlated with the number of days taken from pruning to flowering with a significant correlation coefficient of -0.520. The time taken (days) to attain flowering was having a significant positive correlation with leaf proline content before flowering and canopy air temperature. This suggested that the trees tend to flower earlier under higher canopy temperatures and proline content in the leaves.

It was observed that the weather parameters in Muthalamada region influenced the flowering behaviour in the varieties. The earliness in flowering and flowering duration were positively correlated with average maximum temperature before flowering and the heat units accumulated by the resting bud with a significant correlation coefficient of 0.869 and 0.973 respectively. This indicated the effect of higher temperatures in stimulating flowering. Earliness in flowering showed a significant negative correlation to the average rainfall obtained from pruning to flowering, which indicated the requirement of low rainfall for flowering.

The inflorescence length and width were having negative correlation with average minimum temperature and average rainfall with a significant correlation coefficient of -0.690 and -0.775 respectively. This indicated that the inflorescence attains better length and width under higher daily minimum temperatures and rainfall. Flowering duration exhibited positive correlation with average maximum and minimum temperatures. It also exhibited a significant positive correlation with the heat units accumulated.

The accumulation of proline before flowering was positively correlated to the average maximum temperature and heat units accumulated. A strong negative correlation was observed between leaf proline content and average rainfall. This suggested that the accumulation of proline is associated with higher temperatures and lower rainfall regimes.

Overall perusal of the results indicated that the earliness in flowering in Muthalamada area is due to the influence of the weather conditions prevailing in the region and the growing degree days required by the varieties. The variety Sindhooram was superior in terms of yield but was comparatively late to the other varieties. Considering the earliness in fruit maturity, the variety Banganapalli fetches maximum price and is the most profitable variety for this region.