PRODUCTION TECHNOLOGY AND CROP IMPROVEMENT OF PASSION FRUIT (*Passiflora edulis* Sims.)

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by

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THESIS

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2020

DECLARATION

I, hereby declare that this thesis entitled **"Production technology and crop improvement of passion fruit (*Passiflora edulis* Sims.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Production technology and crop improvement of passion fruit (*Passiflora edulis* Sims.)"** is a record of research work done independently by **Ms. Annjoe V. Joseph (2017-22-001)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, undersigned members of the advisory committee of **Ms. Annjoe V. Joseph** (2017-22-001) a candidate for the degree of **Doctor of Philosophy in Horticulture** with major in Fruit Science, agree that this thesis entitled **"Production technology and crop improvement of passion fruit (*Passiflora edulis* Sims.)"** may be submitted by Ms. Annjoe V. Joseph (2017-22-001), in partial fulfilment of the requirement for the degree.

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LIST OF ABBREVIATIONS

%	per cent
@	at the rate of
^{0} C	Degrees Celsius
AOAC	Association of Official Agricultural Chemists
CD	critical difference
cm	centimeter
et al.	and others
g	gram
ha	hectare
ha^{-1}	per hectare
i.e.	that is
KAU	Kerala Agricultural University
kg	kilogram
MT	metric tons
m	meter
mg	milligram
POP	Package of Practices
ppm	parts per million
t	tons
Var.	Variety
MAP	month after planting
RBD	randomized block design
TSS	total soluble solids

Introduction

1. INTRODUCTION

Concept of balanced nutrition has shifted the focus from food grain to horticultural crops and fruit crops have assumed importance due to their health imparting bioactive components. Increased consumption of fruit and vegetables has been recommended as a key component of a healthy diet for the prevention of chronic diseases. Joshipura *et al*. (2001) observed an increased mortality rate with low consumption of fruits and vegetables. Fruits and vegetables are proven to be lowering the risk of mortality in case of non-communicable diseases like cardiovascular diseases and cancer. The protective role of fruits can be mainly attributed due to the presence of bioactive compounds in them. Hence, fruits due to their health benefiting nutraceuticals and disease preventing characteristics, should be regularly included in our diet.

India is a land of varied soil and agro-climatic conditions, which enables the cultivation of variety of fruit crops in one or the other part of the country. Presently, China is the leading producer of fruits followed by India which accounts about 10 per cent share in the world fruit production (FAO, 2018). But, due to explosion of population and wastage of the harvested produce, the per capita consumption of fruits is 40 g as against the recommended 120 g per day which is far below the required level (Mehta *et al*., 2016). Therefore, it is necessary to increase the area and availability of fruits, by growing suitable fruit crops depending upon agro-climatic requirements.

Passion fruit (*Passiflora edulis* Sims.) should be considered as an important component of our diet since it contains good amount of vitamins, minerals, dietary fibre, antioxidants and different phytochemical components. High nutritional and therapeutic components make passion fruit a tasteful and healthy addition to the diet. It has got various health benefits like cytotoxic, antioxidant, antihypertensive, antimicrobial and gastroprotective effects (Ripa *et al*., 2009). Passion fruit with excellent aroma is appreciated for fresh consumption and also for the preparation of various processed products like squash, syrup, juice, jam *etc*. The seeds contain 23 per cent oil similar to sunflower or soybean oil and rind residue is used as a cattle feed.

Globally passion fruit is grown in an area of 1.50 lakh ha with a production of 10 lakh tonnes and productivity of 6.6 t ha^{-1}. Brazil is the leading producer of passion fruit with a productivity of 30 to 35 t ha^{-1} (FAO, 2018). Passion fruits are grown in various countries, among which Colombia and Brazil grow approximately 170 and 150 species of *Passiflora*, respectively (Cerqueira-Silva *et al*., 2016). Passion fruit has been originated in Brazil and was introduced to India during 20^{th} century. In India, passion fruit is being cultivated in Mizoram, Nagaland, Manipur, Sikkim, Karnataka, Kerala and Tamil Nadu in an area of 0.19 lakh ha, with a production of 1.29 lakh tonnes and productivity of 7 t ha^{-1} (NHB, 2017).

Passion fruit is a perennial woody vine with axillary tendrils belonging to the family Passifloraceae comprising of about 500 species. South America is the centre of diversity of the genus *Passiflora* with the existence of 95 per cent of all species (Nakasone and Paull, 1998). Approximately 40 species are indigenous to Asia and the South Pacific islands (Vieira and Carneiro, 2006). There are mainly two types of passion fruit under cultivation. They are the yellow passion fruit (*Passiflora edulis* f. *flavicarpa* Degener), suited to tropical conditions or the plains and the purple passion fruit (*Passiflora edulis* f. *edulis* Sims) which grows best under sub-tropical conditions or high altitudes. Purple passion fruit is native of tropical America and yellow passion fruit is considered as a mutant of purple variety, or as a natural hybrid between purple and another related species of passion fruit. The yellow passion fruit is tolerant to many of the soil borne pests and diseases that commonly affect the purple type, and is more prolific, bearing larger and heavier fruits with more juice, which has a higher acid content than the purple type. The flavour of the purple type is preferred over that of the yellow type. Compared to purple type, yellow type has higher nutritive content.

Recently, there is a trend among Kerala farmers to shift from traditional cash crops to fruit crop cultivation due to highly volatile nature of market price of cash crops. Due to adaptability of passion fruit under humid tropical regions, it is gaining commercial importance in Kerala (Sulladmath *et al*., 2012). Eventhough, passion fruit has high production potential in Kerala, cultivation has not become popular due to lack of scientific cultivation aspects and suitable varieties and research work is meagre in these aspects.

Studying the existing genetic variability helps in characterization and conservation of different genotypes in passion fruit. Inspite of increasing demand for passion fruit, genetic variability and hybridization studies remain modest. Phenological and pomological studies are useful to assess the genetic variability and for finding out superior genotypes.

Farmers have selected and started cultivating certain morphotypical types which perform best in a given locality based on yield and quality parameters. These types show difference in performance when grown in different agro climatic conditions and have variations in their biochemical and physical characteristics. Genetic diversity may provide the ability to adapt to changing environments, including new pests and diseases and new climatic conditions. In this context, it is a need to find out superior types and to categorize them based on biochemical and morphological characters for enabling selection of suitable ones. Studies at Pineapple Research Station, Vazhakulam has shown wide morphological and biochemical variations among different genotypes (PRS, 2015). Much information is not available about the unique characteristics of different genotypes grown in different areas. The physico-morphological and biochemical characterization of different genotypes grown in various parts of Kerala and identification and categorization of the superior accessions suitable for fresh consumption as well as processing purpose will be highly useful for further crop improvement programmes. Information regarding the relation between the yield and the fruit characters has significance in selecting the breeding material. Knowledge of correlation between different traits is a prerequisite in fruit breeding which is necessary for planning appropriate breeding strategy for the crop.

Hybridization between different elite genotypes for developing superior hybrids suitable for fresh consumption and post harvest quality will be a boon to the farmers and processing sectors. Improved varieties of passion fruit are in great demand owing to the shift in consumer preference. In this scenario, it is necessary to develop elite hybrids, fulfilling the requirements of farmers and processing industries.

Cultivation of passion fruit has a bright future in Kerala, but lack of adequate agronomic package is a barrier for successful cultivation. In Kerala, even though cultivation of passion fruit has gained momentum, due to lack of scientific production technologies, farmers are adopting their own management practices which results in poor yield and inferior quality. Hence, there is a need to develop efficient production technologies and package of practices for passion fruit to get maximum yield and quality. Adequate management of nutrients is crucial for the proper nourishment of the crop and to achieve high yield with better quality.

Nutrient management improves both productivity and quality of produce and contributes a substantial share in the cost of production. Different doses of fertilizers have been recommended for profitable production of passion fruit in different places in India. As per the literature, macronutrients, nitrogen and potassium are required in higher proportion for passion fruit followed by minor quantity of calcium, sulphur, phosphorus and magnesium. Aular *et al*. (2014) reported that fertilizers affect the fruit characteristics like fruit weight, fruit size, rind thickness and internal characteristics like juice per cent and soluble solid content. The Ad hoc production technology for passion fruit for Kerala recommends a fertilizer dose of FYM 10 kg, 25 g N, 10 g P_2O_5 and 25 g K_2O vine^{-1} (PRS, 2015) which needs modification through research work for deriving a solid recommendation.

Availability of required number of disease-free planting material is a constraint in expanding the passion fruit cultivation. Passion fruit is propagated through seeds, cuttings and grafting. Seedling plants take many weeks for transplanting and also results in variability. Stem cuttings can give true to type plants and can transfer all the desirable characters from mother plants to the progeny. It is necessary to standardize the type of stem cutting and concentration of growth regulators for getting maximum success in propagation.

Under these circumstances, the present study on ‘production technology and crop improvement of passion fruit’ was designed with the following objectives:

- To evaluate the performance of cultivars/ genotypes of passion fruit
- To develop superior types for yield and quality through hybridization
- To standardize the propagation technique using stem cuttings and different concentrations of growth regulator
- To standardize the nutrient doses for better performance with respect to yield and quality

Review of literature

2. REVIEW OF LITERATURE

Passion fruit is a perennial woody vine native to tropical America which is rich in vitamins and minerals, used primarily for fresh consumption and have a good position in the processing industry. Passion fruit stands out for its exotic and unique flavour and aroma and also for its amazing nutritional and medicinal properties. Even though it has high production potential in Kerala, its cultivation has not become popular due to lack of technical knowledge regarding production technology and shortage of suitable varieties and good quality planting materials. Commercial cultivation needs high yielding varieties as well as technological support in production technology for sustainable income.

Relevant literature pertaining to the production technology and crop improvement of passion fruit and other fruits are reviewed in this chapter.

2.1 Evaluation of cultivars/ genotypes in passion fruit

Passion fruit cultivation is gaining importance in Kerala because of its high adaptability under humid tropical regions. Farmers have selected and adopted certain types which perform best in a given locality based on yield and quality parameters. Much information is not available about the typical characteristics of different types grown in different areas. The physico-morphological and biochemical characterization of different types selected from various parts of Kerala and identification of the superior types suitable for fresh consumption and processing will be highly useful to the farmers for expanding their cultivation and thereby revenue generation and income enhancement. Felter and Lloyd (1983) reported the use of different species of *Passiflora* in the traditional systems of therapeutic medicine in various parts of the world.

Based on evaluation of different accessions by different researchers, variations have been reported in flower, yield, fruit and quality parameters. The genetic variability is very wide, both within genus and within the most cultivated species, *P. edulis* f. *flavicarpa* (Cunha, 1996).

For commercial cultivation, yellow passion fruit was more popular due to its large fruit size, higher yield, attractive juice colour and higher acidity (Sandi *et al*., 2004).

Superior populations were identified, with possibilities of use in the crop improvement program, in a study to quantify the genetic diversity in yellow passion fruit genotypes from populations of different origins (Viana *et al*., 2006).

The highest genetic diversity of the passion fruit was found in Colombia, where Ocampo *et al*. (2007) observed 167 species, from which 165 were native, followed by Brazil with 127 and Ecuador with 90. According to Ligarreto (2012), in the National System of Germplasm Banks administered by Corpoica (Colombia), there were 170 accessions of passion fruit, with 52 numbers molecularly characterized, including details about their biochemical and agro-industrial properties.

Different cultivated passion fruit species are found in Brazil, Colombia and in general, in tropical America and Central America (Miranda, 2012).

Ocampo *et al*. (2015) collected and characterized sweet granadilla (*P. ligularis*) fruits based on eleven physicochemical variables. Seven elite accessions were identified through the quality parameters like fruit weight (>34 g), ºBrix (>14.4) and pulp + seed (>52%).

Studies at Pineapple Research Station, Vazhakulam has shown wide morphological and biochemical variations among different genotypes. The purple passion fruit type 134P was identified and selected based on its superior growth, yield and quality parameters (PRS, 2015).

Since the number and genetic variability of many species are rapidly declining as a direct or indirect consequence of human actions (Frankham *et al.,* 2008), and the demand for food products and other derivatives (*e.g*., biofuels and new drugs) is growing rapidly (Lee *et al*., 2014), a notable need exists for research that helps establish conservation strategies as well as manage and make use of the variation in available genetic material. The genetic resources are the resources of natural genetic variability, both for breeding programs and conservation strategies. The characterizations of diversity in passion fruit contribute to advances in breeding programs (Cerqueira-Silva *et al*., 2015).

Studying about the existing genetic variability helps in characterization and conservation of different genotypes in passion fruit. Passiflora, belonging to the Passifloraceae family has approximately 520 species. Passion fruits are grown in various countries, among which Colombia and Brazil grow approximately 170 and

150 species of Passiflora, respectively (Cerqueira-Silva *et al.*, 2016). Despite the species richness and wide distribution of the genus *Passiflora* across tropical regions, the lack of ecological and genetic research concerning most passion fruit species has become a risk factor for the conservation of their biodiversity. Over recent decades, the use of molecular techniques in studies related to the characterization of genetic variability has grown exponentially. Together, the variability estimates presented by various authors based on morphological and agronomic characteristics have indicated wide intraspecific variability among the *Passiflora* species (Ocampo *et al.*, 2013; Cerqueira-Silva *et al.*, 2009). Estimates of pathogen resistance observed in various genotypes as reactions to anthracnose, woodiness virus, scab, fusarium and bacterial blights, also support the genetic variability within and among *Passiflora* species (Cerqueira-Silva *et al.*, 2015).

In Kerala also, passion fruit is gaining popularity among farmers. Inspite of increasing demand in passion fruit, genetic variability studies remain modest. Phenological and pomological studies can be used to assess the genetic variability and for finding out superior genotype. Ganji *et al.* (2011) reported that phenological and fruit characters are used for analyzing the genetic variability in plum. Hakan and Yasar (2011) also used phenological and pomological characters to identify superior genotype in walnut.

Cavalcante *et al.* (2016), based on the evaluation of seven cultivars of passion fruit in Brazil, reported that UNEMAT S10 population had high agronomic performance which distinguished it from other cultivars and populations evaluated.

Study conducted for characterizing the production and physiochemical characteristics of passion fruit accessions at Colombia revealed high diversity across 60 accessions including 17 variables associated to yield, production and fruit quality (Mendoza *et al.*, 2018). According to them, fruit volume, pulp and seed weight were the variables that explained 80 per cent of the phenotypic variation.

2.1.1 Flower characters of passion fruit species/ cultivars/ genotypes

In South Wales, Australia, passion fruit flowers started to open in the night or early morning and started to close at about midday of the following day, but the stigmas were fully receptive on the morning of the first day only. Anthers of most of the flowers do not dehisce until the afternoon (Cox, 1957). Fruit set is determined by the amount of pollen deposited on the stigma (Akamine and Girolami, 1959).

Passion fruit flowers open and close at definite times of the day. Those of the purple variety open early in the morning, usually around dawn, and close before noon. Flowers of the yellow variety, however, open about 1.00 p.m. and close at night. Natural hybridization between the two varieties is thus not likely to occur. Studies on the pollination and fruiting behaviour of the yellow variety indicated that cross pollination between flowers of different vines was necessary for fruit setting. Seedlings vary somewhat in their degree of self fertility, but it is generally of very low order. Most of them are completely self-sterile (Akamine *et al*., 1974).

Yellow passion fruit flowers have both male and female parts but are self-sterile. They rely mainly on carpenter bees (*Xylocopa* spp.) for pollination. Other insects and hummingbirds also visit the flowers. The flowers of purple passion fruit are self-pollinated. Pollination took place after 1-2 hours of anthesis when stigma moved downward and placed between the anthers. The temperature and rainfall have significant role in pollination and fruit set (Morton, 1987).

The literature showed that the effective pollination occurred in the period after the stylus curved completely and the flower closed (Silva *et al*., 1999). The time taken from, when the flower opened until the stylus was completely curved, was approximately 90 minutes (Ruggiero *et al*., 1978; Cereda and Urashima, 1989).

The flowers of purple passion fruit open early in the morning, usually around dawn and close before noon. The flowers of the yellow passion fruit open about noon and close about 21:00 or 22:00 hours (Free, 1993; Teixeira, 1994).

Fernandes *et al*. (1996) performed self-pollination in flower buds and obtained 16.67 per cent fruit set rate that indicated the presence of receptive flower before the flower opened. The histochemical tests indicated that the flower remained 80 per cent receptive even 5 hour after flower opening.

The flower opened around midday that means, generally the warmest time of day, until the end of the afternoon, and during this period pollinators (principally bumblebees, *Xylocopa* spp), when collecting nectar, transfer pollen from one flower to another (Hoffmann, 1997).

Factors like pollen non-viability also influence the fertilization rate. Studies on passion fruit pollen grains indicated a fall in the mean male gamete viability per cent during flower opening time, where 30 per cent of the pollen viability was affected over time (Souza *et al*., 2002).

The *in vivo* pollination test showed that, on average, the flower receptivity rate after 5 h was below 35 per cent (Souza *et al*., 2004).

According to Kishore (2006), purple passion fruit flowers, open early in the morning and close in the evening and yellow passion fruit flowers open at noon and closes at night in the north eastern conditions. In the case of Kaveri, flower opens at noon and closes during night and for giant granadilla anthesis takes place in morning and flower closes in the evening (Kishore, 2006).

Most of the flowers of purple (54.50 %) and giant (58.50 %) opened between 6-7 hours, while the maximum per cent of anthesis in yellow (70.00 %) took place between 12-13 hours. Pollen dehiscence and pollination in purple and giant mainly occurred between 7-8 hours, while 13-14 hours was the major period of pollen dehiscence and pollination in yellow fruited varieties. The earliest anthesis (5-6 hours), anther dehiscence (6-7 hours) and pollination (6-7 hours) were recorded in *P. foetida*. The maximum stigma receptivity was recorded on the day of anthesis in both yellow and purple passion fruit. Completely curved style was more common in all passion fruits that gave the maximum fruit set. The maximum number of bees observed between 7-8 hours in purple and giant and between 13-14 hours in yellow. The most common pollinating bee in purple, giant and yellow was *Apis mellifera*, while *A. cerena* was the pollinating agent in *P. foetida* (Kishore *et al*., 2010).

Cleves *et al.* (2012) found that artificial pollination gave about 80 per cent fruit set in allogamous yellow passion fruit.

Reports showed that 80 per cent of the anthesis in purple passion fruit occurred between 6:00 and 8:00 hours, in prevailing flowers with fully curved style (66.40 %) (Rendón *et al*., 2013).

A study was conducted by Soares *et al.* (2015) to analyse the reproductive systems, pollen viability, and pollen–pistil interactions in 11 species of *Passiflora*. According to the pollen ovule interaction ratio, *Passiflora suberosa, Passiflora morifolia, Passiflora capsularis*, and *Passiflora tenuifila* were classified as obligatory autogamous, *Passiflora foetida* was classified as facultative autogamous, and the other species as facultative allogamous. Controlled pollination in the field identified six species as self-incompatible (*Passiflora edulis* f. *flavicarpa, Passiflora gibertii, Passiflora muchronata, Passiflora galbana, Passiflora racemosa,* and *Passiflora edmundoi*) and five species as self-compatible (*P. tenuifila, P. morifolia, P. capsularis, P. foetida, and P. suberosa*). Successful interspecific hybrids were obtained for some combinations, which produced fertile seeds. *P. capsularis* had the highest *in-vitro* pollen germination (80.10 %) and stained pollen grains (96.20 %). Irregular deposition of callose caused pollen tube inhibition in self-incompatible species, while, in self-compatible species, regular deposits of callose was observed.

At higher altitudes, due to the colder environment, production starts later and fruit development lasts longer than at lower sites, as reported by Mayorga (2017) in banana passion fruit.

According to Borges and Lima (2003) day light plays an important role in growth and development of passion fruit. An increase in day length duration enhanced photosynthetic activity, which resulted in increased plant vigour, fruit size and quality. During winter months when the days were shorter passion fruits did not flower. In semi-arid regions of Brazil, where more than 11 hours of sunlight was available along with high temperature flowering occurred throughout the year. As per the reports of Rojas and Medina (1995) light intensity is an important factor which influence the flowering behavior in yellow passion fruit. According to them flowers normally open at 12.00 hours, immediately following the maximum incidence of photosynthetically active radiation (PAR), and close at 15.00 hours; but when light intensity is lower, they close at 14.30 hours.

Temperature plays a significant role in flowering in passion fruit. Liu *et al.* (2015) examined the effect of day/night temperature regimes on growth and flowering of passion fruit 'Tai-nung No. 1' grown in potted conditions. Low temperature regime of (20/15°C) retarded flower production in 'Tai-nung No. 1'. Floral induction was observed in the temperature range of 20-30°C. No significant difference was observed in the days to first blooming and total flower production in the case of 30/25°C and 25/20°C. Temperature regime of 30/25°C exhibited higher abortion rates of floral buds than those at 25/20°C.

Fully developed flower buds start opening from 10. 30 am and complete opening by 1.00 to 2.00 pm. Heavy bee activity was also recorded during flowering season (PRS, 2015).

According to Beena and Beevy (2016), different time of flower opening was reported in different species of passion fruit. Based on the time of anthesis different genotypes were classified in to four groups: flowers opening before 6.00 am (*P. foetida* var. *foetida*, *P. foetida* var. *hispida* and *P. foetida* var. *gossippifolia*), between 7.00 am – 8.00 am (*P. subpeltata*), 9.00 - 10.00 am (*P. quadrangularis*, *P. ligularis* and *P. leshnoultii*) and 12.00-01.30 pm (*P. edulis* var. *edulis*, *P. edulis* f. *flavicarpa* and *P. edulis* cv. Panama Red).

The flowers of yellow passion fruit opened by noon and closed by 9.00 or 10.00 pm. (Deshmukh *et al.,* 2017). They also reported that passion fruit produced solitary flower buds in the axils of leaf.

In Florida, yellow passion fruit flowers open around noon and close about 9 to 10 pm and are self-incompatible while purple passion fruit flowers open early in the morning (about dawn) and close before noon and are self-compatible. When night temperature goes below 16^0C it delays the anthesis. Similarly when there was rain during night and in the morning, then flower did not open and fell down. Further rain coupled with low temperature affected the bee activity and ultimately fruit set got affected (Borges and Lima, 2003).

Flowering nature of passion fruit indicated that pollination occurred on the same day of pollination, as the flowers withered on the same day (PRS, 2015).

According to Deshmukh *et al*. (2017) in purple passion fruit 90 per cent pollen were viable at the time of anthesis while yellow genotypes had pollen viability of 88 per cent. Under natural pollination, 18-25 per cent fruit set could expected with the yellow variety and hand pollination increased fruit set to over 75 per cent. Deshmukh *et al*. (2017) reported that 80-90 days are required from fruit set to harvest.

The pollen viability in both the types ranges between 88-90 per cent. Pollination is not a problem in purple and hybrid varieties of passion fruit but it is a problem in yellow passion fruit varieties. Generally 3-4 days are required for anthesis and fruit set. The purple passion fruit flower open in the morning while yellow passion fruit flower open in the noon and afternoon (Tripathi, 2018).

Optimal storage conditions to bring pollen from different areas has been standardized by Iyer and Schnell (2009) in mango.

2.1.2 Phenological characters in passion fruit species/ cultivars/ genotypes

Growth and flowering response of purple passion fruit was studied at different temperature regimes, *viz.,* 23/18°C, 28/23°C, and 33/28°C by Utsunomiya (1992). At intermediate temperatures of 23ºC to 28ºC, the fruit growth period was 60.30 days, when the temperatures where lower (23ºC) and higher (33ºC) the period was 75.00 days (Utsunomiya, 1992).

Fruit formation starts at 280 days (9^{th} month), starting from the axillary flowers developed on new branches, with a fast accumulation of dry material within the first 60 days and then establishing itself during maturation (370 days, 12^{th} month) (Borges *et al*., 2006). The economic yield starts after 1-2 year of planting and fruits of passion fruits mature between 70-80 days of flowering. 10-11 weeks old fruits are fully matured and can be harvested (Kishore, 2006).

Patel *et al*. (2008) reported that in Meghalaya, purple passion fruits matured in June-July. In yellow passion fruit optimum harvest time was 63 days after anthesis, but when harvested 54 days after anthesis fruits contain 21 per cent less juice (Vianna-Silva *et al*., 2010). *Passiflora* species have flowering behavior varying among the year and consequently with variation in fruit production and harvesting time (Ataide *et al*., 2012).

Rao *et al*. (2013) reported that among the two varieties, Kaveri had taken more days to flower (263.75 days) compared to Purple (235.55 days).

According to PRS (2015) it took 10-14 days from flower bud production to flowering. Liu *et al.* (2015) reported that temperature plays an important role in growth and development of passion fruit. Most rapid growth was noted in plants grown at higher temperature regime of 30/25°C, which produced more leaves and enhanced internode elongation. They also reported that vegetative growth of vine increased with increased temperature.

Beena and Beevy (2016) reported that *P. edulis* var. *edulis* flowering started in the month of April and continued till September. In *P. edulis* f. *flavicarpa* onset of flowering occurred in November and continued to March, with a flowering duration of four months. *P. edulis* cv. Panama Red had two flowering seasons. First season of flowering started in May and ended in August, while second season started in November ending in March.

Beena and Beevy (2016) also reported that flowering duration varied depending on species. In the case of species like *P. foetida* var. *foetida, P. foetida* var. *hispida, P. foetida* var. *gossippifolia* and *P. subpeltata* flowering was observed thrice in a year, peaking in January, May and November. In *P. edulis* cv. Panama Red major flowering season occurred twice in a year (May and November), while in species like *P. quadrangularis* and *P. ligularis* flowering occurred once in a year in the month of March. In *P. leshnoultii* and *P. edulis* var. *edulis* flowering occurred in July which prolonged for three to four months (Beena and Beevy, 2016).

According to Deshmukh *et al.* (2017) purple passion fruit took 18-22 days from flower bud initiation to anthesis and 3-4 days from anthesis to fruit set, while yellow passion fruit took 14-19 days from flower bud initiation to anthesis and 3-4 days from anthesis to fruit set. They also reported that passion fruit plants grown from seedlings begin to fruit at 9 -10 months, whereas plants raised from cuttings / grafting begin to fruit earlier, when they are around 7 months.

Tripathi (2018) reported that passion fruit vines originating from cutting or grafting starts fruiting at 6-7 months while plants raised from seeds come to fruiting at 10-12 months. The initial fruits were obtained from ninth month and full bearing was reached in 16-18 months. About 60-70 days were required from fruit set to the harvest (Tripathi, 2018).

2.1.3 Yield characters of passion fruit species/ cultivars/ genotypes

Various parameters like flower production, fruit production and fruit characters have much influence on yield.

2.1.3.1 Flower production of passion fruit species/ cultivars/ genotypes

When grown under favorable conditions, passion fruit vines grow rapidly and will flower and produce fruit within a year after planting seedlings (Akamine *et al.*, 1974). They also reported that flowering occurred in two distinct periods, the first during early spring and the other during early fall. Because of this flowering behavior, fruit maturity occurred in midsummer and in midwinter.

Morton (1987) reported that purple passion fruit blooms in spring and early summer and again for a shorter period in fall and early winter. Seasonal fluctuations in flowering and fruit production have been reported in several cultivars (Menzel and Simpson, 1994; Nave *et al.,* 2010).

Inadequate light affects the formation of flowers. Regions in which the day length is greater than 11 hours have the best conditions for flowering. In winter months, the plants do not flower because the days are shorter. In the semi-arid regions of Brazil, with more than 11 hours of day light associated with high temperatures throughout the year, the passion fruit flowers continuously and produces fruit throughout the year, as long as there is an adequate supply of water as reported by Borges *et al.* (2006).

According to Kishore *et al*. (2010) purple passion fruit and giant granadilla flower throughout the year under Mizoram conditions but major bloom occur in March-April and July-August. In the yellow passion fruit and Kavery major flowering occurs during May-June and during September-October.

Under favorable conditions passion fruit vines grow rapidly and start flowering within 8-12 months of planting. Eventhough flowering occurs throughout the year only less number of flowers develops during the short day length of the winter. Flowers may appear continuously or intermittently on leaf axil but a certain number of fruits set along the branch, and further fruit setting ceases. This alternating between fruit setting and cessation of setting results in fruit being borne along several sections of the vine, with fruitless spaces between them. But in *P. foetida* all flower set fruit and there is no fruitless space in the vine (Kishore, 2006).

Floral biology of purple, yellow, giant and *Passiflora foetida* was studied at the ICAR Research Complex, Mizoram Centre, Kolasib, Mizoram, India during 2005-06 by Kishore (2006). Purple, giant and *P. foetida* had major bloom during March-April, July-August and September-October. While major bloom in yellow was mainly during May-June and September-October. Purple, giant and *P. foetida* had the maximum duration of bloom of 42.40, 22.50 and 32.60 days, respectively during March-April with the maximum duration of effective bloom of 12.50, 8.60 and 10.40 days in purple, giant and *P. foetida*, respectively. Yellow had the maximum duration of bloom for 28.40 days and effective bloom of 10.50 days during May-June (Kishore *et al*., 2010).

Fourteen promising passion fruit types obtained from different parts of South India were evaluated for their phenology, yield and quality characters at Pineapple Research Station, Vazhakulam. According to the reports of PRS (2015), in the mid lands of Ernakulam district, flowering occurred mostly during the period of February to November. 134P showed a prolonged peak flowering season during May to September. The onset of flowering was earlier in Kaveri (20th February) and latest for 35Y (7th May). Peak flowering was observed in June. Flower production slowly increased from February to June and slowly declined and ceased in November.

As per the reports of PRS (2015) earliest fruiting was observed for Kaveri (7th March) and latest for 55Y (5th July). Fruit harvest started in May, slowly increased, peaked in September, then decreased slowly and ceased in December. September was the peak month of harvest. Among the fourteen types studied, Kaveri was early fruiting type with the onset of fruiting in March. The mid fruiting types were 66Y, 86Y and 125Y with the onset of fruiting in May and June. Late fruiting types were 55Y, 35Y and VP with fruiting in July. They also reported that from flowering to fruit ripening it took 70 days (PRS, 2015).

In Bangladesh, passion fruit start flowering from April to September (Banu *et al*., 2009). In Meghalaya, flowering in purple passion fruit was observed during March-May and least number of flowers developed during the winter season due to short day length (Patel *et al*., 2008).

According to Deshmukh *et al*. (2017) in Jaboticabal and Botucatu, SP (Brazil), the sweet passion fruit flowers for 12 months a year with two flowering peaks, one in January and February and the other in September and October (Ruggiero *et al.,* 1996). The purple form blooms in spring and early summer (July-November) in Queensland and again for a shorter period in fall and early winter (February-April). In Florida, blooming in purple passion fruit occurs from mid-March to April. The yellow form has one flowering season in Queensland (October-June). In Florida, blooming of yellow passion fruit has occurred from mid-April to mid-November.

Passion fruit bears flowers round the year under tropical humid conditions, but there are two main flowering periods March-April and August -September (Tripathi, 2018). The flowering time varies according to the climatic conditions. The flowering duration in passion fruit is 15-22 days depending on the season and varieties. The flowers are borne singly in the axils of the leaves in the terminal region of the new growth. According to Tripathi (2018) passion fruit flowers throughout the year under favourable conditions.

2.1.3.2 Fruit production in passion fruit species/ cultivars/ varieties

Fruit yield is determined by the amount of pollen deposited on the stigma (Akamine and Girolami, 1959).

At intermediate temperatures of 23ºC to 28ºC, the fruit growth period was 60.30 days, whereas when the temperature was lower (23ºC) and higher (33ºC) the period was 75.00 days (Utsunomiya, 1992).

According to Yadav and Patel (2004) purple types were more productive and grown at higher elevations, but they were susceptible to collar rot and nematodes.

According to Borges *et al.* (2006), inadequate light affects the formation of fruits.

Although purple passion fruits are available throughout the year, major seasons of fruit availability are May-June and September-October. A healthy plant produces about 150-180 fruits/year. Purple passion fruit produces more fruits than yellow and giant granadilla due to compatibility of pollens. *P. foetida* produces 300-400 fruits/plant/year. About 4-6 kg of fruit per vine is thought to be the good production from the purple and yellow passion fruit. In a properly managed orchard, the average productivity of passion fruit may be 5-6 t ha^{-1} (Kishore, 2006).

Yellow passion fruits in Puerto Rico flower from April to September and yield fruits from June to October. In some areas, passion fruit plants fruit twice in a year. Plants usually begin blooming and fruiting in their second year (Morton, 1987).

In Bangladesh, the major season of purple passion fruit availability is May-June and September-October (Banu *et al*., 2009).

Seasonal fluctuations in fruit production have been reported in several cultivars (Menzel and Simpson, 1994; Nave *et al*., 2010).

In an experiment to study the effect of irrigation and mulching on growth, yield and quality of passion fruit (*Passiflora edulis* Sims.), among the varieties, Kaveri was found to be superior over Purple, in terms of number of fruits per plant (166.71 and 130.26, respectively) and fruit yield (13.33 t ha^{-1} and 3.97 t ha^{-1}, respectively) (Rao *et al.*, 2013).

According to Tripathi *et al*. (2014) higher fruit yield in Coorg conditions might be due to the favourable pH (5.8-6.2).

According to PRS (2015) fruiting season was found to be from March to December and 134P was profuse in fruiting nature (25 No. /plant).

According to Ocampo *et al.* (2015) banana passion fruit when grown outside their altitudinal range, pest and disease incidence was higher and pollination was affected resulting in reduced fruit production.

On an average, Kaveri, hybrid from IIHR, Bangalore produced 25 tonnes of fruits ha^{-1}. Passion fruit has two main fruiting periods *i.e.* from August to December and March to May. Slightly purple colored fruits along with a small portion of the stem should be picked up. The fruits are ready to harvest when their skin color becomes dark and to avoid shriveling, fruits should be picked up early in the morning. Initially, the color of the fruits is green that turns purple (*edulis*) or yellow (*flavicarpa*) when ripe. To achieve a better quality, passion fruits must be harvested when they are fully ripe. Average yield of purple type is 8-10 t ha^{-1}, yellow type 10-12 t ha^{-1} and Kaveri hybrid yields 16- 20 t ha^{-1} (Deshmukh *et al*., 2013; Deshmukh *et al*., 2017).

Passion fruit flowers and fruits throughout the year under favourable conditions, yet there are two main periods of fruiting: the first harvest extends from August to December and the second one from March to May. The fruit when ripe falls down from the vine. Harvesting is done when fruit turned slightly coloured. Fruit should be harvested along with the stalk. Tripathi (2018) reported that on an average, yield of 10-12 tonnes per hectare per year can be obtained. The vines are perennial and can produce yield for 10 to 15 years but maximum production can be obtained up to six years.

2.1.4 Fruit characters of passion fruit species/ cultivars/ genotypes

Number of seeds and weight of the fruit were determined by the amount of pollen deposited on the stigma (Akamine and Girolami, 1959). According to Knight and Winters, (1962) seed development is directly correlated to the juice content.

Castro (2001) noticed a reduction in fruit size of sweet granadilla (*P. ligularis*) leading to production of 50 per cent fruits of second grade quality, when grown at an altitude less than 1700 m above MSL.

Manual pollination is reported to produce larger and more succulent fruits (Rodriguez-Amaya, 2003). Wide variation in fruit size has been reported by Kishore (2006), who found that the average size of fruits of *P. foetida*, purple, yellow and Giant Granadilla are 3.00 g, 35.00 g, 70.00 g and 600.00g respectively.

Passion fruits are climacteric fruits (Hernandez and Fischer, 2009) implying that fruit growth and development occurs when attached to the plant or after harvest, depending on the state of fruit development.

In an experiment to study the effect of irrigation and mulching on growth, yield and quality of passion fruit (*Passiflora edulis* Sims.), among the varieties, Kaveri was found to be superior over Purple in terms of fruit weight (70.98 g and 26.59 g, respectively) (Rao *et al*., 2013).

Studies conducted in different species of *Passiflora* revealed that the fruit weight varied from 2 ± 0.022 g in *P. foetida* to 95 ± 0.031 g in *P. quadrangularis* (Beena and Beevy, 2016).

Purple type fruits are round or oval, 3 to 5 cm in diameter, green at first and deep purple when ripe and finally becomes crinkled when fully mature. Within the hard leather rind, there are numerous small blackish seeds, each enclosed in a yellowish aromatic, juicy pulp (Deshmukh *et al.,* 2017).

According to Deshmukh *et al.* (2017) the average fruit of yellow type is slightly larger than the purple form and has a bright canary-yellow rind. The pulp is somewhat more acidic and the seeds are dark brown rather than black. This species is prone to frost under Barapani, Meghalaya condition. Therefore, initially it takes more time, at least two years to become hardy and give the satisfactory yield (Deshmukh *et al.,* 2017).

Kaveri produces large size (80-90 g) fruits which are ovoid to round with purple dots. The greenish-yellow fruits of *P. quadrangularis* resemble melons and are the largest in the genus, about 15-20 cm long. The fruit is oblong, with a delicate aroma and a thin, smooth skin, which may have a few faint lengthwise ridges. Inside there is an inch or more of firm, whitish or pinkish flesh and a large central cavity filled with a mass of purplish-pink pulp surrounding ½"-long, dark seeds. Cooked, when not yet ripe, this fruit is considered delicious as a vegetable. Since this plant has attractive, delicious and nutritious fruit and grows easily and rapidly, having the same cultural requirements as *P. edulis,* it deserves wider cultivation (Deshmukh *et al.,* 2017).

Pruthi (1963) reported a close positive correlation between the number of seeds and final fruit diameter. Fruit of maypop have a much thinner and softer rind that easily collapses, compared to other passion fruit species (Arjona, 1990). Arjona *et al.* (1991) reported that passion fruit (*Passiflora edulis* Sims.) was larger in size compared to yellow passion fruit and maypop (*P. incarnata* L.). They also reported that yellow passion fruit had the lowest per cent of pulp, among the three different groups studied. Among the evaluated fruits, purple passion fruits had the highest weight of 59.60 g. Rind weight of fruits also varied significantly from 13.00 g in maypop to 31.10 g in yellow passion fruit. Green house grown maypop produced less number of seeds (15-20 per fruit), compared to wild maypop fruits (~ 60 seeds per fruit). Sema and Maiti (2006) reported variations in fruit diameter in different types of passion fruit.

As per the reports of Jimmenez *et al*. (2011), passion fruit has a round shape 4-6 cm in diameter, changed from green to purple or yellow on maturity, depending on type; fruits contain many gelatinously surrounded seeds in yellow pulp, with intense aroma and sweet acid taste.

As per the variability studies conducted by Joy (2010), both yellow and purple passion fruits are round to ovoid in shape. Purple accessions had a length of 5-8 cm and 4-8 cm in diameter, while yellow was 8-10 cm in length and 4-10 cm in diameter. Both types have yellow to orange coloured pulpy juice with excellent flavor. Evaluation of fifty passion fruit accessions from different parts of South India at Pineapple Research Station, Vazhakulam, Kerala revealed existence of large variability in fruit characters.

Ramaiya *et al*. (2012) studied physico-morphological parameters of yellow and purple passion fruit types and reported that highest fruit length (7.84 cm), fruit width (6.11 cm) and fruit weight (98.47 g) were observed in purple type, whereas, juice weight (37.01 g) was maximum in yellow type.

In a study conducted by Rao *et al*. (2013) at ICAR research complex Manipur, fruit weight was 70.98 g for Kaveri and 26.59 g for the purple variety.

Fruits of the yellow fruited form ranged from 45 to 120 g in Puerto Rico. There is large variation between plants in size and shape of fruits. According to Morton (1987) small fruits were sometimes completely devoid of seeds, and large fruits might have over 200 seeds.

Fruit length of yellow passion fruits harvested at three stages of maturity based on colour development on the rind; *viz.*, 1/3rd yellow, 2/3rd yellow and full yellow fruits, were 8.26 cm, 8.81 cm and 8.80 cm respectively, whereas, equatorial diameter was 7.83 cm, 7.81 cm and 7.91 cm respectively.

Pulp yield in yellow passion fruit was 31.44 to 41.28 per cent (Silva *et al.*, 2008). Average pulp yield of yellow passion fruit was 44.43 per cent as reported by Silva *et al*. (2015).

Oliveira *et al*. (2011) reported that average seed yield of yellow passion fruit was 4.23 per cent. A seed yield of 11.50 per cent was reported by Coelho *et al*. (2011). They stated that seed yield was not correlated with size and shape of fruits in yellow passion fruit.

Cavalcante *et al*. (2007), reported a rind thickness of 0.60 – 0.70 cm, whereas Ferreira *et al*. (2010) reported a rind thickness of 0.71 cm.

Among the six passion fruit genotypes evaluated 90 days after flowering, *P. alata,* recorded maximum weight of 192.87 g and minimum weight of 41.02 g in Megha Purple (Patel *et al*., 2014). Rind thickness in the six genotypes varied from 0.27 cm (*P. alata*) to 1.34 cm (Megha Purple). Among the six types, maximum juice content was recorded as 40.76 per cent in RCPS-1 and minimum in *P. alata.* Rind colour of the genotypes was deep purple, purple and deep yellow. Juice colour was yellowish orange, deep orange and orange.

According to Ghosh *et al*. (2017) purple types have an average fruit diameter of 3-5 cm. Mayorga (2017) conducted a study to evaluate sweet passion fruit grown at higher and lower altitudes. The study revealed that passion fruit grown at higher altitude (2498 m MSL, 14.9°C) had higher fruit weight and size compared to those grown at lower regions (2006 m MSL, 17.9°C).

2.1.5 Quality parameters of passion fruit species/ cultivars/ varieties

Quality of any produce is determined by factors like genetics of the variety, environmental conditions, interaction between genotype and environment and crop management practices (Wyckhuys *et al.*, 2012). Environmental conditions like climate and soil are significant in determining quality of fruits (Miranda, 2012). Environmental factors affect the physiological process like photosynthesis, transpiration, respiration, translocation of assimilates and finally metabolism of the plant, which together influence the quality of fruits (Ladaniya, 2008).

Many researchers have reported wide variations in the quality parameters of different passion fruit types. According to Arjona *et al.* (1991), yellow passion fruit had higher concentration of soluble solids compared to purple passion fruit and maypop. He also reported that purple and yellow passion fruits had lower juice pH than maypop. Wild maypop fruit had the highest non reducing sugar content and purple passion fruit had the lowest, while yellow and purple passion fruit had higher reducing sugar content than maypop (Arjona *et al.*, 1991). According to Kishore *et al.* (2011), TSS and titrable acidity in purple passion fruit pulp were 15.30 °Brix and 3.80 per cent respectively. Pongener *et al.* (2013) evaluated the physicochemical attributes such as TSS and titrable acidity in purple passion fruit, as 16.2 °Brix and 2.34 per cent.

Higher total soluble solids and juice content were recorded in Kaveri (16.71^0 Brix and 31.18 ml fruit^{-1}) than Purple (14.77 ^{0} Brix and 9.37 ml fruit^{-1}), respectively as reported by Rao *et al*. (2013).

Ascorbic acid content of four passion fruit species was studied and highest content of ascorbic acid was found in purple passion fruit (0.32 g kg^{-1} FW) and the lowest in sweet calabash (0.15 g kg^{-1} FW). According to them, highest sucrose content was observed in purple passion fruit (45.5g kg^{-1} FW) and the lowest in sweet calabash (17.00 g kg^{-1} FW), while the glucose content was the highest in giant granadilla (43.7 g kg^{-1} FW) and the lowest in yellow passion fruit (14.1g kg^{-1} FW). Lowest fructose content was reported in yellow passion fruit (14.6g kg^{-1} FW), while highest in giant granadilla (39.00 g kg^{-1} FW) (Ramaiya *et al*., 2013).

Study conducted in yellow passion fruit accessions in Brazil revealed that accessions ‘FB 300’, ‘BRS Sol do Cerrado’ and ‘BRS Ouro Vermelho’ were having better fruit quality (Gama *et al*., 2013).

According to Pongener *et al.* (2013) quality parameters of purple passion fruits were better when harvested after the colour breaker stage (50 per cent colour development).

Patel *et al*. (2014) reported that ascorbic acid in passion fruit cultivars ranged from 22.5 mg $100g^{-1}$ to 48.75 mg $100g^{-1}$. According to Anjana and Joy (2016) ascorbic acid content ranged between 27.49 and 46.31 mg $100g^{-1}$.

Kaveri fruits have 30-35 per cent juice with 12 per cent total sugars and about 3 per cent acidity (Deshmukh *et al.,* 2017).

Mayorga (2017) conducted a study to evaluate sweet passion fruit grown at higher and lower altitudes. The study revealed that passion fruit grown at higher altitude (2498 m MSL, 14.9°C) had higher citric and ascorbic acid content, but TSS was lower compared to those grown at lower regions (2006 m MSL, 17.9°C).

According to Charan *et al*. (2018) ascorbic acid content ranged from 16.98 to 30.50 mg $100g^{-1}$ and total carotenoids varied between 1.07 and 2.81 mg $100g^{-1}$ in passion fruit. Reis *et al*. (2018) reported that acidity in yellow type was 9.06 per cent whereas purple type had an acidity of 2.83 per cent.

Fischer *et al.* (2018) reported that in purple passion fruit, at consumption ripeness, titrable acidity was 3.92 per cent and TSS 16.21°Brix, while in sweet granadilla it was 13.1°Brix. Analyzing three stages of maturity in purple passion fruit, *viz.,* immature, colour breaker and mature, Jimenez *et al.* (2011) found that TSS increased from 13.5°Brix to 17.4°Brix and titrable acidity decreased from 4.68 to 2.51 per cent.

2.2 Hybridization studies in passion fruit

According to Cox (1957), passion fruit flowers are protandrous as anther dehiscence occurs before stigma becomes receptive and stigma continues to be receptive from the time of flower opening to closing.

Being protrandrous in nature, passion fruits are adapted to cross-pollination, main pollinating agents are honeybees *(Apis mellifera),* bumblebees and carpenter bee *(Xylocopa sonorina*) as reported by Akamine and Girolami (1959). They also observed that the fruit set, number of seeds, weight and yield of the fruit were related to the quantity of pollen deposited on the stigma.

Cross-pollination was found necessary in the yellow passion fruit because of its flower morphology where the anthers are placed below the stigma (Corbet and Willmer, 1980), pollen grains are large, heavy and sticky (Akamine and Girolami, 1959) and mainly because of the self-incompatibility (Bruckner *et al*., 1995). The self-incompatibility in the yellow passion fruit is an important factor to be considered in fruit production. Studies on the inheritance of this character have been carried out but there were no conclusive results. The self-incompatibility in the passion fruit has been reported since the 19th century (Nettancourt, 1977) and it was further reported many years later (Akamine and Girolami, 1959). Ho and Shii (1986) suggested that the self-incompatibility of the passion fruit was of the sporophytic type. According to them the self-incompatibility in passion fruit was genetically controlled by a gene locus with five S alleles. Bruckner *et al*. (1995) identified three alleles, S_1, S_2 and S_3, but they also suggested the existence of other S alleles, mostly five. Rego *et al*. (1996, 2000) concluded six alleles (from S_1 to S_6). They stated that the self-incompatibility in passion fruit was controlled by two gene loci, instead of one, probably due to the presence of the gametophyte gene that acted in association with sporophyte gene. According to Falleiro *et al*., (2000), the inheritance of conclusive self-incompatibility in passion fruit was not from S series alleles or from other loci, but due to a gene complex.

Ruberté-Torres and Martin (1974) produced six new hybrids from 42 cross combinations among 7 passion fruit species, demonstrating the possibility of cross breeding among passion fruit species to enhance characters of edible passion fruit. Most of the hybrids obtained were vigorous with slight variations in tendency to flower. Eventhough, certain unique characteristics were observed in hybrids, they were intermediate to parent species in foliage, flower and fruit characters. They also reported a varied degree of pollen sterility. Pollen was mostly aborted, but when used as a female parent showed sufficient fertility to permit some seed production. The cross between *Passiflora edulis* f. *flavicarpa* x *P. alata* produced fruits superior to the parent species.

Knight (1991) has done breeding works in passion fruit and when *Passiflora incarnata* L. was crossed with *P. edulis* f. *flavicarpa* Degener, pollen-sterile and nonfruitful diploid hybrids were obtained. Treating the emergent F_1 hybrids with colchicine, restored fertility in some hybrids by doubling the chromosome number, but all plants were strongly self-incompatible with low pollen viability. A tetraploid hybrid group of four seedling progenies with some cross-compatibility has been produced from the colchicine-treated plants that had been converted to amphiploids. Juice of the amphiploid hybrid was lighter in color compared to that of *P. edulis*, with strong flavor and sweet taste. In 1971, a clone of maypop (*Passifora incarnata*) collected in Tennessee was crossed with *P. Cincinnati* Masters (P. I. 98883), a passion vine from Argentina with spectacularly colorful fowers. The F1, hybrid, named 'Incense', was released in 1973 by U. S. Dept. of Agriculture and continues to be sold in the nursery trade. 'Incense' has the characteristics ornamental value of its pollen parent and the ability of *P. incarnata* to resist temperate zone winters. All aboveground parts of 'Incense' die in the winter, but restarts growth in the spring. The survival of 'Incense' for many years in winter prone areas, suggesting *P. incarnata* as a source of winter hardiness, to combine with the fruit quality of *P. edulis* and *P. edulis* f. *flavicarpa* to obtain an edible passion fruit for use as a perennial crop in temperate zone. Hybridization work were also conducted using *P. edulis* and *P. incarnata* as the parents to develop a group of fertile plants of interspecific hybrid origin, that can function as perennial fruit crop cultivar in temperate areas where purple and yellow passion fruits are not adapted (Knight, 1991).

Development of high yielding varieties can increase the productivity and profitability of the crop. ‘Kaveri’, hybrid between purple and yellow cultivar has been released by CHES, Chettalli (IIHR), which has become popular due to its high yield and excellent fruit quality and is tolerant to leaf spot, collar rot and wilt (Singh *et al.*, 1991).

Bruckner *et al.* (1995) reported that there is no problem of fruit set in purple passion fruit and *P. foetioda* as they are self compatible and cross compatible but yellow passion fruit appears to be self incompatible and some time cross incompatible too.

In general, passion fruits were allogamous plants that exhibited self-incompatibility (Bruckner *et al.*, 2005). However, certain species were self-compatible and can reproduce *via* self-fertilization, like some passion fruit species of the subgenus Decaloba (Varassin and Silva, 1999).

A study was conducted in Brazil, to analyze the vegetative growth, yield and fruit quality of passion fruit hybrids (Meletti *et al.*, 2000). The best performing passion fruit hybrids were 'IAC-3', IAC-5' and 'IAC-7', with yield of approximately 47 ton ha^{-1}, oval and compact fruits, and an orange intense pulp color; the average fruit weight was 170 g to 218 g with a TSS of 15 and 16 °Brix and 400 seeds per fruit. According to Rodriguez-Amaya (2003) manual pollination produced larger and more succulent fruits.

The flower of giant granadilla mostly has drooping habit, which restricts the bee activity and thus fruit set is poor. Pollination takes place after 1-2 hours of anthesis when stigma moves downward and placed between the anthers (Kishore, 2006).

There are different genetic breeding programmes for plants, among which intrapopulation recurrent selection allows the accumulation of favorable alleles at each selection cycle, thus obtaining real profits for the improved characters (Silva *et al.*, 2007).

The origin of the purple variety is southern Brazil through Paraguay to northern Argentina, and that of the yellow variety is unknown. Hybrids of these two varieties show a combination of agriculturally important traits. The commercially grown hybrid cultivar 'Passion Dream' ('PD') flowers twice a year under Mediterranean conditions, during spring and early fall (Nave *et al.*, 2010).

Studies were carried out on reproductive ecology of yellow passion fruit to understand the mode of fruit set in the absence of pollinators and the breeding system (Shivanna, 2012). Although several floral visitors, *Apis cerana*, *Trigona* spp. and an ant (*Camponotus* sp.) visited the flowers, they were all nectar robbers and not the pollinators. There is a unique autonomous self-pollination, involving the movement of anthers and stigmas, during flower opening which provides reproductive assurance to the species even in the absence of pollinators. The populations used in the present study were self-compatible. Thus, the species is able to produce constant fruit set, even when the population size was small and pollinators were absent; evolution of these features seemed to be the main factor for its wide distribution around the world (Shivanna, 2012).

In an experiment conducted at Bangladesh, by Das *et al.* (2013), it was reported that among the pollination methods (self, natural and hand pollination), maximum fruits were produced by pollinating flowers by hand.

Pre-breeding studies conducted at Colombia by Rendon *et al.* (2013), shown that hybridization can be done in *Passiflora* species to obtain cultivar robusticity and productivity. The results showed that the purple passion fruit was an auto fertile species that depended on pollinator insects for genetic flow and productivity. The highest per cent of fruit formation was found in manual self-pollination and geitonogamy treatments (82 and 86 %), followed by cross-pollination (68 %) with significant differences (Rendon *et al*., 2013).

Fourty three promising hybrids from Kaveri × Yellow types were selected for further evaluation, among these hybris, hybrid IIHR-18/42, produced purple coloured, high flavoured fruits with high juice recovery (35-38 %), and was found suitable for processing (Pongener, 2014). Hybrid, IIHR 1/31, yielded fruits with low acidity (0.40 - 0.60 %), more sweetness (TSS: 21-22 °Brix) and could be used for direct consumption (Pongener, 2014).

Eeckenbrugge *et al.* (2011) reported that purple and yellow forms have frequently been crossed and spontaneous hybrids were encountered in Hawaii and Australia.

Preferred crosses have been observed, in the studies conducted with the aim of enhancing the segregation or maintenance of characteristics of interest (Cerqueira-Silva *et al*., 2015).

A study was conducted by Soares *et al.* (2015) to analyse the reproductive systems, pollen viability, and pollen–pistil interactions in 11 species of *Passiflora*. Successful interspecific hybrids were obtained for some combinations, which produced fertile seeds. In a study to evaluate the adaptability and stability of hybrids, the estimates of heritability and genetic gains in the evaluated environments showed good prospects for selection of superior genotypes (Neto *et al*., 2016). There was a pronounced effect of genotype environment interaction (GxE) for all the traits investigated except fruit length, per cent of pulp, soluble solids, titrable acidity and soluble solids /titrable acidity ratio. The most stable and adaptable hybrids in the evaluated environments were BRS Gigante Amarelo, HFOP-09, H09-09, GP09-02, GP09-03 and BRS Sol do Cerrado (Neto *et al*., 2016).

Kaveri is an F_1 hybrid of passion fruit obtained by crossing purple and yellow varieties and observed to be superior to both the parents for many plant and fruit attributes. The vines were very vigorous and exhibited tolerance to important pests and diseases (Deshmukh *et al*., 2017).

According to José *et al*. (1991) the germination period of passion fruit seeds was shorter in summer time than in the cold months, when the period was longer.

Germination studies were conducted in fourteen promising passion fruit types obtained from different parts of South India. The study revealed that seeds started germinating five days after sowing and extended upto 30 days. Germination per cent varied from 18 to 95. Maximum germination of 95 per cent was recorded by Kaveri and pipe line variety 134 P had 85 per cent seed germination (PRS, 2015).

Souto *et al*. (2017) evaluated the germination and early growth characters of passion fruit hybrid seedlings, obtained from different crosses. Hybrids of different genetic combinations were obtained from crosses between progenies from the breeding program of the Universidade Federal de Viçosa with hybrids of the Empresa Brasileira de Pesquisa Agropecuária and of the Viveiros Flora Brasil. They reported significant variation in germination and seedling characters like mean time germination, emergence speed index, seedling height, the length of shoots and roots, and the individual seedling dry matter (root + shoot). Based on their study, hybrid HB2 (UFVM0212 × BRS Sol do Cerrado) showed superior germination and seedling characters and recommended HB2 as a genotype with potential for breeding programs with respect to seed quality.

Tripathi (2018) reported that the passion fruit seeds started sprouting in about 12-15 days after sowing and germination was completed in about a month.

Seeds were sown in Puerto Rico without pretreatment in commercial potting mixture which began germinating in 14 days and completed germination in 24 days with 61 per cent germination (Morton, 1987).

2.3 Response of fruit crops to fertilizer application

Good crop management techniques improve the potential of any crop. Fertilization is a significant factor which affect the fruit quality (Fischer and Al-varez, 2008) and growth, which influences the production (Aular *et al.*, 2014). It is essential to provide adequate manures and fertilizers for proper nourishment and to obtain uniformly high yield with better quality in passion fruit.

Haag *et al.* (1973) observed that the absorption of nutrients in passion fruit was low until 7^{th} to 8^{th} months due to low production of dry matter. After the appearance of the fruits (8^{th} and 9^{th} months), growth becomes exponential, increasing the uptake of N, K and Ca. The macronutrients N, K and Ca were taken up in large quantities, followed by S, P and Mg. Of the micro-nutrients, Mn and Fe were absorbed in large quantities, followed by Zn, B and Cu. Among, the nutrients removed in the harvested fruits, the largest quantity was that of K followed by N (Haag *et al.*, 1973).

Borges *et al.* (2007) reported that passion-fruit has a shallow superficial root system, *i.e.* about 60 per cent of the roots were found in the upper 30 cm of soil, and 87 per cent between 0 and 45 cm from the base of the stem. In young orchards, fertilizers should be distributed in a 20 cm wide area around and 10 cm from the trunk, gradually increasing this distance with the age of the plants. In mature vines it was recommended to apply fertilizers in a band 2 m long and 1 m wide, on both sides of the plants and 20 to 30 cm from the trunk (Borges *et al.*, 2007).

Passion fruit is a surface feeder and very sensitive to nutrients and soil moisture since the roots are confined to the top 15 to 45 cm layer of the soil. Nutrient removal pattern on whole plant analysis revealed that from a hectare area accommodating 1500 plants, with a mean fruit yield of 37 tons, the amount of different nutrients removed were: 202.50 kg N, 17.40 kg P, 184.20 kg K, 151.60 kg Ca, 14.40 kg Mg and 25.00 kg S (IPI, 2002).

According to Aiyelaagbe *et al.* (2005), N 60-480 kg ha^{-1}, when applied to passion fruit plants significantly increased dry weight of leaves, stem weight and whole plant weight when compared to control.

Depending upon different factors, different doses of fertilizers have been recommended for profitable production of passion fruit in India. Sema and Maiti

(2006) have recommended manure and fertilizer schedule for passion fruit grown in two premier belts of India, South India and North East India. The rates were 5:25:10:25 and 2:20:10:10 FYM (kg vine^{-1}): N: P_2O_5: K_2O (g vine^{-1}) for south India and north east India respectively.

A study was conducted by Borges *et al.* (2006) to find out the effect of N on yellow passion fruit. Two different sources of N, urea and calcium nitrate were used with five doses (0 to 800 kg ha^{-1}) and maximum production was observed when 457 kg ha^{-1} of N was applied as urea, without compromising the fruit and juice quality.

Deficiency of major nutrients and B in yellow passion fruit was studied by Freitas *et al.* (2006) and revealed that deficiency of Mg, N, P and S resulted in reduction in the number of fruits per plant.

According to Borges and Lima (2003) at the beginning of reproductive phase, absorption of nutrients increased, in the case of yellow passion fruit, fertilizer demand increased at 250 to 280 days after transplanting, when plants grow rapidly. Absorption of nutrients like N, K, Ca, Mn and Fe increased in this particular phenological stage.

Borges and Lima (2003) also reported that temperature below 18°C reduced the growth of passion fruit, thereby decreased nutrient uptake and fruit production.

A study was conducted with four levels of fertigation (25, 50, 75 and 100 % of recommended dose of fertilizer) at IIHR, Bangalore (Srinivas *et al.*, 2010). The recommended dose of fertilizer used was very high and consisted of 500 N – 300 P_2O_5 - 500 K_20 g per plant per year, nitrogen as urea, phosphorous as single super phosphate and potassium as muriate of potash. The first harvest was done at 185 days after planting and the harvest continued up to 360 days at an interval of 8 - 10 days. The number of fruits harvested and their weights were recorded and summed up after 20 pickings (1st crop) and 15 pickings (2nd crop). Increase in fertigation levels increased the fruit number and yield up to 75 per cent RDF only. The increased yield was 14 per cent with 100 per cent RDF and 13 per cent with 75 per cent RDF as compared to 25 per cent RDF. This increased yield was largely due to increase in fruit number per plant, which was the consequence of higher vine vigour, increase in the relative water content as well as higher nutrient content. The optimum RDF was 54.50 per cent as indicated by the response curve fitted to the yield data (Srinivas *et al.*, 2010).

Deshmukh *et al*. (2013) stated that under northeastern hill condition, well-rotted FYM @ 15 kg/vine/year might be applied in February-March. Besides, 100: 50:100 g as N: P_2O_5: K_2O per vine should be given annually in 2 splits during the month of February-March and July-August (Deshmukh *et al*., 2013).

From the start of fruit formation there is a great demand for energy by the plant and a strong translocation of nutrients from the leaves to the developing fruits and this reduces the vegetative growth of the plant. Aular *et al.* (2014) reported that nitrogen and potassium were required in higher proportion for passion fruit, followed by calcium, sulphur, phosphorus and magnesium. Fertilizers affected the external characteristics, like fruit weight, fruit size, rind thickness and internal characteristics, like juice per cent, soluble solid content, and acid index (Aular *et al.,* 2014).

In an experiment to find out the effect of irrigation and nitrogen on passion fruit var. Purple, Rao *et al*. (2014) found that 150 N kg ha^{-1} was most suitable for improving the growth, yield and quality of passion fruit under foothill condition of Manipur.

The Ad hoc production technology for passion fruit for Kerala recommends a fertilizer dose of 10kg FYM, 25g N, 10g P_2O_5 and 25 g K_2O $vine^{-1}$ (PRS, 2015). Ghosh *et al.* (2017) under North Eastern hill condition, recommended the application of FYM @ 15 kg/vine/year in Feb-March and N: P_2O_5: K_2O at the rate of 100: 50:100 g per vine per year in 2 splits during February-March and July-August. The recommended rate of fertilizer application in Tamil Nadu is FYM 10kg, 20g N, 20g P_2O_5 and 15 g K_2O $vine^{-1}$ (TNAU, 2017).

The passion fruit pulp was evaluated for its production, mass, size, and mineral composition in an experiment with a mineral fertilizer (control) (MIN), cattle manure at a single dose equivalent to potassium fertilizer (ORG) or double dose (2xORG) (Pacheco *et al.*, 2017). The production of fruits in plants applied with MIN and 2xORG was higher than those with ORG. The level of nitrogen, phosphorus, zinc, iron, and copper in the fruit pulp was similar in all the three fertilizer treatments, but calcium and magnesium were higher with ORG and 2xORG. The number and weight of the fruits in the treatment with 2xORG were similar to those with MIN fertilizer, but they recorded more Ca and Mg content (Pacheco *et al.*, 2017).

The fertilizer recommended for south Indian states is more than the recommended fertilizer schedule for north eastern states. Tripathi, (2018) studied the fertilizer requirement of passion fruit. A fertilizer dose of 110 g N, 60 g P_2O_5 and 110 g K_2O per vine per year was recommended for the four year old orchards in south India while 80 g N, 40 g P_2O_5 and 50 g K_2O per vine per year was recommended for the 4 year old orchards for north eastern states. For Kaveri hybrid, 100 g N, 50 g P_2O_5 and 100 g K_2O per vine per year was recommended. They also stated that higher yield of passion fruit in Coorg conditions might be due to the favourable pH (5.8-6.2) existing there. Nitrogen should be applied in 3 split doses in the months of February-March, July-August and October -November along with farmyard manure, evenly spread in a circle of 45-50 cm radius around the stem. Phosphorus and potassium should be given in the two split doses. Sufficient moisture in soil at the time of fertilizer application ensures better use efficiency. In addition to this, 2-3 sprays of 0.50 per cent urea can be given during summer months. The foliar application of micronutrients had been recommended for deficient areas. Surveys have been made to identify the nutrition disorders in passion fruit. The leaf nutrient concentration of passion fruit grown in Nagaland, Mizoram and Manipur in relation to fruit yield/vine showed that vines were severely under fertilized due to sub-optimum concentration of most of the nutrients (Tripathi, 2018).

In an experiment to find the adequate nutritional status for passion fruit, it was recommended that a dose of 36 g $hole^{-1}$ $year^{-1}$ of P_2O_5 should be applied, whether simple or triple superphosphate (Santos *et al*., 2018).

According to Borges *et al*. (2003) passion fruit requires more potassium than nitrogen. As per the reports of Kondo and Higuchi (2013), increased P application increased the Ca absorption in passion fruit.

Potassium plays an important role in the absorption of mineral nitrogen, and in soils which are deficient in K, N efficiency is reduced in plants (Ruan and Gerendas, 2015).

Ca, Mg and S are elements which are taken up by plants in lesser quantities compared to NPK, so they are termed as secondary nutrients. Compared to other divalent cations Mg is more weakly bonded to the charges in the soil (Bhindhu, 2017). Mg is more mobile in the soil compared to Ca. Ca and Mg are present as divalent cations in the soil water phase and on cation exchange sites. Both Ca and Mg are taken up by plants in the cationic form (Bhindhu, 2017).

Ca plays an important role in cell division, cell elongation and maintenance of cell membrane balance. Middle lamella in the cell wall is made up of Ca pectate. Since Ca is immobile in the phloem, older tissues cannot supply Ca to growing regions in the case of Ca deficiency. In Ca deficient soils, root growth of plants are affected and roots are prone to diseases. At low pH, Ca protects from the adverse effect of H^+ ions in the plasma membrane. In acidic soils, Ca deficiency limits the root elongation process (Bhindhu, 2017).

According to Bhindhu (2017) under acidic soil conditions of Kerala, Ca and Mg uptake in plants is affected by soluble/ exchangeable Al and Mn. High rainfall prevailing in the state, results in leaching of bases and accumulation of Al, Fe and Mn. The weathered tropical soils of Kerala is deficient in P, Ca, Mg and toxicity of Al and Mn.

Mg is an important component in the chlorophyll molecule which maintains the integrity of ribosome and stability of nucleic acids (Shaul, 2002). According to Cakmak *et al.* (1994) 35 per cent of total Mg is bond to chloroplast and its deficiency is shown as inter veinal chlorosis in older leaves.

Increased supply of phosphatic fertilizers enhanced N and Mg absorption but decreased K uptake in citrus fruits as reported by Embleton *et al.* (1963).

The N content was 1.56-7.98 per cent in index leaves (youngest fully expanded leaf plus next 9 older leaves) in passion fruit. When concentration of N in the index leaves was 4.5-5.5 per cent, growth and productivity was enhanced (Menzel *et al.*, 1991).

According to Menzel *et al.* (1993), 0.15 - 0.25 per cent was the P content recommended for good productivity in passion fruit plants.

Increased application of K deteriorated the fruit quality in passion fruit (Kondo and Higuchi, 2013).

According to Kondo and Higuchi (2013), leaf P content of 0.21 per cent was recommended for optimum productivity in passion fruit.

In another study, application of NO_3-N showed highest leaf K content and lowest leaf Ca content in passion fruit vines (Moura *et al.*, 2017).

According to the reports of Seng *et al.* (2006), liming did not show any advantage in increasing the soil pH. Crop response to liming is mainly due to the neutralization of Al toxicity. Excess of Al in soil solution have adverse effect on root growth and retards the uptake of nutrients and water by plants.

Liming helps to increase soil pH to neutrality, which increases the bacterial activity, especially nitrifying bacteria, which improve the mineralization of organic matter and release of elements like N, P and S into the soil solution (Bhindhu, 2017).

As per the reports of Frageria and Santos (2008), with increasing soil pH, available P content also increased linearly in Brazilian oxisols.

According to Fageria *et al*. (2008) an increasing response of applied P was observed with increased rate of lime application. This is attributed due to the increased supply of P and enhanced ability of plants to P when Al toxicity was reduced by the application of lime. Barman *et al.* (2014), reported that liming improved available N, P, Ca, Mg, S and Zn in the soil.

According to Deshmukh *et al*. (2017), 5.5 to 6.5 is the suitable pH for passion fruit cultivation.

In an experiment conducted by Kondo *et al*. (2017), higher photosynthetic rate, leaf nitrogen and phosphorus content were observed in pH of 4.7 and 5.4, while in alkaline soil with pH 7.4, vegetative growth showed a decline, which made them to a conclusion that acidic soil is preferred by passion fruit.

Similar finding had been reported by Niwayama and Higuchi (2019). According to them, soil with pH 3.5 promoted root growth after root pruning, which could enhance the vegetative growth of passion fruit. According to them at a high pH of 6.5, number of nodes, number of leaves, leaf area, photosynthetic rate and root dry weight were the lowest. According to them, the reduced root weight might have resulted in water deficiency in plants. These results suggested that stomatal closure caused by water deficiency have reduced the photosynthetic rate at higher pH. Finally, the decreased photosynthetic rate might have resulted in the declined vegetative growth at higher pH.

In a study conducted by Katakura and Yokomizo (1995) in blueberries, the total sugar content was higher in blueberries grown in solution culture of pH 3.5 compared to berries grown in solution culture with pH >4.5.

2.3.1 Effect of different levels of nutrients on growth and performance of fruit plants

N is an important element in crop nutrition and continuous supply of N is required even in fertile soils for better growth and development of the crop.

Increased pseudostem girth in banana has been reported with increased doses of K upto 600 g K_2O plant^{-1} (Sindhu, 1997). According to Geetha (1998), increasing levels of N applied in banana upto 190 g plant^{-1} significantly increased plant girth. According to Tirkey *et al*. (1998), with increasing levels of N from 100 g to 300 g plant^{-1} in banana significantly increased bunch weight. Geetha and Nair (2000) reported that higher levels of N @ 143 and 190 g plant^{-1} significantly increased fruit weight compared to lower levels of N @ 95 g plant^{-1}.

According to Borges *et al.* (2007) potassium deficiency delayed flowering process and decreased production, including fruit size, in passion fruit.

According to Miyake *et al*. (2018), in yellow passion fruit, maximum productivity of 19.84 tons ha^{-1} has reached, by the application of 300 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}.

In an experiment to study the effect of irrigation and mulching on growth, yield and quality of passion fruit (*Passiflora edulis* Sims.), among the two varieties studied, Kaveri had taken more number of days to flower (263.75 days) than Purple (235.55 days). The more number of days taken for flowering might be due to very low temperature prevailed during the winter months (Rao *et al.*, 2013).

With respect to days taken for flower initiation after transplanting, the minimum days taken for flower initiation (210.42 days) was recorded in the treatment with application of 250:125:125 NPK g vine^{-1} and the maximum days taken for flower initiation (265.68 days) was observed in absolute control (Mehta *et al*., 2016).

The minimum days taken for fruiting after transplanting (272.61days) was recorded with the application 250:125:120 g NPK + 1.2 g boron and the maximum number of days (297.22) was recorded in absolute control.

Araújo *et al*. (2006) found that among different doses of K, 6 mmol L^{-1} of K produced bigger fruits and yield plant^{-1}.

Freitas *et al*. (2006) studied the deficiencies of macronutrients and boron in yellow passion fruit and found that the lack of Mg, N, P and S in the nutrient solution resulted in the lowest number of fruits per plant (0, 2, 3 and 4, respectively), compared to the control (10 fruits).

In a study conducted by Chapagain and Wiesman (2004), it was found that days to maturity enhanced by increased application of P in tomato.

Araujo *et al.* (2006) reported that time to fruit maturity was shortened by 25 days, when K concentration was increased from 1 to 8 mmol L^{-1} in passion fruit.

In an experiment to study the effect of increased doses of phosphatic fertilizers, Kondo and Higuchi (2013) revealed that days from pollination to fruit set was not influenced by the different levels of P and it varied from 73.40 to 75.50 days.

According to Borges *et al.* (2007) potassium deficiency delayed flowering process and decreased production, including fruit size in passion fruit, thereby, affecting fruit and juice quality.

Araujo *et al.* (2006) reported that 6 mmol L^{-1} produced heavier fruits, among different levels of K in the nutrient solution, while the thickness of rind increased with increase in K dose from 0 to 8 mmol L^{-1} in passion fruit.

Kundu *et al.* (2007), reported that with high levels of P application, weight of guava fruits increased and external appearance of fruits deteriorated with excess P application.

Rind colour development was delayed with increased P application, while wrinkling nature was not influenced by the different levels of P (Kondo and Higuchi, 2013).

Oliveira *et al.* (2017) conducted a study to compare the fruit characters of organically and conventionally grown passion fruits. Results showed that organic fruits were smaller because organic cropping system induced an oxidative stress in passion fruit, negatively influencing fruit size.

Quality of any produce is determined by factors like genetics of the variety, environmental conditions, interaction between genotype and environment and crop management practices (Wyckhuys *et al.*, 2012). Environmental conditions like climate and soil are significant in determining quality of fruits (Miranda, 2012). Environmental factors affected the physiological process like photosynthesis, transpiration, respiration, translocation of assimilates and finally metabolism of the plant, which together influence the quality of fruits (Ladaniya, 2008).

High content of mineral nutrients is found in passion fruits. In purple passion fruit 14 g $100g^{-1}$ FW Ca and 41 mg $100g^{-1}$ FW P were observed, while Ca content was low (4g $100g^{-1}$ FW) in yellow passion fruit and banana passion fruit (Martin and Nakasone, 1970).

According to Shibuya (1997), acidity of passion fruit decreased with increase in application of nitrogen. According to Borges *et al*. (2007) potassium deficiency delayed flowering process and decreased production, including fruit size in passion fruit. Thereby, affecting fruit and juice quality. Freitas *et al.* (2006) found that TSS was low in fruits deficient in N, P and K content. Lack of N, K and S in the nutrient solution resulted in a reduction in ascorbic acid content.

Araujo *et al.* (2006) reported that with increase in K dose from 0 to 8 mmol/L, vitamin C content also increased. According to Kundu *et al*. (2007) application of P increased the acidity content in guava fruits. As per the reports of Kondo and Higuchi (2013), increased application of P, affected the fruit quality in passion fruit. They also found that acidity was 2.73 per cent with excess of P, which was significantly higher than 2.44 per cent in control.

In a study conducted by Pertuzatti *et al.* (2015) to compare the contents of tocopherols, ascorbic acid and carotenoids in yellow passion fruit grown under two cultivation systems *viz*. organic system and a conventional system, it was found that the amount of total ascorbic acid was 2.3×10^2 and 1.9×10^2 mg $100g^{-1}$ in the samples from the organic and conventional systems respectively. The quantification of individual carotenoids in the organic and conventional grown passion fruit was 13.99 mg $100g^{-1}$ and 25.10 mg $100g^{-1}$ respectively. The conventional passion fruit contained double the content of the carotenoids present in the organic fruits, β-Criptoxanthin was the main carotenoid found in both the fruits.

Oliveira *et al.* (2017) conducted a study to compare the quality characters of organically and conventionally grown passion fruits and reported that organic fruits were having higher soluble solid contents and a lower acidity. At colour breaker stage, PAL activity was 24 per cent higher in organic fruits than in conventional fruits, although, total phenolic content was higher in conventional fruits harvested at both breaker (36.14 mg GAE 100 g^{-1}) and ripe (36.47 mg GAE 100 g^{-1}) stages. Organic fruits showed significantly greater lipid peroxidation degree of biological membranes, also higher ascorbate peroxidase activity and vitamin C contents. Results indicated that organic cropping system induced the antioxidant defense mechanism, through enhancement of vitamin C and antioxidant enzyme activity.

2.4 Propagation studies using stem cuttings in fruit crops

Zimmerman and Hitchcock (1935) reported that higher number of nodes in the cuttings of vine crops resulted in higher root production. Singh and Singh (1972) reported that the combination of four noded cuttings and 800 ppm NAA was superior to other treatments because of the rooting cofactor in its stem or due to the inherent rooting capacity of the species. Basu and Ghosh (1974) reported that superiority in root length could be due to higher C: N ratio in the tissues of cuttings and higher food reserves in the cuttings.

According to Gonzalez *et al.* (1989), 99.89 per cent rooting was observed after 7 days from planting in cuttings of 20-30 cm length, with 2-3 nodes, when placed in medium black polythene bags.

Synthetic plant growth regulators were found to induce rooting in cuttings (Hartman *et al.*, 2002). Sevik and Guney (2013) found that the auxin group hormones (IAA, IBA, and NAA) have an apparent effect on morphological characteristics of the newly generated plants of *Melissa officinalis*, especially in root generation. As per the investigation by Sevik and Guney (2013) it is reported that the cuttings with at least one bud must be used for the successful propagation of *Melissa officinalis* using stem cuttings.

Hardwood and softwood cuttings of *Vitis aestivalis* Michx. ‘Norton’ were rooted under intermittent mist using different concentrations of NAA and IBA by Keeley *et al.* (2002). Eventhough there was little increase in per cent rooting above 22.29 mM IBA or 20.72 mM NAA root number increased linearly on cuttings treated with up to 44.58 mM IBA or 41.44 mM NAA.

In a study conducted in grape cuttings by Mohamed (2005), the highest per cent of established cuttings was reported from untreated basal cuttings, and terminal and medium cuttings treated with 2000 ppm IBA.

According to Singh *et al.* (2014) stem cuttings of *Morus alba* when treated with 1000, 1500 and 2000 mg l^{-1} of IBA and NAA solutions by quick dip method number of sprouted cuttings, length of the roots/cutting, per cent of rooted cutting and lengths of root were higher in IBA 2000 mg l^{-1}.

Ali *et al.* (2017) reported that treating kiwi cuttings with IBA 3500 ppm and paclobutrazol 500 ppm resulted in high rooting per cent (63.33 %), number of primary roots, number of secondary roots, average root length, length of longest root, diameter of longest root, root mass and survivability of rooted cutting.

Ghosh *et al.* (2017) conducted a study at West Bengal to assess the effect of various concentrations of IBA and NAA on the rooting and shooting of hardwood cutting of Phalsa. The study revealed that dipping hard wood cutting in IBA 200 ppm for 24 hours resulted in maximum rooting (70.55 %), root number (40.85) and root length (27.47 cm). Hard wood cuttings treated with IBA 200 ppm (37.82 %) followed by NAA 200 ppm (30.47 %) was found superior over all the treatments in case of field survival.

According to Ahmed *et al.* (2017) in grape cuttings maximum mean number of sprouts per cutting, leaves per cutting, roots per cutting and fresh weight of roots was achieved when treated with NAA 1000 mg l^{-1}.

Rolaniya *et al.* (2018) reported that 2000 ppm IBA was found best for maximum rooting, growth and success of grape cuttings.

2.4.1 Propagation studies using stem cuttings in passion fruit

In the propagation study conducted at CHES, Chettalli, it was found that NAA was more effective auxin for promoting root and different root characters in passion fruit semi-hardwood cuttings compared to IBA (Kumar *et al*., 2008).

Three noded cuttings performed better in respect to length of shoot and number of roots, while four noded cuttings showed better response in terms of survival per cent as reported by Bemkaireima *et al*. (2012). According to Bemkaireima *et al*. (2012), interaction effect of four noded cuttings treated with IBA showed superiority with respect to survival per cent. They also reported that number of leaves (6.53), total leaf area (55.9 cm^2) and survival per cent (45) were highest in four noded cuttings.

Treating cutting with 200 ppm NAA for very short period or 80 ppm NAA for 12 hours increased the rooting in stem cuttings (Tripathi *et al*., 2014).

According the reports of PRS (2015), three to four noded cuttings gave the maximum success in passion fruit propagation in which buds started sprouting after 21 days of planting. On an average, stem cuttings started rooting in twenty to thirty days. However, all the sprouted buds were not successful in sustaining the growth, showing a reduction in survival per cent with the passage of time. The highest number of sprouts was recorded on the 28th day after planting, which decreased slowly. After 36 days of planting, the final survival was 46.60 per cent. Regular irrigation to maintain 100 per cent relative humidity was important because of rapid loss of water from the vine cuttings.

Deshmukh *et al*. (2017) reported that a high yielding mother vine with good quality fruits and free of viral diseases should be selected for taking stem cuttings. The cuttings were planted in nursery beds/polythene bags having suitable potting media during July-August and in December-January. Rooting initiated in 30 days and the sprouted cuttings could be transplanted to the main field after three months. According to Deshmukh *et al*. (2017), mature 25-30 cm long stem cutting with 3 nodes, of pencil thickness, should be selected and the basal part of the cutting should be right at the node and the terminal part should be slightly above the node and with one leaf. Rooting may be hastened by hormone treatment of cuttings with IBA formulations like rootone/rootex/seradix B powder (Deshmukh *et al*., 2017).

According to Tripathi (2018), 30-35 cm long mature portion of the vines having 3 to 4 nodes selected for the cutting gave best results.

Materials and methods

3. MATERIALS AND METHODS

The present study on "Production technology and crop improvement of passion fruit (*Passiflora edulis* Sims.)" was conducted at the Department of Fruit Science, College of Horticulture, Vellanikkara, Thrissur, during 2018 - 2020. The details of experimental site, the materials used and methods adopted are discribed in this chapter. The present investigation comprised of four experiments as listed below.

Experiment 1. Performance evaluation of cultivars/ genotypes

Experiment 2. Hybridization/ selfing studies in selected parents

Experiment 3. Standardization of nutrient management techniques

Experiment 4. Standardization of propagation techniques

3.1 Performance evaluation of cultivars/ genotypes

Eight different accessions from research stations and farmers' fields were collected from different parts of Kerala. These accessions were evaluated for flower and fruit characters including yield and quality parameters.

3.1.1 Location

The experiment 'Performance evaluation of cultivars/ genotypes' was conducted at Fruits Crops Research Station, Kerala Agricultural University, Vellanikkara. The experimental site was situated at 10˚ 31' North latitude and 76˚ 3' East longitude and at an altitude of 22.25 m above mean sea level, with typical warm humid tropical climate of Kerala.

3.1.2 Experimental Design and Layout

Design	: RBD
Treatments	: 8
Replication	: 3
Number of plants /replication	: 4
Spacing	: 4m×4m
Plot Size	: 16m^2

3.1.3 Field planting and cultural practices

Rooted cuttings of three month old was planted in September 2018 at a spacing of 4m x 4m and the cultural practices were followed as per the Adhoc Package of Practices Recommendations by PRS, Vazhakulam (PRS, 2011). General view of the experimental field is given in Plate 1, 2, 3 and 4.

3.1.4 Materials

Eight different accessions (yellow and purple types) of passion fruit were collected from different parts of Kerala used as material for the experiment are listed in Table 1.

3.1.5 Main items of observations

Observations were recorded for one year from all the plants in each replication and the average was worked out for statistical analysis. The fruits were harvested at maturity when they showed colour change, turning yellow or purple depending on the type.

3.1.5.1 Vegetative characters

3.1.5.1.1 Stem girth (cm)

Girth of main branch was recorded using a thread at 15 cm above soil surface and measured using a scale and expressed in cm.

3.1.5.1.2 Number of branches

Number of branches arising below the pandal level was counted and recorded.

3.1.5.2 Flower characters

Observations on flower characters like time of anthesis, days from flower bud initiation to anthesis, days from anthesis to fruit set, per cent fruit set, pollen viability, pollen storage and stigma receptivity were recorded when the plants started flowering.

3.1.5.2.1 Time of anthesis

Flower opening was recorded at hourly intervals during a 12 hour cycle to find out the peak time of anthesis.

3.1.5.2.2 Days from flower bud initiation to anthesis

Days taken from flower bud initiation to the day of anthesis was observed and recorded.

3.1.5.2.3 Days from anthesis to fruit set

Number of days taken from anthesis to fruit set was recorded.

3.1.5.2.4 Per cent fruit set

Per cent fruit set was calculated using the following formula,

Fruit set (%) = (Number of fruits/Total number of flowers) x 100

Plate 1. Field planting of different passion fruit accessions

Plate 2. Field establishment of different passion fruit accessions

Plate 3. Field establishment of passion fruit accessions at three month stage

Plate 4. Fruiting stage of passion fruit accessions

Table 1. Passion fruit accessions collected from different parts of Kerala

Accession	Type	Place of collection
Acc. 1 (T_1)	Purple	Kuthukuzhi, Ernakulam
Acc. 2 (T_2)	Purple	Vazhakulam, Ernakulam
Acc. 3 (T_3)	Yellow	Puttady, Idukki
Acc. 4 (T_4)	Purple	Kovilkadavu, Idukki
Acc. 5 (T_5)	Purple	Ambalavayal, Wayanad
Acc. 6 (T_6)	Yellow	Ambalavayal, Wayanad
Acc. 7 (T_7)	Yellow	Madakkathara, Thrissur
Acc. 8 (T_8)	Purple	Pazhayanoor, Thrissur

3.1.5.2.5 Pollen viability

Pollen viability was worked out by counting the normal well stained pollen grains and expressed in percentage. Acetocarmine one per cent solution was prepared in water and two drops were dropped on a microscope slide. Then, pollen was dusted over it and covered with a coverslip and observed under a phase contrast microscope and the pollen grains were counted.

Viability was calculated as the percentage of normal, well stained pollen grains to the total number of pollen grains in each slide.

Pollen viability (%) = (Number of viable pollen/ Total number of pollen) x 100

3.1.5.2.6 Stigma receptivity

Selected flowers were observed at flower opening to find out whether stigma was receptive or not.

3.1.5.2.7 Pollen storage

To find the optimal storage conditions for pollen with minimum reduction in pollen viability at the time of anthesis, pollen was collected irrespective of the accessions and subjected to storage under different atmospheric conditions. The study was conducted by storing pollen in different environmental condition as given below.

T_1 - Keeping over calcium chloride in a dessicator at room temperature

T_2 - Keeping in refrigerator at 4°C

T_3 - Keeping over calcium chloride in a dessicator under refrigerated condition at 4°C

T_4 - Keeping at room temperature

Pollen viability test was done after 24, 48 and 72 hours by acetocarmine staining technique and expressed in per cent.

3.1.5.3 Yield characters

3.1.5.3.1 Number of flowers/vine/month

Number of flowers produced in a vine in a month was counted and recorded.

3.1.5.3.2 Number of fruits/vine/month

Number of fruits produced per month in a vine was counted and recorded.

3.1.5.3.3 Total flower production/vine

Total number of flowers produced per vine was calculated by counting the flowers produced from a single plant in a year.

3.1.5.3.4 Total fruit production/vine

Total number of fruits which were set per vine was calculated by counting the number of fruits produced from a single plant in a year.

3.1.5.3.5 Peak flowering month

Peak flowering month was identified as the month which had the highest flower production.

3.1.5.3.6 Peak fruiting month

Peak fruiting month was identified as the month which had the highest fruit production.

3.1.5.3.7 Days taken for first flowering

Time taken for first flowering was recorded from the date of planting to visual flower emergence and expressed in days.

3.1.5.3.8 Days taken for first fruiting

Time taken for first fruiting was recorded from the date of planting to visual fruit set and expressed in days.

3.1.5.3.9 Duration of vegetative phase (days)

Time taken for first flowering was recorded from the date of planting and expressed in days as duration of vegetative phase.

3.1.5.3.10 Flowering to harvest duration (days)

Time taken from flowering to harvest was recorded and expressed in days as duration of flowering to harvest.

3.1.5.4 Fruit characters

3.1.5.4.1 Rind colour

Fruit rind colour was expressed as purple or yellow based on external colour appearance.

3.1.5.4.2 Pulp colour

Pulp colour was expressed as yellow or orange based on external pulp colour appearance.

3.1.5.4.3 Fruit girth (cm)

Fruit girth was measured using a thread and expressed in centimeters.

3.1.5.4.4 Fruit diameter (cm)

Diameter of the fruit was measured and expressed in centimeters.

3.1.5.4.5 Fruit weight (g)

Fruit weight was taken using a weighing balance and expressed in grams.

3.1.5.4.6 Pulp weight (g)

The pulp weight was measured using a weighing balance after extracting the pulp and expressed in grams.

3.1.5.4.7 Juice weight (g)

The juice weight was measured using a weighing balance after extracting juice from the pulp and expressed in gram.

3.1.5.4.8 Seed weight (g)

Juice weight was subtracted from total extracted pulp weight to obtain the seed weight and expressed in grams.

3.1.5.4.9 Rind weight (g)

Weight of rind was taken using weighing balance and expressed in gram.

3.1.5.4.10 Rind thickness (cm)

Rind thickness was measured using digital vernier caliper and was expressed in centimeters.

3.1.5.4.11 Physical composition (%)

Each physical component, *viz.,* rind, juice and seed were weighed separately and their proportions to the total weight of the fruit were expressed as given below.

Physical composition (%) = (Weight of physical component/ Weight of fruit) x 100

3.1.5.5 Quality parameters

Ripe fruits of each accession were subjected to quality analysis.

3.1.5.5.1 Total Soluble Solids (TSS)

Total Soluble Solids was recorded using a hand refractometer and expressed in degree brix (Ranganna, 1997).

3.1.5.5.2 Titrable acidity (%)

Titrable acidity was determined by the procedure proposed by Ranganna (1997) and the mean value was expressed as per cent anhydrous citric acid.

3.1.5.5.3 Total sugars (%)

The total sugar content of the samples was determined by using the method described by AOAC (1998) and expressed as per cent on fresh weight basis.

3.1.5.5.4 Reducing sugar (%)

The content of reducing sugars in the samples was estimated by using the method prescribed by AOAC (1998) and expressed as per cent on fresh weight basis.

3.1.5.5.5 Non reducing sugar (%)

The non reducing sugar content was estimated by deducting the values of reducing sugars from the values of total sugars and the mean values were expressed in per cent (Ranganna, 1997).

3.1.5.5.6 Sugar/acid ratio

The value of total sugar was divided by the value of acidity to compute sugar/acid ratio.

3.1.5.5.7 Ascorbic acid (mg per 100g)

Ascorbic acid was estimated as per the procedure suggested by AOAC (1998) and expressed mg per 100g.

3.1.5.5.8 Total carotenoids (mg per 100g)

Carotenoids were estimated using the procedure suggested by Saini *et al.* (2001) and expressed as mg per 100g.

3.1.5.5.9 Shelf life of fruits at ambient conditions (days)

Number of days from ripening to the stage when fruit skin shrinks and became unsuitable for consumption was recorded as shelf life of fruits at ambient condition.

3.1.5.5.10 Organoleptic evaluation

Organoleptic evaluation of fruits was done by a ten member panel of judges belonging to the age group of 18-40 years as suggested by Jellinek (1985). Pulp taken from each treatment was evaluated for appearance, colour, taste, after taste, odour, flavour, texture and overall acceptability. The scores were given using a nine point hedonic scale as per procedure given by Srivastava and Kumar (2002). Hedonic scale rating method measures the level of liking of any product based on a test which relies on the people's ability to communicate their feelings of like or dislike.

Like extremely - 9

Like very much - 8

Like moderately - 7

Like slightly - 6

Neither like nor dislike - 5

Dislike slightly - 4

Dislike moderately - 3

Dislike very much - 2

Dislike extremely - 1

3.1.5.6 Meteorological observations

Monthly observations on temperature (ºC), relative humidity (%) and rainfall (mm) were recorded during the experimental period.

3.1.5.7 Incidence of major pests and diseases

Incidence of major pests and diseases was monitored throughout the cropping period.

3.1.6 Statistical analysis

Observations were recorded on physico-morphological and biochemical characters and data were analysed statistically in Randomized Block Design and significance was tested using analysis of variance technique (Panse and Sukhatme, 1985).

For organoleptic analysis, the different scores given by 10 judges in the sensory panel were analysed using the Kruskall – Wallis test to get the mean rank values for all the treatments (Sidney, 1988).

3.2 Hybridization/selfing in selected parents

Hybridization work was undertaken among six selected superior parents based on preliminary evaluation, at Malanadu passion fruit plantations, Puttady, Idukki. General view of Malanadu passion fruit plantation is shown in Plate 5 and 6. These six parents were crossed following full diallel mating design. Passion fruit flower bud and flower are shown in plates 7, 8, 9 and 10. Selfing was also done in all the selected parents. The flower buds or open flowers chosen were healthy and well formed. Flower buds to be pollinated were emasculated, on previous day evening and flower buds were bagged before anthesis to avoid undesirable pollination. Flower buds were transversely opened with the aid of a pin, eliminating together parts of sepals, petals and corona filaments using scissors, removing the immature anthers preserving only the stigma, attached to the filament. Pin and scissors were sterilized in 70 per cent alcohol before using them. Pollen was collected from required parent at the time of anthesis. Stigmas were pollinated by rubbing the collected pollen over them with the help of tooth picks at the time of flower opening. After pollinating, flowers were bagged again. The fruit set was observed after 4 days of pollination. Plates 11 and 12 shows the procedure of emasculation, pollination and bagging. Different stages of fruit development are shown in plate 13. The fruits were harvested 70 days after pollination. Plates 14 to 19 shows the different successful hybrids developed at Puttady, Idukki. Parents selected for hybridization studies are given below:

Parent 1- Purple coloured accession (P_1)

Parent 2 - Purple coloured accession (P_2)

Parent 3 - Purple coloured accession (P_3)

Parent 4 - Purple coloured accession (P_4)

Parent 5 - Purple coloured accession (P_5)

Parent 6 - Yellow coloured accession (P_6)

Hybridization and selfing work resulted in successfully evolving nine hybrids for further evaluation. This experiment consisted of two parts; basic evaluation of hybrids for 3 months at nursery level and field level evaluation of hybrids along with parents for identifying superior hybrids.

3.2.1 Basic evaluation of hybrids/selfed progeny in the nursery

Seeds were extracted from the hybrids obtained in the crosses and the selfed progeny and sown in the nursery in grow bags and observations were taken upto three months in the nursery. Germinated hybrid seedlings are shown in Plate 20.

3.2.1.1 Experimental Design and Layout

Design	: CRD
Treatments	: 9 (8 hybrids + 1 selfed)
Replications	: 3
Number of seeds /replication	: 30

3.2.1.2 Treatment details

Eight hybrids and one selfed progeny obtained from the hybridization programme were as follows.

S_1 - P_3 x P_3

H_1 - P_3 x P_6

H_2 - P_4 x P_2

H_3 - P_4 x P_6

H_4 - P_5 x P_4

H_5 - P_6 x P_1

H_6 - P_6 x P_2

H_7 - P_6 x P_4

H_8 - P_6 x P_5

3.2.1.3 Main items of observations

3.2.1.3.1 Per cent seed germination

Germination was observed up to 30 days from the day of seed sowing. Germination per cent was calculated as the mean of the three replications, each replication containing 30 seeds. Per cent seed germination was calculated using the formula, (ISTA, 1999)

Seed germination (%) = (No. of seeds germinated/Total no. of seeds sown) X 100

3.2.1.3.2 Days for germination

Time taken for germination was recorded and expressed as the number of days for germination.

3.2.1.3.3 Seedling vigour index (SVI)

Seedling vigour index was calculated using the following formula at 3MAP,

SVI= Seed germination (%) x seedling length

3.2.1.3.4 Number of leaves

Fully developed leaves were counted at 3 MAP, to get the number of leaves in the selfed and hybrid seedlings.

Plate 5. General view of Malanadu passion fruit plantations, Puttady, Idukki

Plate 6. General view of Malanadu passion fruit plantations, Puttady, Idukki

Plate 7. Passion fruit flower bud Plate 8. Passion fruit flower

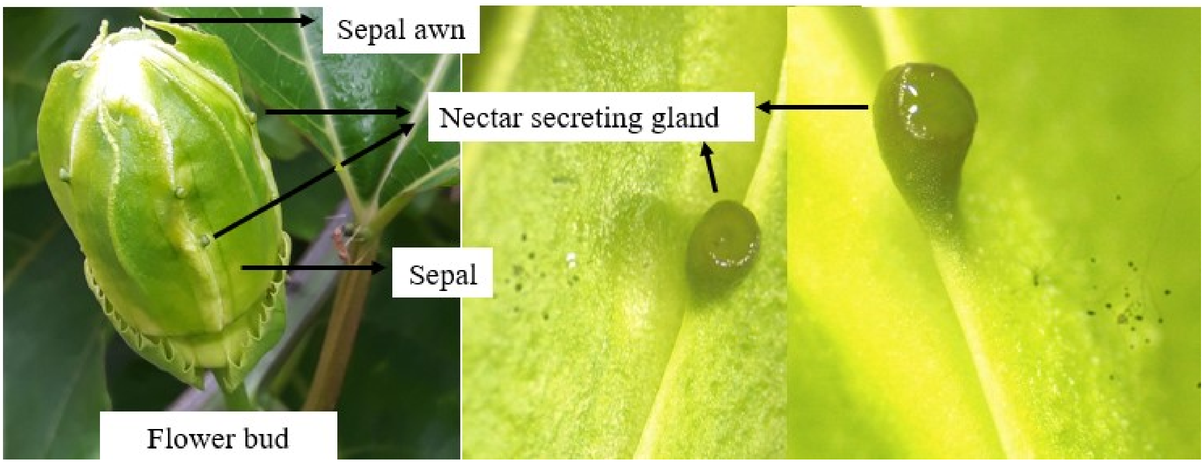


Plate 9. Passion fruit flower bud with nectar secreting glands

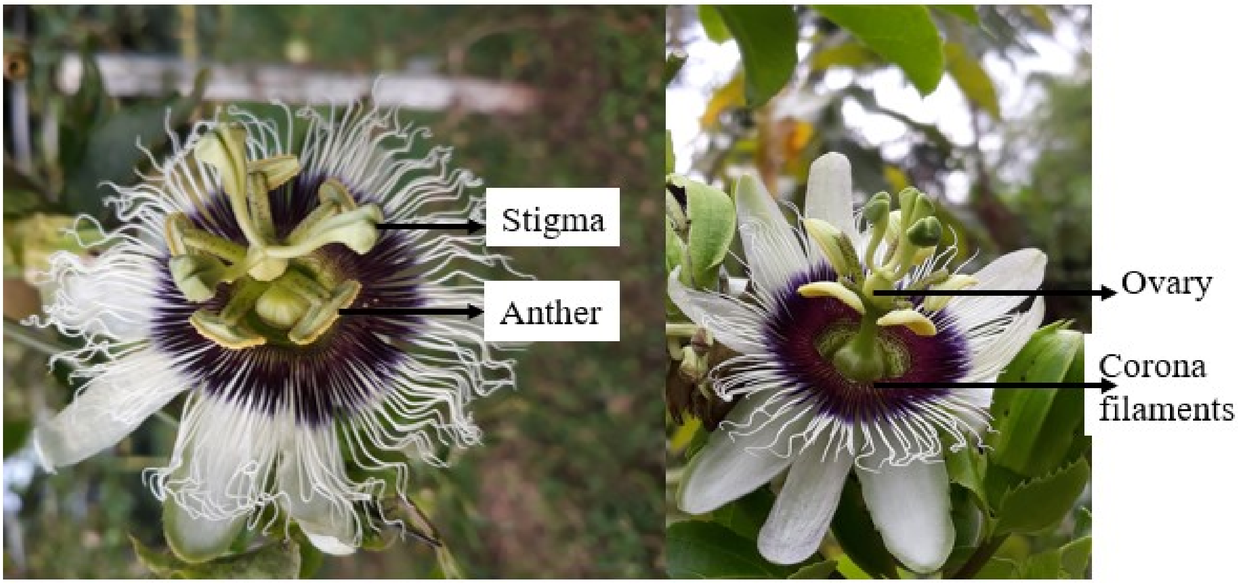


Plate 10. Parts of passion fruit flower

Plate 11. Passion fruit flower and flower bud before and after emasculation

Plate 12. Pollination and bagging of passion fruit flower in hybridization

Plate 13. Different stages of fruit development

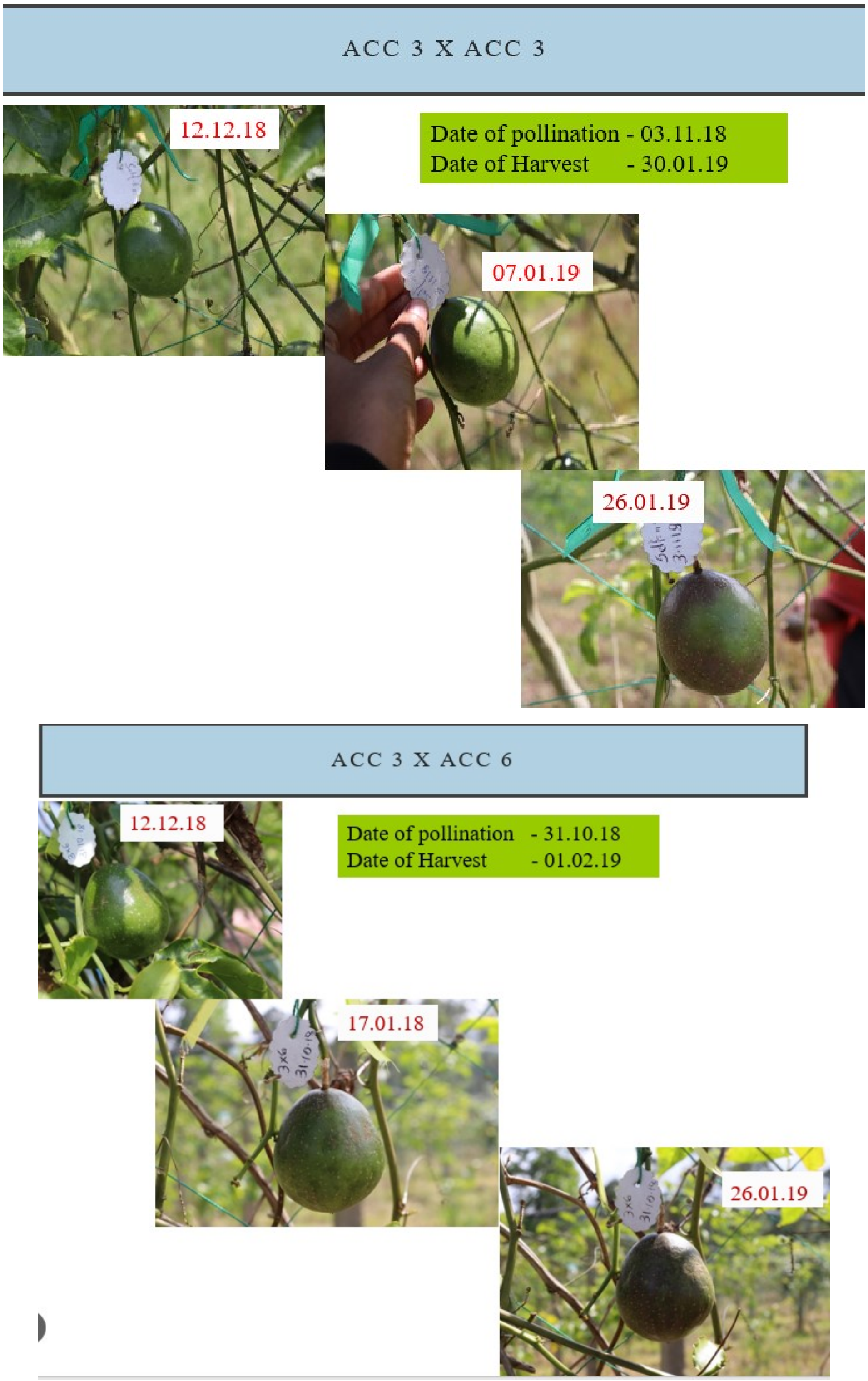


Plate 14. Different hybrids developed at Malanadu passion fruit plantations, Idukki

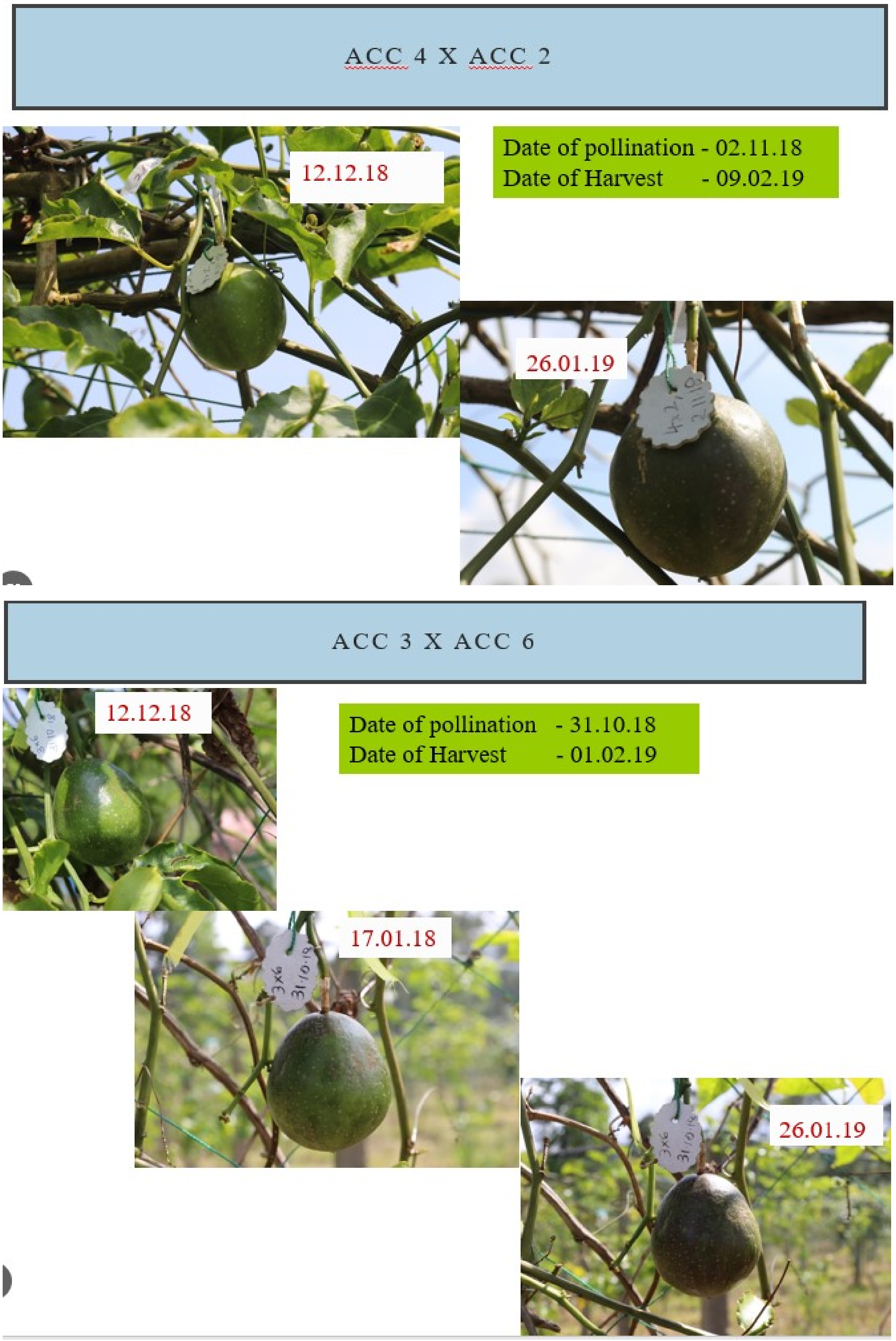
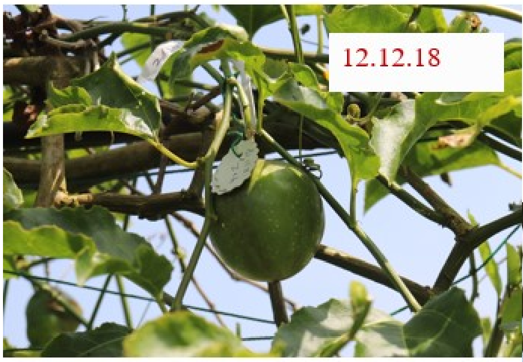


Plate 15. Different hybrids developed at Malanadu passion fruit plantations, Idukki

ACC 4 X ACC 2



Date of pollination - 02.11.18
Date of Harvest - 09.02.19

ACC 4 X ACC 6

Date of Pollination - 01.11.18
Date of Harvest - 09.02.19

Plate 16. Different hybrids developed at Malanadu passion fruit plantations, Idukki

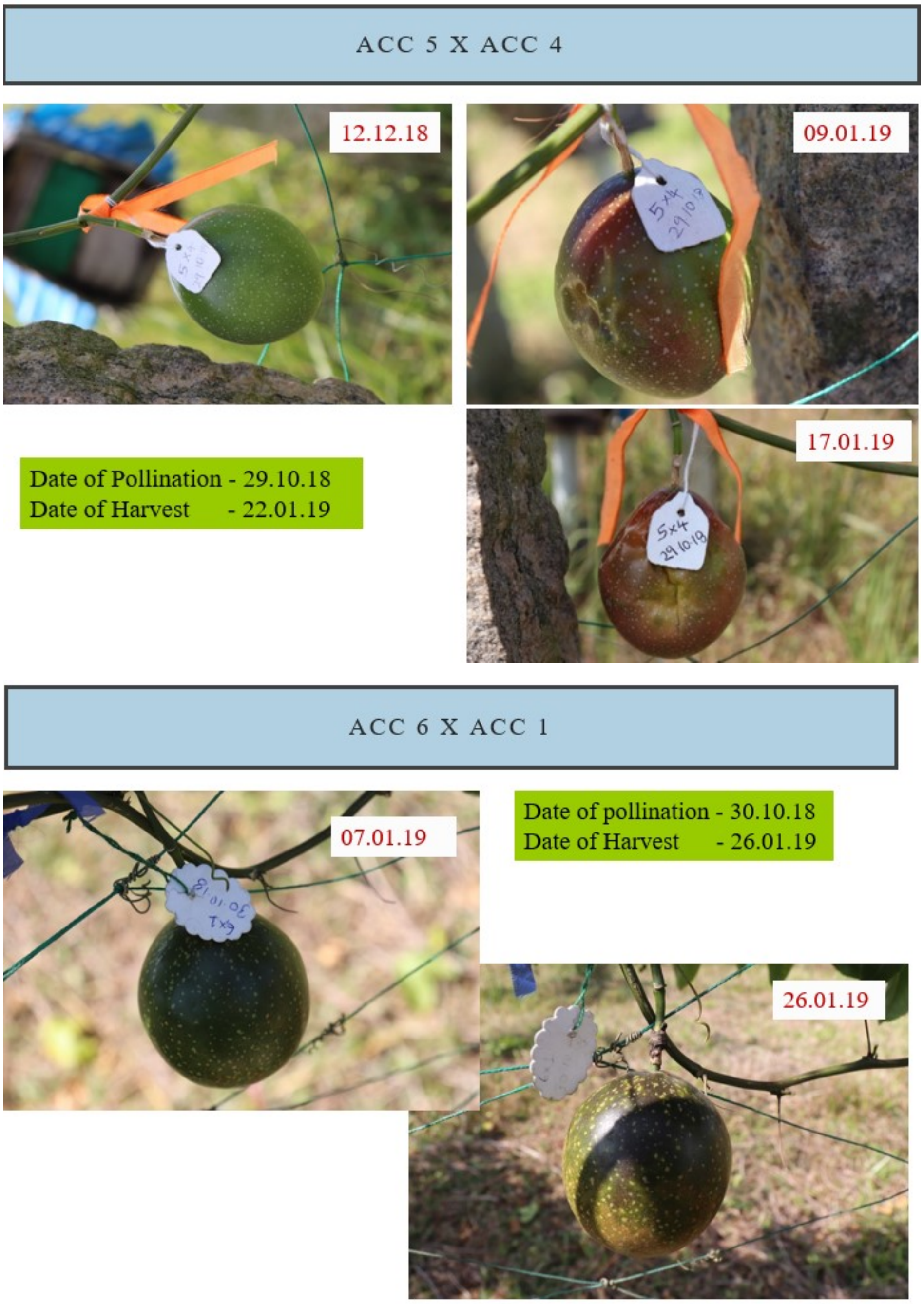


Plate 17. Different hybrids developed at Malanadu passion fruit plantations

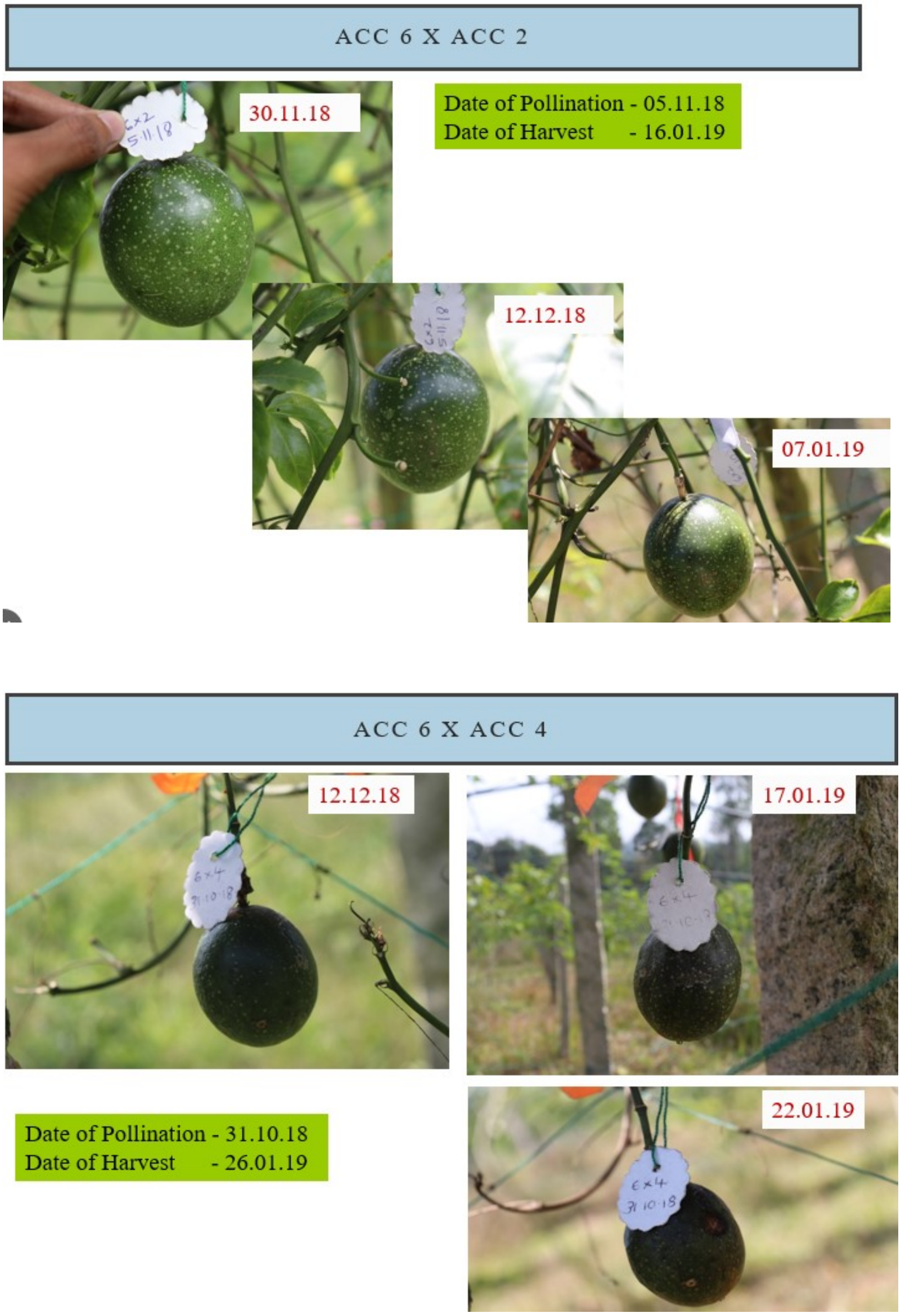


Plate 18. Different hybrids developed at Malanadu passion fruit plantations

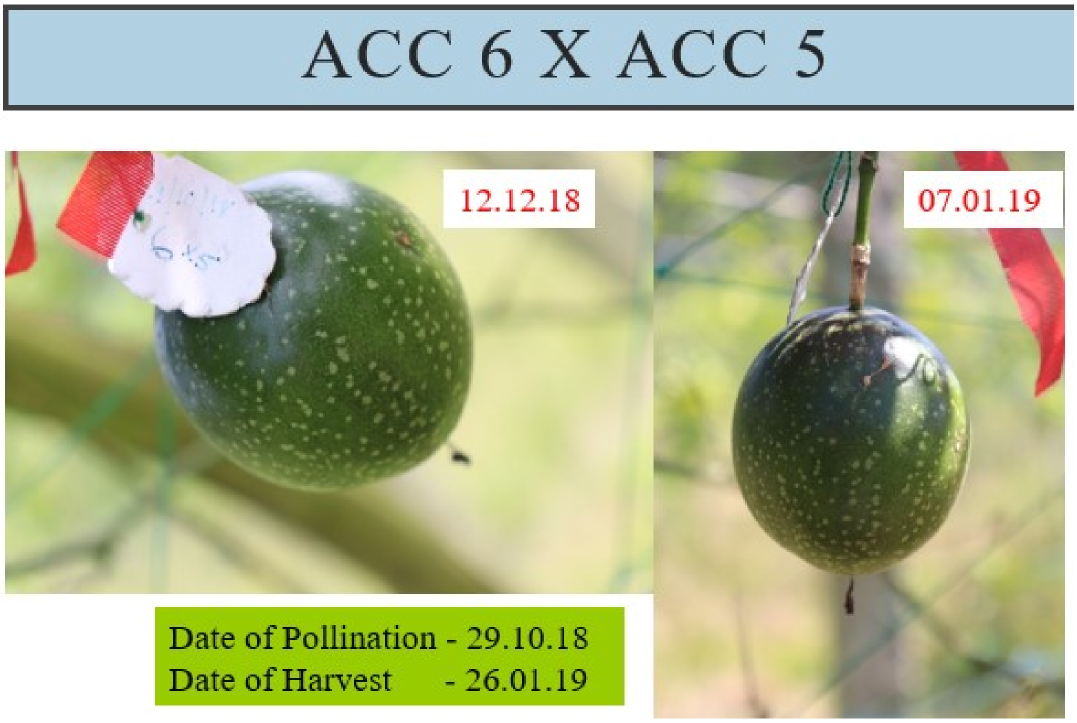


Plate 19. Different hybrids developed at Malanadu passion fruit plantations

Plate 20. Germinated hybrid and selfed seedlings

3.2.1.3.5 Total leaf area

Total leaf area was calculated by drawing the sketch of leaf in a graph paper and was expressed in cm^2.

3.2.1.3.6 Seedling height

Seedling height was measured from the point of attachment at the ground level to the tip of the plant and expressed in cm.

3.2.1.3.7 Seedling girth

Seedling girth was recorded with the help of digital calipers and expressed in cm.

3.2.1.4 Statistical analysis

Observations recorded on physico-morphological and biochemical characters were analysed statistically in Randomized Block Design and significance was tested using analysis of variance technique (Panse and Sukhatme, 1985).

3.2.2 Field evaluation of hybrids and selfed progeny

Seedlings of the hybrid and rooted cuttings of the parents were planted in the orchard, Dept. of Fruit Science, College of Horticulture, Vellanikkara during May 2019. Planting was done at a spacing of 4m x 4m and the cultural practices were followed as per the Adhoc Package of Practices Recommendations by PRS, Vazhakulam (PRS, 2011). General view of the experimental field is given in Plate 21.

3.2.2.1 Experimental Design and Layout

Design	: RBD
Treatments	: 15
Replications	: 2
Number of plants /replication	: 4
Spacing	: 4m×4m
Plot Size	: $16m^2$

3.2.2.2 Treatment details

P_1 - Parent 1

P_2 - Parent 2

P_3 - Parent 3

P_4 - Parent 4

P_5 - Parent 5

P_6 - Parent 6

S_1 - P_3 x P_3

H_1 - P_3 x P_6

H_2 - P_4 x P_2

H_3 - P_4 x P_6

H_4 - P_5 x P_4

H_5 - P_6 x P_1

H_6 - P_6 x P_2

H_7 - P_6 x P_4

H_8 - P_6 x P_5

3.2.2.3 Main items of observation

The growth of hybrids, selfed progeny and parents were monitored and observations were taken on vegetative, flower, yield and fruit characters including quality.

3.2.2.3.1 Vegetative characters

Observations on vegetative characters stem girth and number of branches 12 month after planting.

3.2.2.3.1.1 Stem girth (cm)

Stem girth was recorded as in 3.1.5.1.1.

3.2.2.3.1.2 Number of branches

Number of branches was recorded as in 3.1.5.1.2.

3.2.2.3.2 Flower characters

Observations on flower characters like time of anthesis, days from flower bud initiation to anthesis, days from anthesis to fruit set, per cent fruit set, pollen viability and stigma receptivity were taken when the plants started flowering.

3.2.2.3.2.1 Time of anthesis

Time of anthesis was observed as in 3.1.5.2.1

3.2.2.3.2.2 Days from flower bud initiation to anthesis

Days from flower bud initiation to anthesis was recorded as in 3.1.5.2.2

Plate 21. General field view of passion fruit parents, hybrids and selfed seedlings

3.2.2.3.2.3 Days from anthesis to fruit set

Days from anthesis to fruit set was observed as in 3.1.5.2.3.

3.2.2.3.2.4 Per cent fruit set

Per cent fruit set was measured as in 3.1.5.2.4.

3.2.2.3.2.5 Pollen viability

Pollen viability was recorded as in 3.1.5.2.5.

3.2.2.3.2.6 Stigma receptivity

Stigma receptivity was recorded as in 3.1.5.2.6.

3.2.2.3.3 Yield characters

3.2.2.3.3.1 Number of flowers/vine/month

Number of flowers was counted as in 3.1.5.3.1.

3.2.2.3.3.2 Number of fruits/vine/month

Number of fruits was counted as in 3.1.5.3.2.

3.2.2.3.3.3 Total flower production/vine

Total flower production was recorded as in 3.1.5.3.3.

3.2.2.3.3.4 Total fruit production/vine

Total fruit production was recorded as in 3.1.5.3.4.

3.2.2.3.3.5 Peak flowering month

Peak flowering month was identified as in 3.1.5.3.5.

3.2.2.3.3.6 Peak fruiting month

Peak fruiting month was identified as in 3.1.5.3.6.

3.2.2.3.3.7 Days taken for first flowering

Time taken for first flowering was recorded as in 3.1.5.3.7.

3.2.2.3.3.8 Days taken for first fruiting

Days taken for first fruiting was computed as in 3.1.5.3.8.

3.2.2.3.3.9 Duration of vegetative phase (days)

Duration of vegetative phase was recorded as in 3.1.5.3.9.

3.2.2.3.3.10 Flowering to harvest duration (days)

Flowering to harvest duration was recorded as in 3.1.5.3.10.

3.2.2.3.4 Fruit characters

3.2.2.3.4.1 Rind colour

Rind colour was expressed as in 3.1.5.4.1.

3.2.2.3.4.2 Pulp colour

Pulp colour was expressed as in 3.1.5.4.2.

3.2.2.3.4.3 Fruit girth (cm)

Fruit girth was measured as in 3.1.5.4.3.

3.2.2.3.4.4 Fruit Diameter (cm)

Diameter was recorded as in 3.1.5.4.4.

3.2.2.3.4.5 Fruit weight (g)

Fruit weight was recorded as in 3.1.5.4.5.

3.2.2.3.4.6 Pulp weight (g)

Pulp weight was measured as in 3.1.5.4.6.

3.2.2.3.4.7 Juice weight (g)

Juice weight was measured as in 3.1.5.4.7.

3.2.2.3.4.8 Seed weight (g)

Seed weight was calculated as in 3.1.5.4.8.

3.2.2.3.4.9 Rind weight (g)

Weight of the rind was taken as in 3.1.5.4.9.

3.2.2.3.4.10 Rind thickness (cm)

Rind thickness was measured as in 3.1.5.4.10.

3.2.2.3.5 Quality of fruits

Ripe fruits of each accession were subjected to quality analysis.

3.2.2.3.5.1 Total Soluble Solids (TSS)

TSS was determined as in 3.1.5.5.1.

3.2.2.3.5.2 Titrable acidity

Titrable acidity determined as in 3.1.5.5.2.

3.2.2.3.5.3 Total sugars (%)

Total sugar was identified as in 3.1.5.5.3.

3.2.2.3.5.4 Reducing sugar (%)

Reducing sugar was determined as in 3.1.5.5.4.

3.2.2.3.5.5 Non reducing sugar (%)

Non reducing sugar was determined as in 3.1.5.5.5.

3.2.2.3.5.6 Sugar/acid ratio

Sugar/acid ratio was determined as in 3.1.5.5.6.

3.2.2.3.5.7 Ascorbic acid (mg per 100g)

Ascorbic acid was determined as in 3.1.5.5.7.

3.2.2.3.5.8 Total carotenoids (mg per 100g)

Total carotenoids were determined as in 3.1.5.5.8.

3.2.2.3.5.9 Shelf life of fruits at ambient conditions (days)

Shelf life was studied as in 3.1.5.5.9.

3.2.2.3.5.10 Organoleptic evaluation

Organoleptic evaluation was done as in 3.1.5.5.10.

3.2.2.3.6 Meteorological observations

Monthly observations on temperature (ºC), relative humidity (%) and rainfall (mm) were recorded during the experimental period.

3.2.2.3.7 Incidence of major pests and diseases

Incidence of major pests and diseases was monitored throughout the cropping period.

3.2.2.4 Statistical analysis

Observations recorded on physico-morphological and biochemical characters were analysed statistically in Randomized Block Design and significance was tested using analysis of variance technique (Panse and Sukhatme, 1985).

For organoleptic analysis, the different scores given by 10 judges in the sensory panel were analysed using the Kruskall – Wallis test to get the mean rank values for all the treatments (Sidney, 1988).

To know the superiority of hybrids relative heterosis and heterobeltiosis were computed using the following formula proposed by Hayes *et al.* (1955).

$$\text{Relative heterosis (\%)} = \frac{\text{F1- Average performance of the parents}}{\text{Average performance of the parents}} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{\text{F1- Performance of better parent}}{\text{Performance of the better parent}} \times 100$$

The significance of difference of F1 means over mid parental value and better parent is confirmed by estimating critical difference (CD) value (Briggle, 1963).

3.3 Standardization of nutrient management technique in passion fruit

The pipeline variety 134P from Pineapple Research Station, Vazhakulam under Kerala Agricultural University, Thrissur was used for the experiment.

3.3.1 Location

The experiment was conducted at Cashew Research Station, Kerala Agricultural University, Vellanikkara. The experimental site was situated at 10˚ 31' North latitude and 76˚ 3' East longitude at an altitude of 22.25 m above mean sea level, having typical warm humid tropical climate of Kerala.

3.3.2 Experimental Design and Layout

Design	: RBD
Pipeline variety	: 134P
Treatments	: 5
Replications	: 4
Number of plants / replication	: 4
Spacing	: 4m x 4m
Plot size	: $16m^2$

Field experiment was laid out in randomized block design (RBD) with five treatments, each with four replications and four plants per replication.

3.3.3 Methodology

Planting of three month old rooted cutting was done on November, 2018, at a spacing of 4m x 4m and other cultural practices were followed as per the Adhoc Package of Practices Recommendations by Pineapple Research Station, Vazhakulam, except fertilizer application (PRS, 2011). General view of the experimental field is given in Plate 22 and 23.

3.3.4 Treatments

T_1 - 12.5 N: 5 P_2O_5:12.5 K_2O (g $vine^{-1}$)

T_2 - 25 N: 10 P_2O_5: 25 K_2O (g $vine^{-1}$)

T_3 - 37.5 N: 15 P_2O_5: 37.5 K_2O (g $vine^{-1}$)

T_4 - 50 N: 20 P_2O_5: 50 K_2O (g $vine^{-1}$)

T_5 - Absolute control

Plate 22. Field view at the time of planting

Plate 23. Field view at different stages of growth

T_2 is the Adhoc recommendation for passion fruit as per the Adhoc Package of Practices Recommendations by PRS, Vazhakulam (PRS, 2011). At the time of planting FYM @10 kg vine^{-1} and half doses of N, P_2O_5 and K_2O were applied. The remaining quantities were applied seven months after planting.

3.3.5 Main items of observations

Observations were recorded for one year, from all the plants in each replication and the average was worked out for analysis. The fruits were harvested at maturity when they showed colour change.

3.3.5.1 Vegetative characters

3.3.5.5.1 Stem girth (cm)

Stem girth was recorded as in 3.1.5.3.1.

3.3.5.5.2 Number of branches

Number of branches was recorded as in 3.1.5.3.2.

3.3.5.2 Yield characters

3.3.5.2.1 Number of flowers/vine/month

Number of flowers was counted as in 3.1.5.3.1.

3.3.5.2.2 Number of fruits/vine/month

Number of fruits was counted as in 3.1.5.3.2.

3.3.5.2.3 Total flower production/vine

Total flower production was recorded as in 3.1.5.3.3.

3.3.5.2.4 Total fruit production/vine

Total fruit production was recorded as in 3.1.5.3.4.

3.3.5.2.5 Peak flowering month

Peak flowering month was identified as in 3.1.5.3.5.

3.3.5.2.6 Peak fruiting month

Peak fruiting month was identified as in 3.1.5.3.6.

3.3.5.2.7 Days taken for first flowering

Time taken for first flowering was recorded as in 3.1.5.3.7.

3.3.5.2.8 Days taken for first fruiting

Days taken for first fruiting was computed as in 3.1.5.3.8.

3.3.5.2.9 Duration of vegetative phase (days)

Duration of vegetative phase was recorded as in 3.1.5.3.9.

3.3.5.2.10 Flowering to harvest duration (days)

Flowering to harvest duration was calculated as in 3.1.5.3.10.

3.3.5.3 Fruit characters

3.3.5.3.1 Rind colour

Rind colour was expressed as in 3.1.5.4.1.

3.3.5.3.2 Pulp colour

Pulp colour was expressed as in 3.1.5.4.2.

3.3.5.3.3 Fruit girth (cm)

Fruit girth was measured as in 3.1.5.4.3.

3.3.5.3.4 Fruit diameter (cm)

Diameter was recorded as in 3.1.5.4.4.

3.3.5.3.5 Fruit weight (g)

Fruit weight was recorded as in 3.1.5.4.5.

3.3.5.3.6 Pulp weight (g)

Pulp weight was measured as in 3.1.5.4.6.

3.3.5.3.7 Juice weight (g)

Juice weight was measured as in 3.1.5.4.7.

3.3.5.3.8 Seed weight (g)

Seed weight was calculated as in 3.1.5.4.8.

3.3.5.3.9 Rind weight (g)

Weight of the rind was taken as in 3.1.5.4.9.

3.3.5.3.10 Rind thickness (cm)

Rind thickness was measured as in 3.1.5.4.10.

3.3.5.4 Quality of fruits

Ripe fruits of each treatment were subjected to quality analysis.

3.3.5.4.1 Total Soluble Solids (TSS)

TSS was determined as in 3.1.5.5.1.

3.3.5.4.2 Titrable acidity

Titrable acidity determined as in 3.1.5.5.2.

3.3.5.4.3 Total sugars (%)

Total sugars were determined as in 3.1.5.5.3.

3.3.5.4.4 Reducing sugar (%)

Reducing sugar was determined as in 3.1.5.5.4.

3.3.5.4.5 Non reducing sugar (%)

Non reducing sugar was determined as in 3.1.5.5.5.

3.3.5.4.6 Sugar/acid ratio

Sugar/acid ratio was determined as in 3.1.5.5.6.

3.3.5.4.7 Ascorbic acid (mg per 100g)

Ascorbic acid was estimated as in 3.1.5.5.7.

3.3.5.4.8 Total carotenoids (mg per 100g)

Total carotenoids were estimated as in 3.1.5.5.8.

3.3.5.4.9 Shelf life of fruits at ambient conditions (days)

Shelf life was studied as in 3.1.5.5.9.

3.3.5.4.10 Organoleptic evaluation

Organoleptic evaluation was done as in 3.1.5.5.10.

3.3.5.5 Soil analysis

Soil samples were taken from the experimental area before and after the experiment. Before the experiment, the composite soil samples were analysed for pH, EC, organic carbon, available N, P, K, Ca and Mg. After the final harvest, composite samples were collected from each experimental plot. Samples were air dried, powdered and passed through a 2 mm sieve and analysed for pH, EC, organic carbon, available N, P, K, Ca and Mg, following standard methodology as given in Table 2.

3.3.5.6 Plant nutrient analysis

Leaf samples were collected from each plot after final harvest and analysed for total N, P, K, Ca and Mg (Table 3). According to Malavolta *et al.* (1997), third and fourth leaves from the apex of the shoot were collected to carry out the nutritional analysis. Fully developed leaves were chopped and oven dried at 70 ^{0}C for 48 hours to a constant weight. Samples were ground and passed through a 0.5 mm mesh. The required quantity of samples was digested and used for nutrient analysis.

Table 2. Methods of soil analysis followed in the experiment

Parameter	Method	Reference
Soil pH	Soil water suspension of 1:25 and reading by a pH meter	Jackson, 1958
Electrical conductivity	Soil water suspension of 1:25 and reading by an electrical conductivity meter	Jackson, 1958
Organic carbon	Walkley method	Walkley and Black, 1934
Available nitrogen	Alkaline permanganate method	Subbiah and asija, 1956
Available phosphorous	Ascorbic acid reduced molybdophosphoric blue colour method	Watanabe and Olsen, 1965
Available potassium	Neutral normal ammonium acetate using photometry	Jackson, 1958
Available calcium and magnesium	Using atomic absorption spectrophotometer	Hesse, 1971

Table 3. Methods of plant analysis followed in the experiment

Parameter	Method	Reference
Nitrogen	Estimated by CHNS analyser (Model: Elementar'svario EL cube).	Jackson, 1973
Phosphorous	Diacid digestion of leaf sample followed by filtration. Vanabdomolybdate phosphoric yellow colour in nitric acid system.	Piper, 1966
Potassium	Diacid digestion of leaf sample followed by filtration. Flame photometry determination.	Jackson, 1973
Calcium and magnesium	Diacid digestion of leaf sample followed by filtration. The filtrate was collected, analysed for Ca and Mg using Perkin- Elmer sing atomic absorption spectrophotometer	Piper, 1966

3.3.5.7 Meteorological observations

Monthly observations on temperature (ºC), relative humidity (%) and rainfall (mm) were recorded during the experimental period.

3.3.5.8 Incidence of major pests and diseases

Incidence of major pests and diseases was monitored throughout the cropping period.

3.3.6 Statistical analysis

Observations recorded on physico-morphological and biochemical characters were analysed statistically in Randomized Block Design and significance was tested using analysis of variance technique (Panse and Sukhatme, 1985).

For organoleptic analysis, the different scores given by 10 judges in the sensory panel were analysed using the Kruskall – Wallis test to get the mean rank values for all the treatments (Sidney, 1988).

3.4 Standardization of propagation techniques in passion fruit

Experiment on propagation was laid out at Fruits Crops Research Station, Kerala Agricultural University, Vellanikkara during 2019 using stem cuttings and bio regulator NAA. Semi-hardwood cuttings were taken from disease free, vigorous growing adult vines of 134P. 134P is a purple coloured (*Passiflora edulis var. edulis*) pipeline variety from Pineapple Research Station, Vazhakulam. Stem cuttings were planted in grow bags of size 15 cm x 10 cm filled with potting mixture, sand: soil: compost in the ratio1:1:1. Quick dip method was followed for application of NAA. Plates 24, 25, 26, 27 and 28 shows the preparation of cuttings, different noded cuttings used, dipping in different concentrations of NAA and general view of cuttings planted.

3.4.1 Experimental Design and Layout

Design : CRD

Variety : 134P

Treatments : 20

Replications : 2

Number of cuttings/ replication : 25

The polybags were arranged as per the layout and placed in the propagation structure.

Treatment details

Factor A: Number of nodes on the cutting

One noded

Two noded

Three noded

Four noded

Factor B: Different concentrations of NAA

200 ppm

400 ppm

600 ppm

800 ppm

Control

The treatments comprised of combinations of different noded cuttings and different concentrations of NAA. There were twenty combinations as listed in Table 4.

3.4.3 Main items of observations

Observations were recorded on days to sprout, number of leaves, total leaf area, seedling height and survival per cent at 3 months after planting.

3.4.3.1 Days to sprout

Time taken to sprout (bud breaking) was observed from the day of planting to visual emergence of new sprout and expressed in days.

3.4.3.2 Survival per cent

Survival per cent was calculated using the following formula at 3 months after planting.

Survival per cent = (No. of survived cuttings/Total no. of cuttings planted) x 100

3.4.3.3 Number of leaves

Number of leaves was counted at 3 months after planting.

Plate 24. Preparation of cuttings

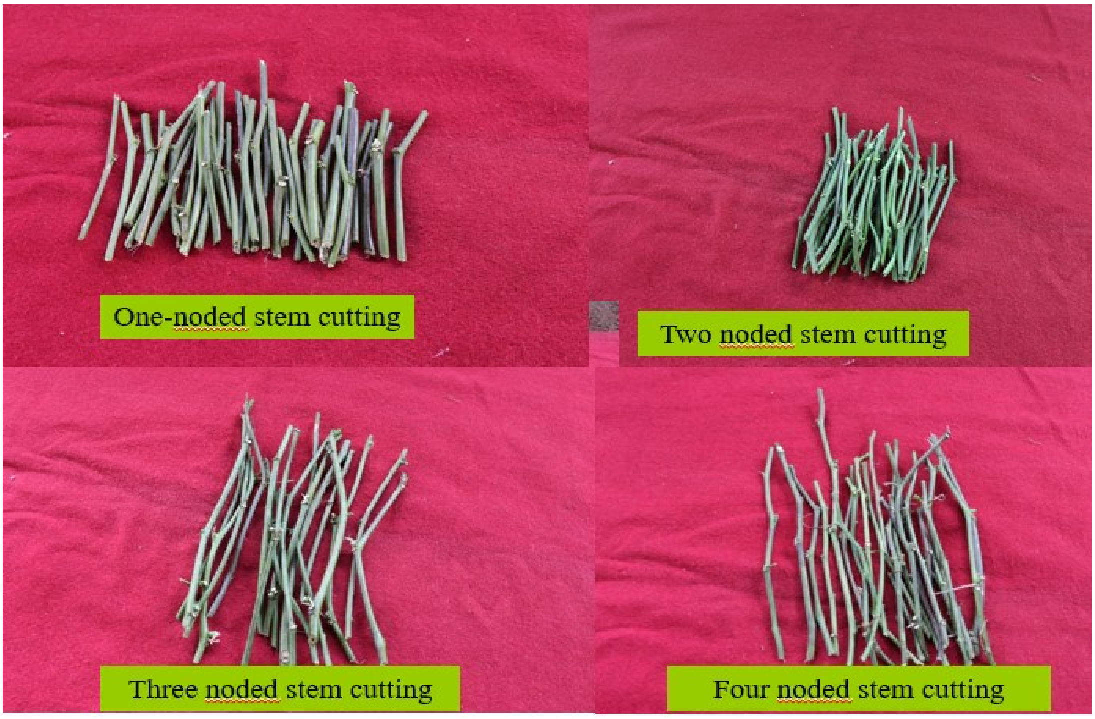


Plate 25. Different noded cuttings used for the propagation experiment

Plate 26. Dipping in different concentrations of NAA

Plate 27. General view of cuttings planted

Plate 28. General view of sprouted cuttings

Table 4. Treatments showing the number of nodes in the cuttings and NAA concentrations employed for the propagation study

Treatments	Number of nodes in the cuttings and NAA concentrations
T_1	One noded, without NAA (control)
T_2	One noded + 200ppm NAA
T_3	One noded + 400ppm NAA
T_4	One noded + 600ppm NAA
T_5	One noded + 800ppm NAA
T_6	Two noded, without NAA (control)
T_7	Two noded + 200ppm NAA
T_8	Two noded + 400ppm NAA
T_9	Two noded + 600ppm NAA
T_{10}	Two noded + 800ppm NAA
T_{11}	Three noded, without NAA (control)
T_{12}	Three noded + 200ppm NAA
T_{13}	Three noded + 400ppm NAA
T_{14}	Three noded + 600ppm NAA
T_{15}	Three noded + 800ppm NAA
T_{16}	Four noded, without NAA (control)
T_{17}	Four noded + 200ppm NAA
T_{18}	Four noded + 400ppm NAA
T_{19}	Four noded + 600ppm NAA
T_{20}	Four noded + 800ppm NAA

3.4.3.4 Total leaf area (cm^2)

Total leaf area was calculated by using graph paper method and expressed in cm^2.

3.4.3.5 Shoot length (cm)

Shoot length of newly emerged shoot was measured using a scale from base to tip and expressed in cm.

3.4.3.5 Root length (cm)

Length of longest root was measured using a scale and expressed in centimeters.

3.4.4 Statistical analysis

Data were analysed statistically in Completely Randomized Design and significance was tested using analysis of variance technique (Panse and Sukhatme, 1985).

Results and discussion

4. RESULTS AND DISCUSSION

The results and discussion of the study pertaining to 'Production technology and crop improvement of passion fruit (*Passiflora edulis* Sims.)' conducted during 2018-2020 under the humid agroclimatic conditions are presented in this chapter. The study was conducted in four experiments under the following heads.

1. Performance evaluation of cultivars/ genotypes
2. Hybridization/selfing in selected parents
3. Standardization of nutrient management technique
4. Standardization of propagation technique

4.1 PERFORMANCE EVALUATION OF CULTIVARS/ VARIETIES

Eight accessions of passion fruit collected from different locations were planted at Fruits Crops Research Station, Vellanikkara in September, 2018. These accessions were evaluated for their performance with respect to vegetative, flower, fruit, yield and qualitative characters. The results and discussion of the experiment are furnished here.

4.1.1 VEGETATIVE CHARACTERS OF DIFFERENT PASSION FRUIT ACCESSIONS

Vegetative characters like stem girth and number of branches were recorded, analyzed and the results are presented in Table 5.

4.1.1.1 Stem girth (cm)

Stem girth at 12 MAP varied significantly among the different accessions. Stem girth varied from 7.83 cm in Accession 5 to 13.83 cm in Accession 2 (Table 5). The highest stem girth was observed in Accession 2 which was significantly superior to all the other accessions. All other accessions were on par with each other with respect to stem girth. This might be due to the difference in genotypic constitution of various genotypes.

4.1.1.2 Number of branches

Statistically number of branches per vine did not vary significantly (Table 5). The mean number of branches varied from 6.33 in Accession 1 to 13.33 in Accession 4.

4.1.2 FLOWER CHARACTERS OF DIFFERENT PASSION FRUIT ACCESSIONS

Observations on flower characters *viz*., time of anthesis, days from flower bud initiation to anthesis, days from anthesis to fruit set, per cent fruit set were recorded, analysed and the results are presented in Table 6.

4.1.2.1 Time of anthesis

Slight variation was observed in the time of anthesis, among the different passion fruit accessions, which varied from 01.03 in Accession 3 to 01.42 in Accession 2 (Table 6).

The time of anthesis of *P. edulis* was observed to be from 11.00 am to 12.30 pm by Banu *et al*. (2009) in Bangladesh. Kishore *et al*. (2010) reported that different genotypes of *Passiflora* responded differently to environmental factors. Hence, the slight changes in time of anthesis among the genotypes as observed in the present study.

4.1.2.2 Days from flower bud initiation to anthesis

Number of days from flower bud initiation to anthesis did not vary significantly in the passion fruit accessions evaluated which ranged from 18 days (Accession 6) to 23 days (Accession 8) as shown in Table 6.

4.1.2.3 Days from anthesis to fruit set

There was no significant difference for the number of days from anthesis to fruit set among the passion fruit accessions evaluated, which ranged from 2.33 days (Acc 2, Acc 3 and Acc 8) to 3.00 days (Acc 5 and Acc 6) (Table 6).

Table 5. Vegetative characters of passion fruit accessions at 12 MAP

Accessions	Stem girth (cm)	No. of branches
Acc 1 (P)	8.33	6.33
Acc 2 (P)	13.83	12.00
Acc 3 (Y)	9.50	8.00
Acc 4 (P)	8.17	13.33
Acc 5 (P)	7.83	11.33
Acc 6 (Y)	8.17	10.67
Acc 7 (Y)	8.17	10.33
Acc 8 (P)	8.50	8.00
CD (0.05)	2.44	NS

Table 6. Flower characters of different passion fruit accessions

Accession	Time of anthesis (H)	Days from flower bud initiation to anthesis	Days from anthesis to fruit set	Fruit set (%)	Pollen viability (%)	Stigma receptivity at the time of anthesis
Acc 1 (P)	01.35 pm	19.33	2.67	83.22	86.50	Receptive
Acc 2 (P)	01.42 pm	20.67	2.33	82.19	88.33	Receptive
Acc 3 (Y)	01.03 pm	21.00	2.33	80.11	87.00	Receptive
Acc 4 (P)	01.07 pm	22.33	2.67	81.54	88.67	Receptive
Acc 5 (P)	01.05 pm	20.00	3.00	79.36	89.00	Receptive
Acc 6 (Y)	01.10 pm	18.00	3.00	81.43	87.20	Receptive
Acc 7 (P)	01.25 pm	20.00	2.67	73.99	88.17	Receptive
Acc 8 (P)	01.08 pm	23.00	2.33	73.45	89.67	Receptive
CD (0.05)	-	NS	NS	8.39	NS	-

4.1.2.4 Fruit set (%)

Per cent fruit set did not show significant difference among the accessions (Table 6). It ranged from 73.45 per cent in Accession 8 to 83.22 per cent in Accession 1.

Akamine and Girolami (1959) found that fruit set was dependent on the amount of pollen deposited on the stigma. In another study, Akamine *et al*. (1974) reported a fruit set of about one per cent in self-pollinated passion flowers, whereas a fruit set of about 53 per cent was obtained in cross-pollinated passion flowers. Deshmukh *et al.* (2017) noticed 18-25 per cent fruit set under natural pollination, while hand pollination increased fruit set to 75 per cent. The high fruit set percentage observed in the present study might be due to the increased pollinators and the mixed planting of different genotypes which might have contributed to high cross pollination. It is reported that in passion fruit, pollination and fruit set get enhanced when there is mixed planting of different genotypes (PRS 2015).

4.1.2.5 Pollen viability (%)

Pollen viability is an important factor for getting high success in fertilization in crop breeding programmes. In the present study, pollen viability of different accessions did not vary significantly. Pollen viability ranged from 86.50 per cent in Accession 1 to 89.67 per cent in Accession 8 (Table 6). Viable and non-viable pollen is represented in plate 29.

According to Soares *et al.* (2013a) more than 70 per cent pollen viability was regarded high when dyes were used for pollen viability estimation. All the accessions of passion fruit used in the experiment had more than 70 per cent viability, thus could be considered as having high pollen viability. Among the different *Passiflora* species studied, *Passiflora edulis* Sims. recorded the highest pollen viability of 85 per cent (Soares *et al.,* 2013a). Pollen viability of 81.33 per cent has been recorded in BGP Accession of *P. edulis* f. *flavicarpa* in a study conducted by Soares *et al.* (2013b).

4.1.2.6 Stigma receptivity

Stigma was receptive at the time of anthesis in all the accessions studied (Table 6). Receptive and non-receptive stigma is shown in Plate 30.

4.1.2.7 Pollen storage

During the investigation, to standardize the optimal pollen storage condition for passion fruit, storage study with different treatments was carried out (Plate 31). The data are given in Table 7 and the results of the study are discussed hereunder.

Pollen viability under different storage conditions after three intervals of time *viz.,* 24 h, 48 h, 72 h varied significantly. After 24 h of storage under different treatments, pollen stored under T_2 retained maximum pollen viability of 80.22 per cent, which was on par with T_1 with a pollen viability of 78.26 per cent. It was followed by T_3 with pollen viability of 69.50 per cent and T_4 with 66.57 per cent (Table 7).

Maximum pollen viability of 61.18 per cent was recorded in T_3, after 48 h of pollen storage which was superior to all other treatments. It was followed by T_4 with 52.47 per cent pollen viability. T_1 had pollen viability of 47.87 per cent which was on par with T_2 (44.93 %) (Table 7).

After 72 h of pollen storage under different treatments, pollen viability was highest in T_3 (50.88 %), which was superior to all other treatments. It was followed by T_4 (41.92 %), T_1 (34.58 %) and T_2 (28.83 %) (Table 7).

The results indicated that after 24 hour of storing, keeping in refrigerator at 4°C recorded the maximum pollen viability of 80.22 per cent. However, with the progress in time, the maximum pollen viability was observed when kept over calcium chloride in a desiccator under refrigerated condition at 4°C (61.18 %) after 48 hours of storage as well as after 72 hours of storage (50.88 %) (Table 7).

Thus, passion fruit pollen can be stored viable up to 72 hours after anthesis with 50.88 per cent pollen viability when stored in a desiccator under refrigerated condition at 4°C. Optimal storage conditions in order to bring pollen from different areas have also been standardized by Iyer and Schnell (1991) in mango. In mango, pollen storage studies conducted with similar storage conditions, revealed that mango pollen could be stored with maximum pollen viability of 42.52 per cent when stored in refrigerated condition at 4°C, over calcium chloride in a desiccator (Aswini, 2019).

4.1.3 PHENOLOGICAL CHARACTERS OF PASSION FRUIT ACCESSIONS

The duration taken for first flowering, first fruiting and flowering to harvest duration of the different passion fruit accessions are presented in Table 8.

4.1.3.1 Days taken for first flowering

Days taken for first flowering, which indicates the duration of vegetative phase, varied significantly among the accessions (Table 8). The least number of days to flowering, of 157.33 days was observed in Accession 7, which was on par with Accession 5 (160.33 days), Accession 6 (165.00 days), Accession 4 (169.33 days) and Accession 1 (171.00 days). The maximum number of days for first flowering was observed in Accession 3 (239.67 days), which was significantly higher than all other accessions. Accession 2 took 216.00 days for first flowering. Accession 8 (178.00 days), Accession 1 (171.00 days), Accession 4 (169.33 days) and Accession 6 (165 days) were on par with one another.

Banu *et al*. (2009) in Bangladesh reported that flowering behavior of *P. foetida* was influenced by factors like temperature and humidity. According to Crimmins *et al*. (2010) the phenological responses in flowering plants are linked to the changes in temperature and altitude. The different genetic make-up of the accessions in the present study might also have contributed to the differences in days taken for first flowering. Varietal difference in the duration of flowering has been reported in passion fruit. Studies conducted at PRS (2015) revealed that passion fruit behaved as a photosensitive plant in the mid land plains of Ernakulam. They also reported difference in the number of days taken for first flowering in various genotypes and varieties. Flowering was observed earlier in Kaveri, which took 224.47 days and was late in Accession VP which took 287.50 days. They reported that on an average different passion fruit accessions took 252.86 days for first flowering. In the present finding, the average number of days taken for first flowering was 245.25 days which is comparable with the findings of PRS (2015).

Table 7. Pollen viability of passion fruit under different storage treatments

Treatment	Pollen viability after different time interval of storage (%)		
	24 h	48 h	72 h
T_1 (kept over calcium chloride in a desiccator at room temperature)	78.26	47.87	34.58
T_2 (kept in refrigerator at 4°C)	80.22	44.93	28.83
T_3 (kept over calcium chloride in a desiccator under refrigerated condition at 4°C)	69.50	61.18	50.88
T_4 (kept at room temperature)	66.57	52.47	41.92
CD (0.05)	2.88	4.48	3.51

Table 8. Phenological characters of passion fruit accessions

Accessions	Duration (days)		
	First flowering	First fruiting	Flowering to harvest
Acc 1 (P)	171.00	173.33	59.67
Acc 2 (P)	216.00	218.67	68.00
Acc 3 (Y)	239.67	242.67	83.33
Acc 4 (P)	169.33	172.33	59.33
Acc 5 (P)	160.33	163.33	67.00
Acc 6 (Y)	165.00	168.00	69.33
Acc 7 (Y)	157.33	159.67	63.00
Acc 8 (P)	178.00	181.00	79.33
CD (0.05)	15.54	15.74	9.76

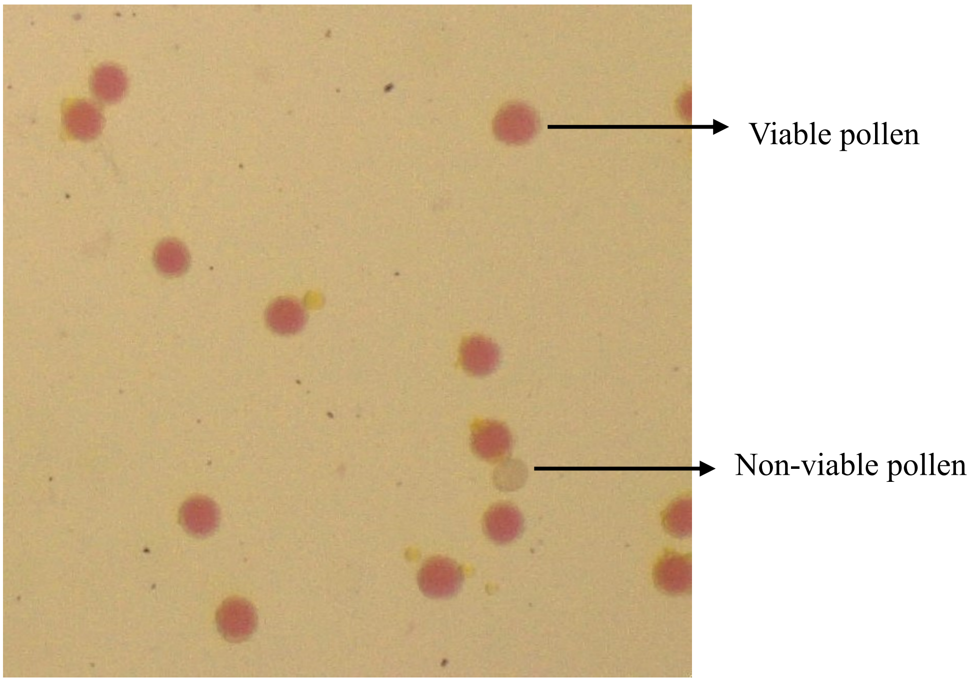


Plate 29. Viable and non-viable pollen

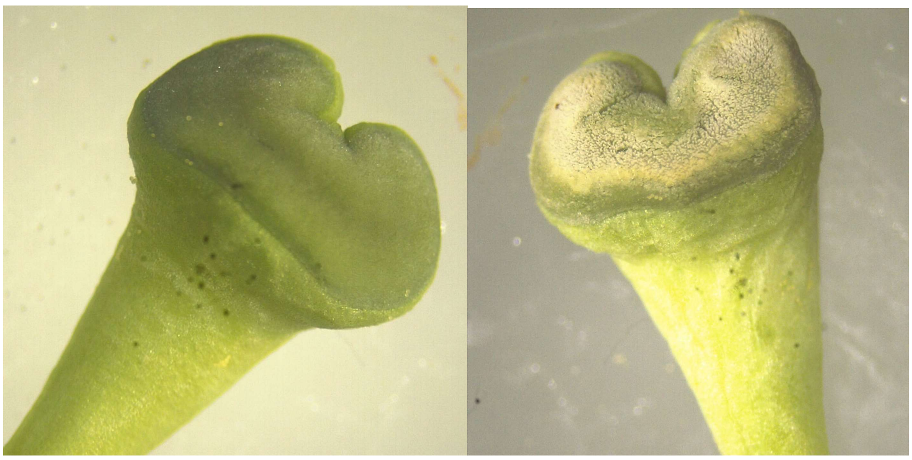


Plate 30. Receptive and non receptive stigma

Plate 31. Pollen storage studies

4.1.3.2 Days taken for first fruiting

The data for the days taken for first fruiting revealed significant difference among the accessions (Table 8). The least number of days for first fruiting was found in Accession 7 with 159.67 days, which was on par with Accession 5 (163.33). Accession 6 took 168.00 days for first fruiting which was on par with Accession 4 (172.33 days) and Accession 1 (173.33 days). The longest duration for first fruiting was observed in Accession 3 (242.67days). Accession 2 took 218.67 days and Accession 8 took 181.00 days for the first fruiting.

According to Haag *et al*. (1973) fruit formation started 280 days after planting (9^{th} month), starting with the flowers developing at new branches, with a sudden accumulation of dry matter within first 60 days and then slow growth till maturation (370 days/ 12^{th} month). In the present experiment the duration for first fruiting was comparatively less which might be because of the use of rooted cutting as planting material.

Mayorga (2017) reported that at higher altitudes, due to lower temperature fruit production started late compared to lower altitude, in banana passion fruit. The variations in days taken for first fruiting observed in the present experiment might be due to changes in genotypic constitution.

4.1.3.3 Flowering to harvest duration

Flowering to harvest duration of various accessions varied significantly (Table 8). Flowering to harvest duration was the least in Accession 4 (59.33 days) which was on par with Accession 1 (59.67 days), Accession 7 (63.00 days), Accession 5 (67.00 days), and Accession 2 (68.00 days). The longest duration from flowering to harvest was observed in Accession 3 (83.33 days), which was on par with Accession 8 (79.33 days).

Borges and Lima (2003) reported that from flowering to harvest it took 60.30 days when temperature was in the range of 23ºC to 28ºC, but when the temperature was lower than 23ºC and higher than 33ºC, it took 75 days from flowering to harvest.

Different number of days for maturity was recorded among the flowering to harvest duration studied in different species of *Passiflora* by Beena and Beevy (2016). In general, the ripening duration was 85 to 155 days among the different species studied. Earliest maturity of 85 days was recorded in *P. subpeltata.* Wild varieties of *P. foetida* reported to have a ripening period of 90 days. The flowering to harvest duration in *P. edulis* var. *edulis*, *P. edulis* f. *flavicarpa* and *P. edulis* cv. Panama Red was 110-120 days. The lesser duration for harvest recorded in the present study might be due to the difference in climatic conditions and the inherent character of the genotypes.

Mayorga (2017) found that in banana passion fruit more number of days were taken for ripening *ie.* fruit development took longer time at higher altitudes where lower temperature existed.

4.1.4 YIELD CHARACTERS OF DIFFERENT PASSION FRUIT ACCESSIONS

4.1.4.1 Flower production of different passion fruit accessions at monthly intervals

The monthly flower production of different accessions are presented in Table 9.

Data on flower production per vine in the month of February showed significant difference among the accessions (Table 9). High flower production was observed in Accession 4 (29.00), which was on par with Accession 6 (21.67). Accession 6 was on par with Accession 5 (14.00) and Accession 7 (13.33). Flowers were not observed in Accession 2 and Accession 3, during the month of February.

Production of flowers in March varied significantly among the accessions as depicted in Table 9. Flower production was the maximum in Accession 4 (25.33), which was significantly superior to all other accessions. It was followed by Accession 6 (16.67) which was on par with Accession 5 (16.00), Accession 1 (14.67), Accession 8 (13.00) and Accession 7 (12.67). Accession 2 and Accession 3 did not produce flowers during March.

Flower production in April showed significant variation among the accessions (Table 9). Eventhough high flower production was recorded in Accession 2 (18.67), it was on par with Accession 4 (17.33), Accession 5 (16.67), Accession 8 (12.33) and Accession 7 (11.67). Minimum flower production was observed in Accession 3 (2.33), which was on par with Accession 1 (4.33) and Accession 6 (4.67).

Data regarding flower production per vine in May (Table 9) indicated significant difference among the accessions. High flower production was observed in Accession 2 (31.67) which was on par with Accession 6 (30.67), Accession 3 (29.33) and Accession 1 (22.33). The lowest flower production of 12.67 was recorded in Accession 7 and Accession 8, which was on par with Accession 5 (13.00) and Accession 4 (14.00).

Significant variation was observed in mean flower production per vine in June as shown in Table 9. Maximum flower production was observed in Accession 2 (34.67) which was on par with Accession 4 (28.33) and Accession 6 (27.00). Lower flower production was observed in Accession 7 (6.67) which was on par with Accession 5 (7.67).

Flower production in July did not vary significantly among the different accessions, which was observed in the range of 18.00 (Accession 5) to 35.00 (Accession 1).

Flower production in August did not show significant variation among the accessions and it ranged from 13.00 in Accession 6 to 36.67 in Accession 3 (Table 9).

Flower production per vine in September did not show significant variation. The flower production ranged from 19.67 in Accession 3 to 37.00 in Accession 1 (Table 9).

The radiation from the sun, which includes its quality, duration and intensity, is a primary factor in the development of plant and its flower production (Adjaloo *et al*., 2012) which might have contributed to the variations in flower production in various months, since there is high variation in the solar radiation in different months.

Beena and Beevy (2016) reported that the species like *P. edulis* var. *edulis*, *P. ligularis, P. subpletata* and *P. leshnoultii*, habitating in high ranges bloomed from April to September. In the present study the flower production increased from April to September, which is in line with the findings of Beena and Beevy (2016).

4.1.4.2 Peak flowering month

Peak flowering was recorded in September in Accessions 1, 2, 4, 5, 6, 7 and 8. In Accession 3, August was found to be the peak flowering month.

4.1.4.3 Total flower production per vine per year

Total flower production per vine varied significantly among the accessions (Table 9, Figure 1). The maximum flower production was recorded in Accession 4 (190.67), which was on par with Accession 2 (181.67) and Accession 6 (180.33). Minimum flower production was observed in Accession 3 (135.67) which was on par with Accession 5 (138.33) and Accession 7 (140.67).

The significant differences in total flower production per vine per year among different accessions might be due to the inherent nature and varying responses of accessions to prevailing climatic conditions. According to Borges and Lima (2003) day light played an important role in growth and development of passion fruit. An increase in day length duration enhanced photosynthetic activity, which resulted in increased plant vigour. They also reported that flower production was heavy in areas where day length was more than 11 hours. The favourable day length available in plains of Thrissur would have caused the genotypes to flower profusely.

4.1.4.4 Fruit production in passion fruit accessions at monthly intervals

Fruit production per vine per month in various accessions are presented in Table 10.

Fruit production in February did not show significant variation and it ranged from 0.00 (Accession 2, Accession 3 and Accession 8) to 12.33 (Accession 4).

Table 9. Flower production in passion fruit accessions

Accession	Number of flowers /vine								
	February '19	March '19	April '19	May '19	June '19	July '19	August '19	September '19	Total flowers
Acc 1 (P)	6.67	14.67	4.33	22.33	25.33	35.00	19.00	37.00	164.33
Acc 2 (P)	0.00	0.00	18.67	31.67	34.67	32.00	28.67	36.00	181.67
Acc 3 (Y)	0.00	0.00	2.33	29.33	21.00	26.67	36.67	19.67	135.67
Acc 4 (P)	29.00	25.33	17.33	14.00	28.33	22.33	22.67	31.67	190.67
Acc 5 (P)	14.00	16.00	16.67	13.00	7.67	18.00	20.00	33.00	138.33
Acc 6 (Y)	21.67	16.67	4.67	30.67	27.00	29.00	13.00	37.67	180.33
Acc 7 (Y)	13.33	12.67	11.67	12.67	6.67	27.67	21.67	34.33	140.67
Acc 8 (P)	9.33	13.00	12.33	12.67	21.67	28.33	22.33	32.33	152.00
CD (0.05)	10.03	6.98	10.89	12.81	8.60	NS	NS	NS	14.09

Fruit production per vine in March showed significant difference among the accessions. Maximum fruit production was recorded in Accession 4 (22.33), which was on par with Accession 5 (16.33). There was no fruit production in Accession 2 and Accession 3. Accession 8 (2.67) and Accession 7 (5.33) were on par with each other (Table 10).

Fruit production per vine in April did not show significant variation and it varied from 2.00 (Accession 3) to 14.00 (Accession 4).

Fruit production per vine in May showed significant variation among the accessions (Table 10). Maximum fruit production was recorded in Accession 2 (27.67), which was on par with Accession 6 (24.67), Accession 3 (24.33) and Accession 1 (19.00). It was followed by Accession 8 (11.00), which was on par with Accession 4 (10.67), Accession 7 (10.00) and Accession 5 (8.67).

Fruit production per vine in June showed significant difference among the accessions as depicted in Table 10. Accession 2 showed highest mean value of 29.00, which was on par with Accession 4 (23.67) and Accession 6 (23.33). The lowest fruit production was observed in Accession 7 (4.67), which was on par with Accession 5 (5.67). The fruit production per vine in July did not show significant variation among the accessions. It ranged from 21.33 (Accession 5) to 33.67 (Accession 1).

Fruit production per vine in August and September did not vary significantly (Table 10). It varied from 12.00 (Accession 6) to 29.00 (Accession 3) in August while it ranged from 16.33 (Accession 3) to 33.67 (Accession 1) during September.

According to Ataide *et al*. (2012) harvesting time and fruit production showed differences in *Passiflora* species throughout the year depending on the changes in flowering behavior. The variations in monthly fruit production might be due to the variations in flowering response and different genetic behaviour of the genotypes.

In a study conducted by Beena and Beevi (2016), harvesting time also varied among different genotypes. In *P. edulis* var. *edulis* and *P. edulis* f. *flavicarpa* flowering started in the first week of March, while in *P. edulis* cv. Panama Red, two seasons of harvest was noted with first season starting from second week of November and second season from second week of March onwards. The variations in total fruit production per vine in the present study might be due to variations in the harvesting seasons in different genotypes. This is in line with the findings of Beena and Beevi (2016) who reported variations in harvesting time among the genotypes.

4.1.4.5 Peak fruiting month

Peak fruiting month was found to be September in all most all accessions, except for Accession 3 were peak fruit production was observed in the month of August and for Accession 4, July was the peak fruiting month. In the case of Accession 2, June and September were the peak fruiting months.

4.1.4.6 Total fruit production per vine per year

Statistical analysis of total fruit production per vine per year showed significant differences among the accessions (Table 10, Figure 1). Maximum fruit production per vine per year was observed in Accession 4 (155.33), which was on par with Accession 2 (149.33) and Accession 6 (146.67). The lowest fruit production was observed in Accession 7 (104.00) which was on par with Accession 3 (108.67), Accession 5 (109.67) and Accession 8 (111.667).

According to Borges and Lima (2003) day light played an important role in growth and development of passion fruit. An increase in day length duration enhanced photosynthetic activity, which resulted in increased plant vigour which might have resulted in increased fruit production.

Among the varieties, Kaveri was found to be superior over Purple in terms of number of fruits per plant (166.71 and 130.26 respectively) and fruit yield (13.33 t ha^{-1} and 3.97 t ha^{-1} respectively) (Rao *et al*., 2013).

Occurrence of two flowering seasons in a year and the two times of harvest in *P. edulis* cv. Panama Red has been reported by Beena and Beevi (2016) which might have contributed to the increased yield of the genotype, adding to its value for commercial cultivation. Accordingly in the present study, Accessions 4, 2 and 6 with high yield can be used for commercial cultivation.

4.1.5 FRUIT CHARACTERS OF DIFFERENT PASSION FRUIT ACCESSIONS

Fruit characters of different passion fruit accessions with respect to fruit diameter, fruit girth, fruit weight, pulp weight, rind weight, rind thickness, seed weight, juice weight, shelf life, physical components, rind and pulp colour were studied. Data pertaining to fruit characters are shown in Table 11, 12, 13 and 14. Fruits from different accessions are shown in Plate 32. All the fruit characters studied varied significantly among different accessions, results and discussion are presented hereunder.

4.1.5.1 Fruit diameter of passion fruit accessions

Statistical analysis of fruit diameter showed significant difference among the different accessions (Table 11). Fruit diameter was high in the case of Accession 3 (7.40 cm), which was on par with Accession 4 (7.32 cm), Accession 2 (7.21 cm) and Accession 8 (7.12 cm). This was followed by Accession 5 (6.47 cm) which was on par with Accession 7 (6.36 cm) and Accession 6 (6.21 cm). The low values were observed for fruit diameter in Accession 1 (6.00 cm) and Accession 6 (6.21 cm) which were on par with each other.

According to Borges and Lima (2003) day light played an important role in growth and development of passion fruit, and an increase in day length duration enhanced photosynthetic activity, which resulted in an increased fruit size.

The variations in fruit diameter in different genotypes of passion fruit in the present study, are in line with the results of Sema and Maiti (2006), wherein they observed difference in the fruit diameter among different genotypes.

In a study for evaluating promising passion fruit accessions at CHES, Chettalli, variations in fruit diameter had been reported by Tripathi *et al.* (2014).

They reported fruit diameter variation in the range of 5.03 cm in CHES PF-2-11 to 7.08 cm in CHES PF-7, which is in conformity with the observed values of fruit diameter in the various genotypes in the present study.

Investigations conducted by Beena and Beevy (2016) indicated that in passion fruit size of cultivated variety dominated over the wild varieties. Beevy and Bai

(2012) also reported dominance of the cultivar in *Momordica charantia* compared to the wild genotypes. Eventhough the increased fruit size is regarded primitive in nature; it can be used as a desirable character to enhance fruit production in breeding programs.

Ghosh *et al*. (2017) observed that purple passion fruit types have an average fruit diameter of 3-5 cm and concluded that it might be due to genotypic and environmental factors which affected the size of fruits.

4.1.5.2 Fruit girth of passion fruit accessions

Fruit girth exhibited same trend as that of fruit diameter. Fruit girth of various accessions varied significantly (Table 11, Figure 2). High fruit girth was observed in Accession 3 (23.30 cm), which was on par with Accession 4 (23.00 cm), Accession 2 (22.67 cm) and Accession 8 (22.37 cm). This was followed by Accession 5 (20.33 cm), which was on par with Accession 7 (20.00 cm) and Accession 6 (19.50 cm). The minimum fruit girth was noticed for Accession 1 (18.83 cm) which was on par with Accession 6 (19.50 cm).

According to Charan *et al.* (2018), fruit girth ranged from 18.30 to 21.16 cm and 19.20 to 22.83 cm in yellow and purple passion fruits respectively, which is in line with the present findings, wherein it ranged between 18.83 cm and 23.30 cm. The significant variations in fruit girth might also be due to the variations in fruit diameter of passion fruit accessions as observed earlier.

4.1.5.3 Fruit weight of passion fruit accessions

Fruit weight of various accessions varied significantly among the different accessions (Table 11, Figure 3). The highest fruit weight was found in Accession 3 (120.33 g), which was superior to all other accessions and was followed by Accession 4 (110.00 g). It was followed by Accession 8 (98.67 g) which was on par with Accession 2 (98.33 g). Lower fruit weight of 66.00 g was observed for Accession 1, which was on par with Accession 6 (73.33 g) and Accession 7 (74.83 g).

Table 10. Fruit production in passion fruit accessions

Accession	Number of fruits/vine								
	February ‘19	March ‘19	April ‘19	May ‘19	June ‘19	July ‘19	August ‘19	September ‘19	Total fruits
Acc 1 (P)	5.33	9.33	3.33	19.00	20.67	28.33	17.00	33.67	136.67
Acc 2 (P)	0.00	0.00	13.33	27.67	29.00	26.00	24.33	29.00	149.33
Acc 3 (Y)	0.00	0.00	2.00	24.33	16.67	20.33	29.00	16.33	108.67
Acc 4 (P)	12.33	22.33	14.00	10.67	23.67	26.33	22.00	24.00	155.33
Acc 5 (P)	8.33	16.33	9.67	8.67	5.67	18.00	15.33	27.67	109.67
Acc 6 (Y)	10.67	13.67	3.00	24.67	23.33	26.00	12.00	33.33	146.67
Acc 7 (Y)	6.67	5.33	9.67	10.00	4.67	23.00	16.00	28.67	104.00
Acc 8 (P)	0.00	2.67	11.33	11.00	13.67	24.67	21.67	26.67	111.67
CD (0.05)	NS	6.41	NS	11.55	7.64	NS	NS	NS	13.61

Table 11. Fruit characters of passion fruit accessions

Accession	Fruit diameter (cm)	Fruit girth (cm)	Fruit weight (g)	Pulp weight (g)	Rind weight (g)
Acc 1 (P)	6.00	18.83	66.00	28.41	37.59
Acc 2 (P)	7.21	22.67	98.33	46.67	51.67
Acc 3 (Y)	7.40	23.30	120.33	52.00	68.33
Acc 4 (P)	7.32	23.00	110.00	48.17	58.50
Acc 5 (P)	6.47	20.33	83.67	39.67	44.00
Acc 6 (Y)	6.21	19.50	73.33	31.70	41.63
Acc 7 (Y)	6.36	20.00	74.83	31.77	43.33
Acc 8 (P)	7.12	22.37	98.67	44.00	55.67
CD (0.05)	0.34	1.08	9.43	6.60	6.76

There are many reports regarding the fruit weight of passion fruit as a varietal character. Wide variation in fruit size has been reported by Kishore (2006), who reported that the average size of fruits of purple and yellow passion fruits was 35.00 g and 70.00 g respectively.

Patel *et al*. (2008) who evaluated different passion fruit genotypes under mid hill conditions of Meghalaya found that fruit weight varied from 36.33 g to 117.90 g, which is in line with the results of the present study, in which the range was 66.00 g to 120 g.

The present results of fruit weight are comparable with the reports of Tripathi *et al*. (2014). They conducted a study at CHES, Chettali to evaluate passion fruit accessions and found that fruit weight varied from 44.10 g in CHES PF-2-11 to 99.10 g in CHES PF-7, thus deriving a conclusion that there were genotypic differences in fruit weight.

According to Beena and Beevy (2016) the fruit weight was 15±0.023 g, 20±0.024 g, 26±0.021 g in *P. edulis* var. *edulis*, *P. edulis* f. *flavicarpa* and *P. edulis* cv. Panama Red respectively. The values of fruit weight observed were very low which might be due to the varied climatic conditions and difference in the genotypes, which they used.

Mendoza *et al*. (2018) reported that fruit volume is a variable that contributed to 80 per cent phenotypic variations among 60 accessions of passion fruits evaluated at Colombia. Fruit volume is an important factor contributing to fruit weight. The phenotypic variations might have contributed to the weight differences in the fruits, in the present study.

4.1.5.4 Pulp weight of passion fruit accessions

Data on pulp weight of different accessions indicated significant variations (Table 11, Figure 3). Pulp weight was maximum in Accession 3 (52.00 g), which was on par with Accession 4 (48.17 g) and Accession 2 (46.67 g). Lower pulp weight was observed in Accession 1 (28.41g) which was on par with Accession 5 (31.70 g) and Accession 6 (31.77 g).

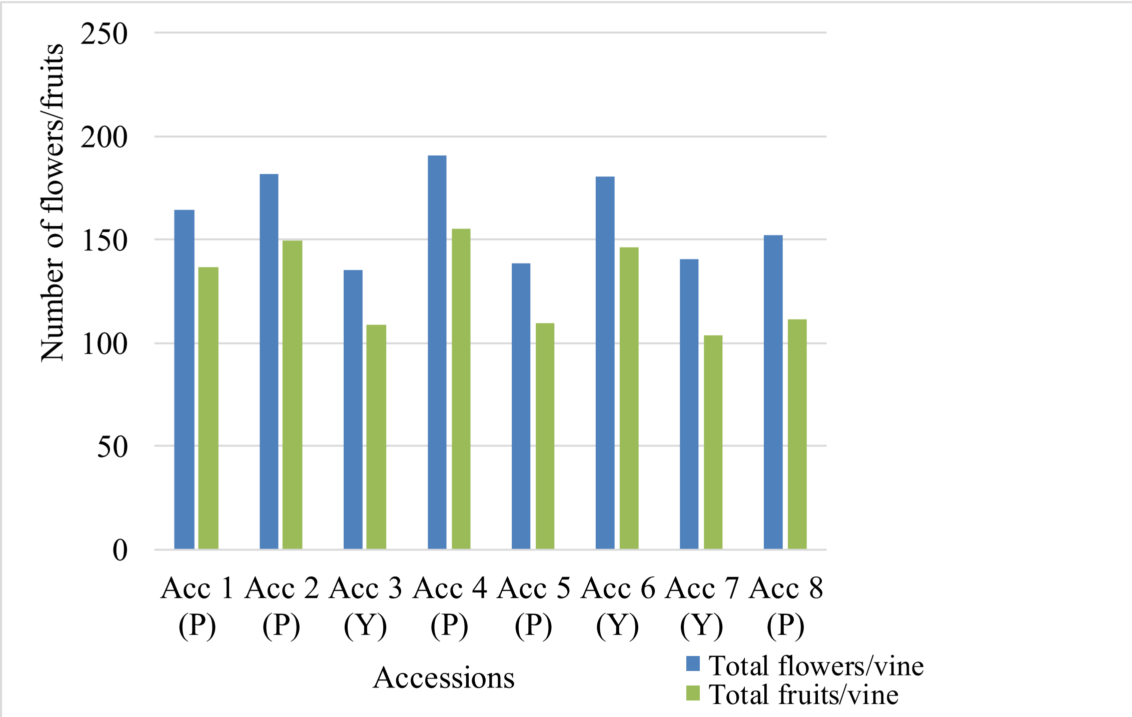


Figure 1. Total number of flowers and fruits in passion fruit accessions

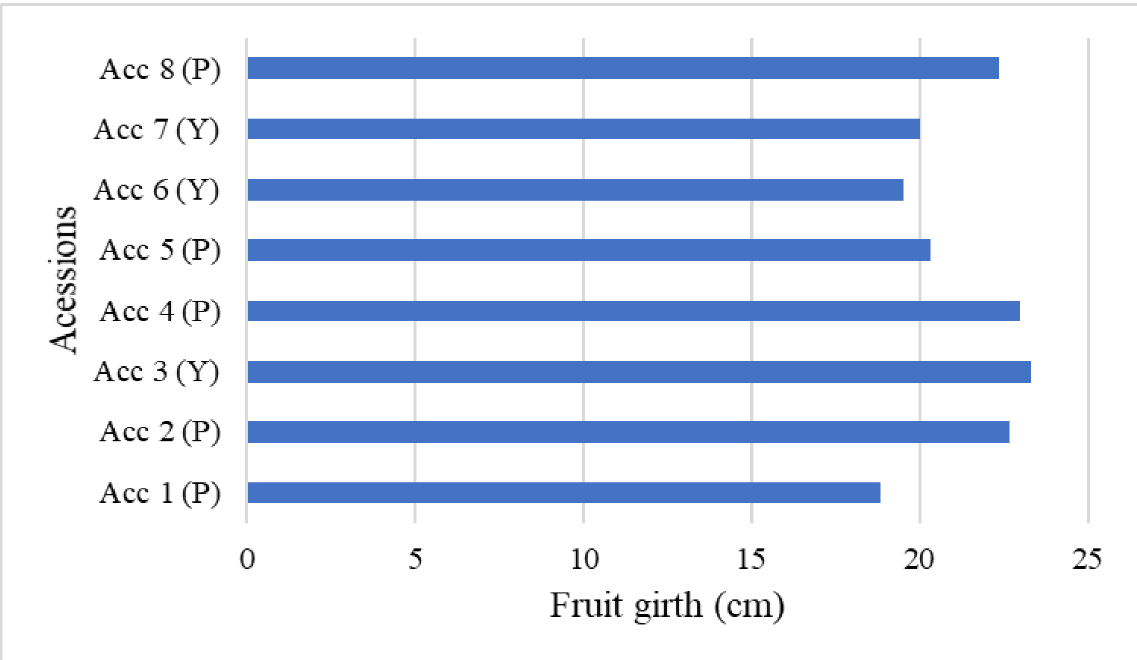


Figure 2. Fruit girth of passion fruit accessions

Plate 32. Variation in fruits of passion fruit accessions

According to Vieira and Carneiro, (2006) fruit characteristics can be used as selection criteria for yield potential in yellow passion fruit. Pulp weight, one of the important fruit characteristics, has been recorded in the present study, as superior in Accession 3, Accession 4 and Accession 2 and hence could be selected as superior in terms of yield potential also.

In a study for evaluation of promising passion fruit accessions at CHES, Chettalli variations in pulp weight has been reported by Tripathi *et al.* (2014). They reported pulp weight variation in the range of 13.10 g in CHES PF-2-11 to 50.10 g in CHES PF-3, which is in conformity with the observed values of pulp weight in the present study. Extensive variations within and among the passion fruit species has been recorded in pomological characters like fruit size and weight of the fruit (Beena and Beevy, 2016). Such variations were observed in the present study also with significant difference in the pulp weight.

Study conducted for characterizing physiochemical parameter of passion fruit accessions at Colombia revealed high diversity across 60 accessions including 17 variables associated to yield, production and fruit quality (Mendoza *et al*., 2018).

They reported that pulp weight was a variable that explained 80 per cent of the phenotypic variation. In the present study also the phenotypic variation in the selected genotypes could be explained on the basis of the variation in pulp weight.

4.1.5.5 Rind weight of passion fruit accessions

Among the different components of passion fruit, rind contributes a major share to the fruit weight (Table 11). Statistical analysis of rind weight revealed significant difference among the accessions. The highest rind weight was observed in Accession 3 (68.33 g), which also had the highest fruit weight and was superior to all other accessions. Lower rind weight was recorded in Accession 1 (37.59 g) which was on par with Accession 6 (41.63 g), Accession 7 (43.33 g) and Accession 5 (44.00 g).

According to the studies conducted at PRS (2015) among 14 accessions evaluated at Pineapple Research Station, Vazhakulam, the average rind weight was 40.65 g. In the present study the average rind weight observed was 50.10 g, which might be due to the differences in the genotypes selected.

4.1.5.6 Rind thickness of passion fruit accessions

Rind thickness, which is a contributing factor towards shelf life of various accessions varied significantly and maximum rind thickness was found in Accession 3 (0.91 cm), which was on par with Accession 5 (0.78 cm). Accession 6 had a rind rickness of 0.67 cm which was on par with Accession 5. Eventhough lower rind thickness was observed in Accession 1 (0.47 cm), which was on par with Accession 2 (0.50 cm), Accession 7 (0.53 cm), Accession 8 (0.58 cm) and Accession 4 (0.60 cm) (Table 12, Figure 4).

Variation in rind thickness from 0.46 cm to 0.70 cm in yellow types and 0.46 cm to 0.96 cm in purple types had been reported by Charan *et al.* (2018). This is in agreement with the observed values of rind thickness in the present investigation which ranged from 0.50 cm to 0.91 cm. Silva *et al.* (2015) recorded a rind thickness of 0.56 cm to 0.58 cm in passion fruit. There may be difference according to the genotypes. So accessions 1 and 7 with low rind weight and rind thickness can be exploited for processing industries and value addition.

4.1.5.7 Seed weight of passion fruit accessions

The study revealed that seed weight also varied significantly with respect to different accessions of passion fruit (Table 12). Accession 3 had the maximum seed weight of 9.67 g, which was on par with Accession 5 (8.50 g), Accession 4 (8.20 g) and Accession 2 (8.17 g). The minimum seed weight was observed in Accession 1 and Accession 7 (5.67 g), which was on par with Accession 6 (6.17 g) and Accession 8 (7.00 g).

According to Beena and Beevy (2016) considerable variations were observed in the number of seeds, which directly contributed to the seed weight among the wild and cultivated *Passiflora* species studied, *viz.*, *P. foetida and P. edulis*. In the present study also, significant variations were observed in the seed weight which is in line with the reports of Beena and Beevy (2016). Study conducted for characterizing the physiochemical parameters of passion fruit accessions at Colombia revealed high diversity across 60 accessions in 17 variables associated to yield, production and fruit quality (Mendoza *et al.*, 2018). According to them, seed weight was a variable that explained 80 per cent of the phenotypic variations. In the present study also the phenotypic variations in the genotypes could also be explained on the basis of seed weight.

4.1.5.8 Juice weight of passion fruit accessions

Statistical analysis of juice weight also showed significant difference among the accessions and juice weight significantly varied from 22.82 g (Acc 1) to 43.30 g (Acc 4). The maximum juice weight was recorded for Accession 4 (43.30 g), which was on par with Accession 3 (42.33 g), Accession 2 (38.50 g) and Accession 8 (37.00 g). Lower juice weight was observed in Accession 1 (22.82 g), which was on par with Accession 6 (25.53 g) and Accession 7 (26.10 g) (Table 12).

Ramaiya *et al.* (2013) reported that juice weight varied from 22.96±2.61 g to 73.44±1.80 g in passion fruit. The results of the present study are in conformity with the findings of Ramaiya *et al.* (2013), where the juice weight recorded varied from 22.82 g to 43.30 g. The variations might be due to the different genotypes. Studies by Reni (2014) indicated that temperature plays an important role in influencing the fruit morphological traits in *Populus euphratic* and *Baccaurea dulcis*. The variations in the juice weight might be due to the variations in the genotypes and climatic conditions of the region.

4.1.5.9 Shelf life of passion fruit accessions

Different accessions had significant effect on shelf life of passion fruits at ambient conditions (Table 12, Figure 4). Accessions 3 recorded high shelf life of 15.67 days which was on par with Accession 5 (15.33 days). This was followed by Accession 6 (14.33 days) which was on par with Accession 4 (14.17 days), Accession 8 (14.00 days), Accession 7 (13.67 days) and Accession 2 (13.33 days). Lower shelf life was observed in Accession 1 (12.33 days) which was on par with Accession 2 (13.33 days).

Accession 3 had the longest shelf life followed by Accession 5 and Accession 6, which had rind thickness of 0.91 cm, 0.78 cm and 0.67 cm respectively. The increased shelf life might be attributed to the increased rind thickness, since the accessions having more rind thickness exhibited more shelf life.

Table 12. Fruit characters of passion fruit accessions

Accession	Rind thickness (cm)	Fresh seed weight (g)	Juice weight (g)	Shelf life (days)
Acc 1 (P)	0.47	5.67	22.82	12.33
Acc 2 (P)	0.50	8.17	38.50	13.33
Acc 3 (Y)	0.91	9.67	42.33	15.67
Acc 4 (P)	0.60	8.20	43.30	14.17
Acc 5 (P)	0.78	8.50	31.17	15.33
Acc 6 (Y)	0.67	6.17	25.53	14.33
Acc 7 (Y)	0.53	5.67	26.10	13.67
Acc 8 (P)	0.58	7.00	37.00	14.00
CD (0.05)	0.14	1.75	6.44	1.10

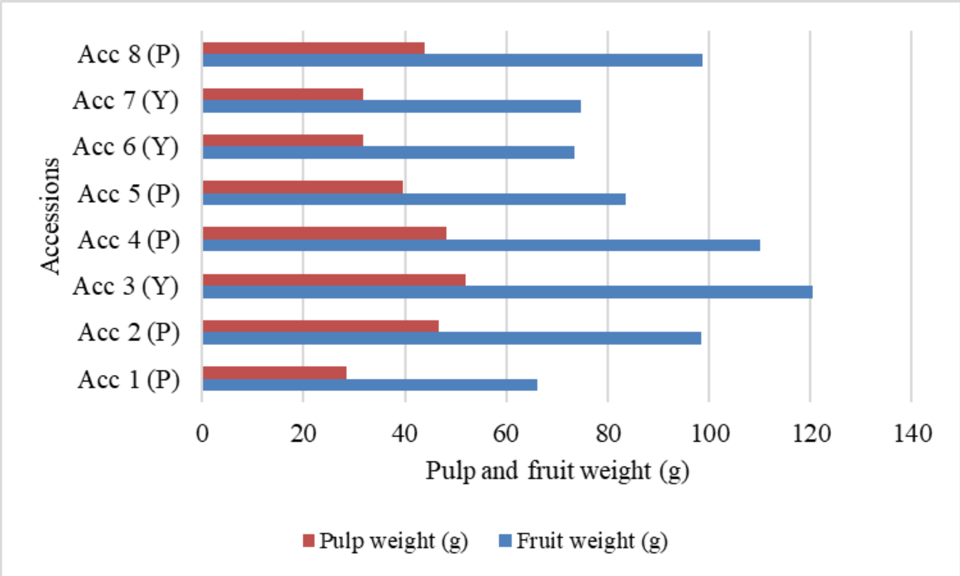


Figure 3. Pulp weight and fruit weight of passion fruit accessions

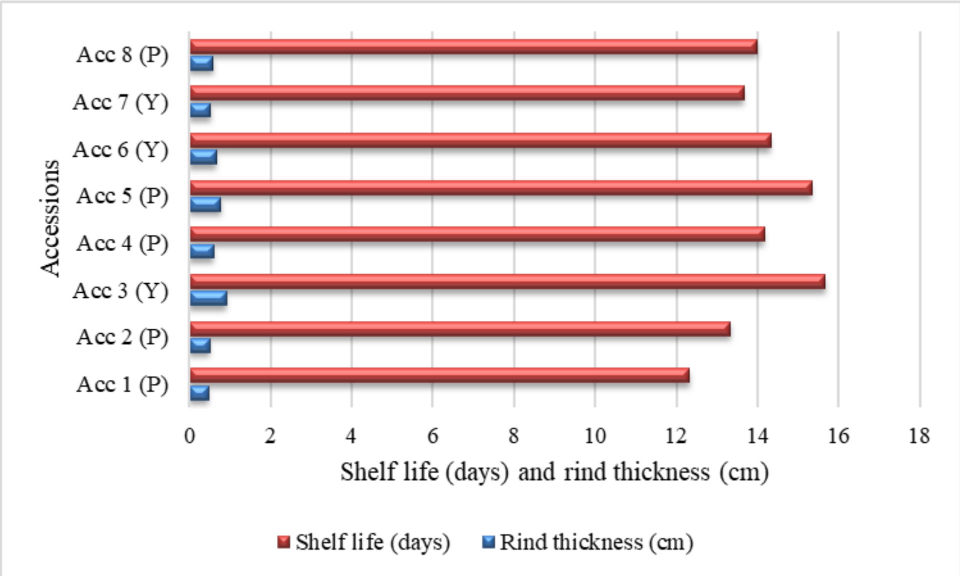


Figure 4. Shelf life and rind thickness of passion fruit accessions

4.1.5.10 Physical components of passion fruit accessions

Different accessions had significant effect on physical components, *viz*., juice per cent, rind per cent and seed per cent of passion fruit. The related data are presented in Table 13 and Figure 5.

Juice per cent varied from 34.05 (Accession 7) to 39.34 per cent (Accession 4). High juice recovery is of importance in the processing industry and value addition. Juice per cent recorded was the maximum in Accession 4 (39.34 %), which was on par with Accession 2 (39.00 %), Accession 8 (37.48 %) and Accession 5 (37.19 %). Eventhough the lowest juice per cent was found in Accession 7 (34.05 %) it was on par with Accession 1 (34.44 %), Accession 6 (34.96 %), Accession 3 (35.17 %), Accession 5 (37.19 %) and Accession 8 (37.48 %).

Juice per cent varied from 15.27 per cent to 46.46 per cent in different passion fruit accessions evaluated by Charan *et al.* (2018). This is in agreement with the values of juice per cent observed in the present findings where a narrow range could be observed from 34.05 to 39.34 per cent, which might be due to the genotypic variations.

Rind which constitutes the major waste portion in passion fruit was found to be maximum in Accession 7 (57.86 %), which was on par with Accession 1 (57.05 %), Accession 3 (56.78 %), Accession 6 (56.61 %) and Accession 8 (56.38 %). Lower rind per cent was observed in Accession 5 (52.55 %), which was on par with Accession 2 (52.61 %), Accession 4 (53.14 %) and Accession 8 (56.38 %) (Table 13).

Similar variations in rind weight per cent has been reported by other scientists also. The reports of Arjona *et al.* (1991) is in conformity with the findings of the present study. Charan *et al.* (2018) reported a variation in rind per cent from 37.78 to 78.12 per cent in the different passion fruit accessions evaluated.

Seed, which is another constituent of passion fruit, also showed significant variation among the different accessions studied (Table 13). The highest seed per cent was observed in Accession 5 (10.15 %), which was superior to all other accessions. This was followed by Accession 7 (9.10 %), which was on par with Accession 1 (8.58

%), Accession 6 (8.42 %) and Accession 2 (8.29 %). The lowest seed per cent was observed in Accession 8 (7.08 %), which was on par with Accession 4 (7.44 %).

Charan *et al.* (2018) found seed per cent difference in the range of 6.58 to 15.52 per cent in yellow accessions and 9.84 to 18.47 per cent in purple accessions, which is in consonance with the findings of the present study, where a range of 7.08 per cent to 10.15 per cent was noticed.

Accessions like Accession 4, 2, 8 and 5 with highest juice recovery and lower rind per cent may be exploited for processing industries, since they will be highly suitable for the preparation of value added products and beverages.

4.1.3.11 Rind and pulp colour of passion fruit accessions

Qualitative characters of passion fruit accessions, rind colour and pulp colour are shown in Table 14. Rind colour was yellow with white specks in Accession 3, Accession 6 and Accession 7 and purple with white specks in all other accessions. Pulp colour was deep yellow in Accession 3 and Accession 7, while it was yellowish orange in all other accessions.

Accessions like 3 (yellow) and 4 (purple) with superior fruit characters like fruit girth, fruit diameter, fruit weight, pulp weight and juice weight could be used for commercial cultivation as well as crop improvement programmes.

4.1.6 QUALITY CHARACTERS OF PASSION FRUIT ACCESSIONS

Quality characters of passion fruit accessions are given in Table 15 and Table 16. All the quality parameters studied varied significantly among the accessions.

4.1.6.1 TSS content of different passion fruit accessions

TSS content of passion fruit varied significantly among the accessions. High TSS of 18.33 °Brix was recorded in Accession 4, which was on par with Accession 8 (17.80 °Brix), Accession 2 (17.45 °Brix) and Accession 5 (17.33 °Brix) (Table 15, Figure 6). The minimum TSS was recorded in Accession 6 (13.00 °Brix) and Accession 3 (14.18 °Brix) which was on par with each other.

Table 13. Physical components of passion fruit accessions

Accessions	Physical components (%)		
	Juice (%)	Rind (%)	Seed (%)
Acc 1 (P)	34.44	57.05	8.58
Acc 2 (P)	39.00	52.61	8.29
Acc 3 (Y)	35.17	56.78	8.02
Acc 4 (P)	39.34	53.14	7.44
Acc 5 (P)	37.19	52.55	10.15
Acc 6 (Y)	34.96	56.61	8.42
Acc 7 (Y)	34.05	57.86	9.10
Acc 8 (P)	37.48	56.38	7.08
CD (0.05)	3.64	3.99	0.88

Table 14. Qualitative characters of passion fruit accessions

Accession	Rind colour	Pulp colour
Acc 1 (P)	Purple with white specks	Yellowish orange
Acc 2 (P)	Purple with white specks	Yellowish orange
Acc 3 (Y)	Yellow with white specks	Deep yellow
Acc 4 (P)	Purple with white specks	Yellowish orange
Acc 5 (P)	Purple with white specks	Yellowish orange
Acc 6 (Y)	Yellow with white specks	Yellowish orange
Acc 7 (Y)	Yellow with white specks	Deep yellow
Acc 8 (P)	Purple with white specks	Yellowish orange

According to Borges and Lima (2003) day light played an important role in the growth and development of passion fruit. An increase in day length duration enhanced photosynthetic activity, which resulted in increased fruit quality. Charan *et al.* (2018) also stated that the level of photosynthate accumulation depended on growing conditions and genotypes. Variations in TSS content observed in the present study might be due to the genotypic difference.

According to Kishore *et al*. (2011), TSS in purple passion fruit pulp was 15.30 °Brix. TSS of 16.20 °Brix was reported by Pongener *et al*. (2013) while evaluating the purple passion fruit. Ramaiya *et al.* (2014) reported a TSS range of 10.70 °Brix to 17.20 °Brix among the different passion fruit accessions evaluated. While evaluating promising passion fruit accessions at CHES, Chettalli variations in TSS from 12.20 °Brix in CHES PF-7 to 18.10 °Brix in CHES PF1-6 has been reported by Tripathi *et al.* (2014). Charan *et al.* (2018) recorded a TSS of 12.66 °Brix to 17.73 °Brix. The observed TSS values in the present study are in conformity with these reports by various researchers.

4.1.6.2 Acidity content of different passion fruit accessions

Statistical analysis of data pertaining to acidity showed significant difference among the accessions (Table 15, Figure 7). Eventhough the lowest acidity was recorded in Accession 2 (2.37 %), it was on par with Accession 5 (2.73 %) and Accession 8 (2.86 %). Maximum acidity was observed in Accession 6 (3.99 %) which was on par with Accession 3 (3.54 %).

Reis *et al*. (2018) reported that acidity content in yellow type was 9.06 per cent whereas purple type had an acidity of 2.83 per cent. Present study also revealed that yellow accessions had high acidity when compared to purple accessions which is in conformity with findings of Reis *et al.* (2018). According to Kishore *et al*. (2011), titrable acidity in purple passion fruit pulp was 3.80 per cent. Pongener *et al*. (2013) reported a titrable acidity of 2.34 per cent in purple passion fruit. The results of the present study are comparable with these findings.

Table 15. Quality characters of passion fruit accessions

Accession	TSS (° Brix)	Titrable Acidity (%)	Total sugars (%)	Reducing sugar (%)
Acc 1 (P)	16.17	3.15	10.86	6.66
Acc 2 (P)	17.45	2.37	9.47	5.94
Acc 3 (Y)	14.17	3.54	9.43	7.84
Acc 4 (P)	18.33	3.23	12.32	10.34
Acc 5 (P)	17.33	2.73	13.55	7.63
Acc 6 (Y)	13.00	3.99	11.85	9.14
Acc 7 (Y)	14.83	3.43	8.58	5.92
Acc 8 (P)	17.80	2.86	10.50	6.75
CD (0.05)	1.51	0.50	1.27	0.91

4.1.6.3 Total sugar content of different passion fruit accessions

Data regarding the total sugar content revealed significant difference among the accessions (Table 15). Maximum total sugar per cent was recorded in Accession 5 (13.55 %), which was on par with Accession 4 (12.32 %). The minimum total sugar per cent was obtained for Accession 7 (8.58 %), which was on par with Accession 3 (9.43 %) and Accession 2 (9.47 %).

Total sugar content was higher in purple accessions compared to yellow accessions as reported by many research workers. Since purple accessions had higher total sugar and lower acidity, purple types were sweeter compared to yellow accessions. Patel *et al.* (2014) also observed a similar trend in passion fruit. Charan *et al.* (2018) reported that total sugar content varied from 4.98 to 10.80 per cent in yellow accessions and 6.31 to 13.04 per cent in purple accessions. The present findings are in conformity with the reports of Patel *et al.* (2014) and Charan *et al.* (2018) and the total sugar ranged between 8.58 per cent (yellow type) and 13.55 per cent (purple type).

4.1.6.4 Reducing sugar content of passion fruit accessions

Data on reducing sugar content also varied significantly among different accessions (Table 15). The highest reducing sugar was recorded in Accession 4 (10.34 %), which was superior to all other accessions. It was followed by Accession 6 (9.14 %), which was on par with Accession 3 (7.84 %) and Accession 5 (7.63 %). The lowest reducing sugar was recorded in Accession 7 (5.92 %), which was on par with Accession 2 (5.94 %), Accession 1 (6.66 %) and Accession 8 (6.75 %).

Reducing sugars, glucose and fructose which are primarily responsible for adding to the sweetness which ranged from 2.34 per cent to 8.06 per cent in a study conducted by Charan *et al.* (2018), which is in accordance with the present findings in passion fruit.

4.1.6.5 Non reducing sugar content of different passion fruit accessions

Regarding non-reducing sugar per cent, Accession 5 recorded the highest non reducing sugar per cent of 5.92, which was superior to all other accessions (Table 16).

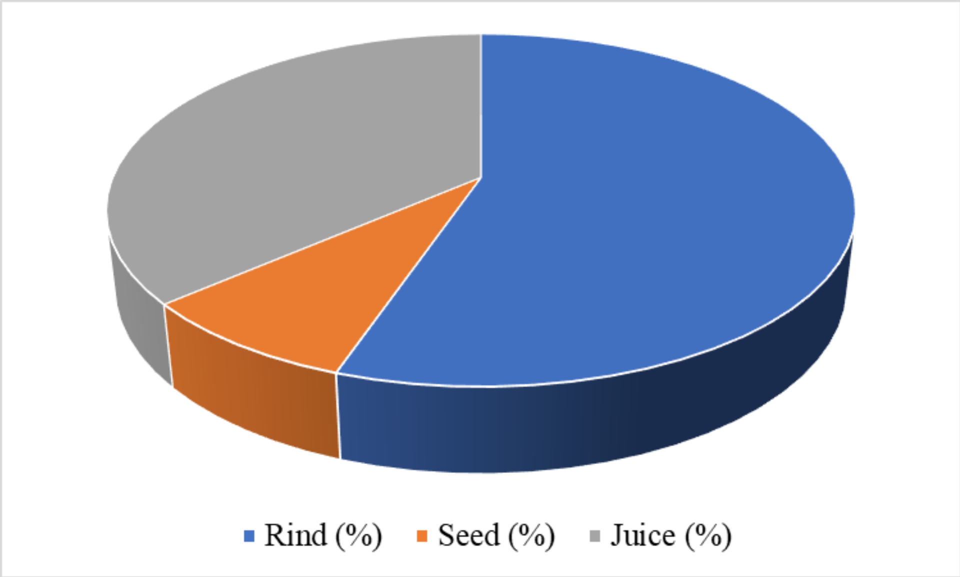


Figure 5. Physical components in passion fruit

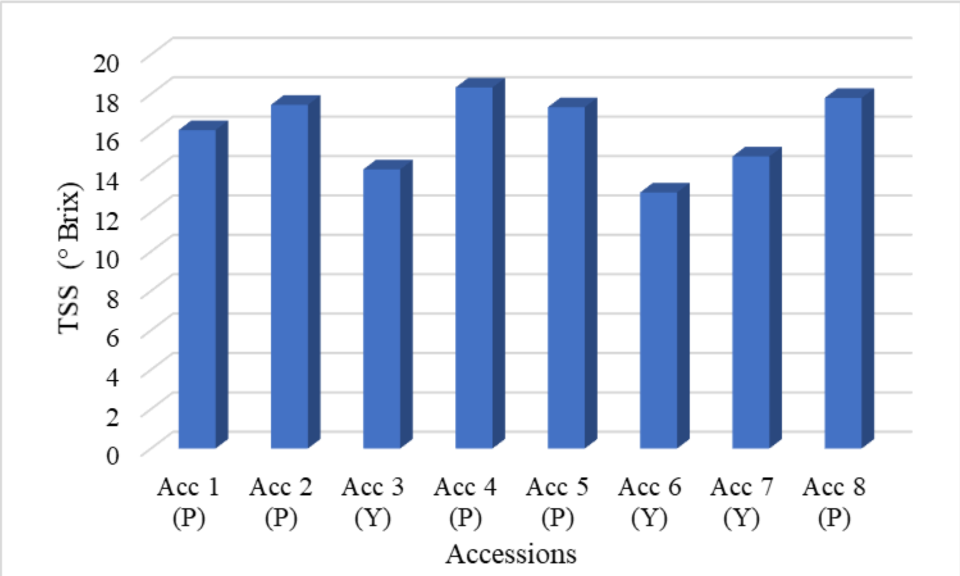


Figure 6. TSS content in different passion fruit accessions

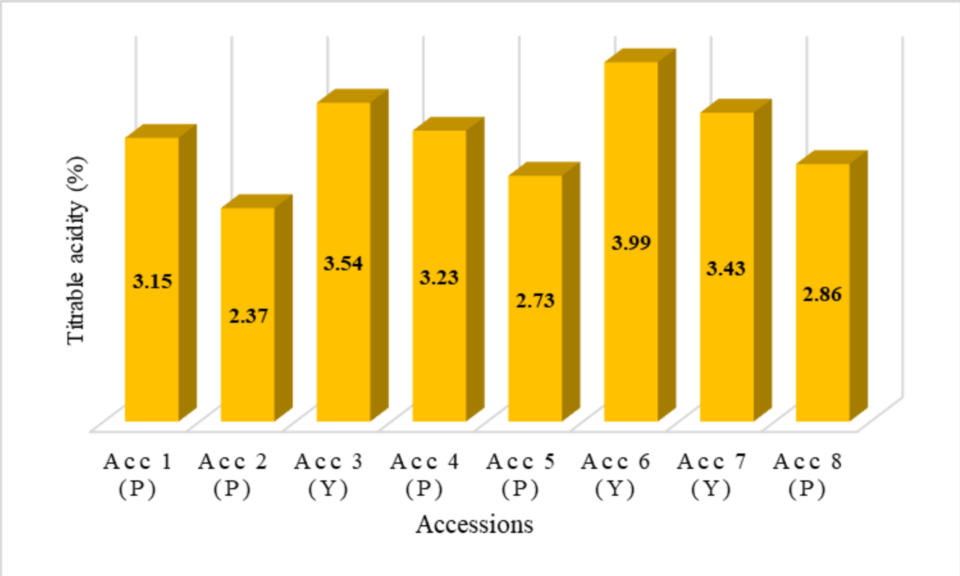


Figure 7. Titrable acidity content in passion fruit accessions

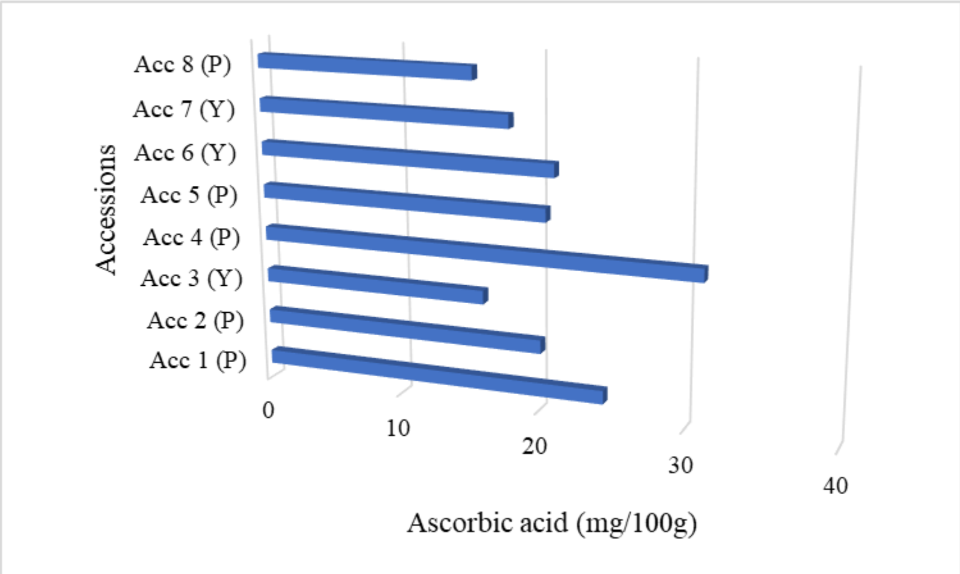


Figure 8. Ascorbic acid content in passion fruit accessions

Table 16. Quality characters of passion fruit accessions

Accession	Non reducing sugar (%)	Sugar/ acid ratio	Ascorbic acid (mg 100g^{-1})	Total carotenoids (mg 100g^{-1}**)**
Acc 1 (P)	4.20	3.44	24.52	1.17
Acc 2 (P)	3.52	4.00	20.17	1.27
Acc 3 (Y)	1.97	2.68	16.12	1.99
Acc 4 (P)	1.98	3.81	31.15	1.57
Acc 5 (P)	5.92	4.97	20.55	2.40
Acc 6 (Y)	2.71	2.99	21.14	1.90
Acc 7 (Y)	2.66	2.53	18.03	3.38
Acc 8 (P)	3.75	3.68	15.53	2.34
CD (0.05)	0.98	0.47	2.92	0.59

Table 17. Sensory evaluation of different passion fruit accessions

Accession	Appearance	Colour	Texture	Flavour	Taste	After taste	Odour	Overall acceptability
Acc 1 (P)	7.40	5.90	5.50	6.40	6.70	6.10	6.10	6.80
Acc 2 (P)	7.30	5.60	5.70	6.70	7.10	6.90	6.40	7.40
Acc 3 (Y)	6.90	6.40	5.70	7.00	6.70	6.40	6.20	6.50
Acc 4 (P)	7.00	6.90	5.70	6.70	7.10	6.70	5.90	7.60
Acc 5 (P)	7.10	6.10	6.10	7.40	6.20	6.50	6.10	6.80
Acc 6 (Y)	6.90	5.80	5.90	7.50	6.30	6.30	6.10	7.00
Acc 7 (Y)	7.20	6.30	5.90	7.10	6.40	5.90	6.30	6.70
Acc 8 (P)	6.90	6.40	5.60	6.70	6.60	6.50	5.60	7.00
K W value	3.86	13.16	2.98	11.41	9.90	7.10	3.93	11.96

Correlation coefficient matrix shows highly significant positive correlation of yield per vine with fruit diameter (0.80), fruit girth (0.80), fruit weight (0.76), pulp weight (0.77) and juice weight (0.84). Fruit weight had significant and positive correlation with rind weight (0.98), pulp weight (0.98), seed weight (0.78) and juice weight (0.98). Shelf life was positively and significantly correlated with rind thickness (0.95). Juice weight which is the commercial useful proportion is significantly and positively correlated with fruit diameter (0.98), fruit girth (0.98), rind weight (0.93), pulp weight (0.98) and seed weight (0.83).

In banana highly positive and significant association of bunch yield with number of fingers was reported by Rosamma and Namboodiri (1990) and George (1994). In grapes positive and significant correlations between fruit characters like bunch weight with bunch length (r = 0.76), width of bunch (r = 0.86), weigh of berry (r = 0.76), length of berry (r = 0.61) and diameter of berry (r = 0.76) has been reported by Leao *et al*. (2011). Highly significant positive correlation of bunch weight with fruit characters like number of fingers, pedicel strength index and number of hands was recorded by Joseph (2017) in Nendran banana. Joseph (2017) also reported that weight of finger had significant and positive correlation with fullness index, girth of finger and fruit curvature, which is in line with the results of the present study. From the correlation studies, it can be concluded that yield can be improved by exercising selection for the characters like fruit weight (0.76), fruit diameter and fruit girth (0.80), pulp weight (0.77) and juice weight (0.84).

Different accessions showed difference in physicochemical characters which helps to identify the suitable types for fresh consumption as well as for utilization in the processing industry.

Table 18. Correlation matrix for different characters of passion fruit accessions

Traits	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	1									
X2	0.80*	1								
X3	0.80*	1.00*	1							
X4	0.76*	0.97*	0.97*	1						
X5	0.68	0.94*	0.94*	0.98*	1					
X6	0.77*	0.97*	0.97*	0.98*	0.93*	1				
X7	0.61	0.78*	0.78*	0.85*	0.79*	0.90*	1			
X8	0.84*	0.98*	0.98*	0.98*	0.93*	0.98*	0.83*	1		
X9	0.08	0.31	0.31	0.50	0.53	0.47	0.71	0.37	1	
X10	0.15	0.41	0.41	0.55	0.56	0.54	0.72*	0.46	0.95*	1

X1 Yield/vine (kg)   X6 Pulp weight (g)   * significant at 5% level

X2 Fruit diameter (cm)   X7 Seed weight (g)

X3 Fruit girth (cm)   X8 Juice weight (g)

X4 Fruit weight (g)   X9 Rind thickness (cm)

X5 Rind weight (g)   X10 Shelf life (days)

The wide diversity among the different accessions found in the present investigation which can be attributed to changes in environmental factors and inherent characters of the genotype can be used as selection indices in breeding programs.

Therefore, Accession 4, which is early in flowering and fruiting, superior in yield, fruit and with high values for most of the quality characters can be considered superior and used for commercial cultivation and crop improvement programmes. Due to low levels of acidity and high TSS purple types was found to be sweeter and have good flavour compared to yellow accessions. Accessions like 4, 2, 8 and 5 which are having highest juice recovery with the lower rind per cent may be exploited for processing industries, since they will be highly suitable for the preparation of value added products and beverages. The Accession 4 (purple type) with highest TSS (18.33 °Brix), higher total sugar (12.32 %), highest reducing sugar (10.34 %) and highest ascorbic acid (31.15 mg $100g^{-1}$) can be selected as a superior accession based on quality parameters. Organoleptic analysis also revealed that Accession 4 had the highest score for overall acceptability, which shows the consumer preference of Accession 4. Based on the characterization of passion fruit accessions in the present study, further crop improvement programmes can be initiated to develop varieties suitable for fresh consumption and for processing industries by utilizing the accession which have the required characteristics.

4.2 Hybridization and selection in selected parents

There are only very limited number of cultivars and hybrids available in passion fruit which hinders the access of farmers to high-agronomic quality propagation materials as reported by Goncalves *et al.* (2007). Hence development of superior hybrids with high yield and quality will be useful for farmers for getting high returns and will result in area expansion of passion fruit cultivation. According to Goncalves *et al.* (2008) genetic breeding programs are emerging tools to identify superior genotypes. Crossing and selfing were conducted in six selected parents, P_1, P_2, P_3, P_4, P_5 and P_6 in all possible combinations. The accessions used were all purple coloured except P_6, which was yellow.

In the present hybridization work which involved six parents, only 8 crosses were successful as depicted from Table 19. Eventhough initial fruit set was observed in all the selfed purple coloured parents, only parent 3 has retained the selfed fruit until maturity and there was no fruit set in the selfed yellow coloured parent. Successful hybridization has been reported by various researchers in passion fruit (Rendon *et al.*, 2013; Cerqueira-Silva *et al*., 2015). Self-incompatibility in yellow coloured genotype may be the reason for the failure in setting fruits in parent 6. Self-incompatibility in yellow genotypes has been reported by Bruckner *et al.* (1995). The selfing and crossing resulted in 8 hybrids and one selfed progeny, *viz.,* (S_1 (P_3 x P_3), H_1 (P_3 x P_6), H_2 (P_4 x P_2), H_3 (P_4 x P_6), H_4 (P_5 x P_4), H_5 (P_6 x P_1), H_6 (P_6 x P_2), H_7 (P_6 x P_4) and H_8 (P_6 x P_5). In a cross between *Passifora incarnata* L. and *P. edulis* f. *flavicarpa* Degener, pollen-sterile and non-fruitful diploid hybrids were obtained. Treating the emergent F1 hybrids with colchicine restored fertility in some hybrids by doubling the chromosome number, but all plants were strongly self-incompatible with low pollen viability as reported by Ruberté-Torres and Martin (1974).

The successful hybrids and selfed progeny were evaluated at nursery stage and also at field level. The results and discussion on the evaluation of progenies conducted are briefed under the following heads.

I. Basic evaluation of hybrids/selfed seedlings in the nursery

II. Field evaluation of parents and hybrids/selfed seedlings

4.2.1 SEEDLING CHARACTERS OF HYBRIDS/SELFED SEEDLINGS

Observations on days for germination, seedling vigour index, number of leaves, total leaf area, seedling height and seedling girth were taken and the results are given in Table 20.

According to Vieira and Carneiro (2005) yellow passion fruit seeds germinated within two to three weeks after sowing. In the present study also the seeds of the crosses involving yellow parent had taken two weeks' time for germination.

Rego *et al*. (2014) reported that seed coat of yellow passion fruit was hard which inhibited water uptake to an extent, mechanical restraint to radicle protrusion and also interfered with gas exchange. In the present study, the time taken for germination of passion fruit hybrid/ selfed seeds ranged between 13.00 to 19.33 days, comparatively larger duration when compared to other fruit crops which might be due to the hard seed coat as reported by Rego *et al.* (2014).

Table 19. Diallel mating carried out in the hybridization programme

Parents	Female / Male	P_1	P_2	P_3	P_4	P_5	P_6
P_1		SC	x	x	x	x	CC
P_2		x	SC	x	CC	x	CC
P_3		x	x	SC	x	x	x
P_4		x	x	x	SC	CC	CC
P_5		x	x	x	x	SC	CC
P_6		x	x	CC	CC	x	SI

CC-Cross Compatible, SC-Self Compatible, SI - Self incompatible, x – Not successful

Table 20. Seedling characters of passion fruit selfed and hybrid seedlings

Selfed/ Hybrid No.	Days for germination	Seed germination (%)	Seedling vigour index	No. of leaves	Total leaf area (cm^2)	Seedling height (cm)	Seedling girth (cm)
S_1 (P_3 x P_3)	18.33	82.98	9.67	7.00	111.83	11.67	0.57
H_1 (P_3 x P_6)	19.33	78.78	9.73	6.67	106.17	12.33	0.57
H_2 (P_4 x P_2)	15.00	76.26	8.39	5.00	103.67	11.00	0.70
H_3 (P_4 x P_6)	19.33	86.74	12.87	5.00	100.83	14.83	0.63
H_4 (P_5 x P_4)	17.33	78.49	14.17	10.33	181.17	18.00	1.20
H_5 (P_6 x P_1)	13.00	85.04	13.75	7.33	131.83	16.17	0.60
H_6 (P_6 x P_2)	16.33	90.12	15.09	8.33	170.83	16.83	0.80
H_7 (P_6 x P_4)	15.67	85.45	14.05	8.00	153.83	16.50	0.60
H_8 (P_6 x P_5)	14.33	83.11	12.73	5.33	123.83	15.33	0.63
CD (0.05)	1.32	5.80	3.10	1.95	23.26	4.75	NS

The present results are in conformity with the finding of PRS (2015). According to them passion fruit seeds started germinating five days after sowing and the germination extended up to 30 days.

4.2.1.2 Seed germination (%)

The hybrids showed significant difference with respect to per cent seed germination (Table 20). The maximum seed germination was observed in H_6 (90.12 %) which was on par with H_3 (86.74 %), H_7 (85.45 %) and H_5 (85.04 %). It was followed by H_8 (83.11 %), which was on par with S_1 (82.98 %), H_1 (78.78 %) and H_4 (78.49 %). The lowest seed germination per cent was recorded in H_2 (76.26 %).

According to PRS (2015) germination per cent of different passion fruit accessions varied and it was in the range of 18 - 95 per cent. The maximum germination of 95 per cent was reported in Kaveri, followed by 88 per cent in 142 P and 85 per cent in 134 P. In the present study germination per cent varied between 76.26 to 90.12 per cent. The high germination per cent could be attributed to the difference in the genetic make-up of the hybrids.

Ghosh *et al.* (2017) in a study conducted to find best pre-germination methods to enhance the germination in *P. edulis* var. *flavicarpa,* reported a germination of 89.51 per cent which is comparable with the results of the present study.

4.2.1.3 Seedling vigour index

Seedling vigour index varied significantly among different hybrids (Table 20, Figure 9). The maximum seedling vigour index was exhibited by H_6 (15.09) which was on par with H_4 (14.17), H_7 (14.05), H_5 (13.75), H_3 (12.87) and H_8 (12.73). The lowest seedling vigour index was observed in H_2 (8.39) which was on par with S_1 (9.67) and H_1 (9.73).

Gurung *et al.* (2014) in a study to evaluate the influence of different days of sowing on germination, growth and vigour of passion fruit seedlings reported a vigour index of 15.36 in the control treatment, which is comparable with the values obtained in the present study. The significant variations in seedling vigour index observed in the present study might be due to the difference in the genetic make-up of the hybrids which is in agreement with the reports of Souto *et al*. (2017) that germination characters in passion fruit seedlings were connected to genotype of the plant.

4.2.1.4 Number of leaves

Significant variation was observed in number of leaves among different hybrids (Table 20). The highest number of leaves was recorded in H_4 (10.33), which was significantly superior to all other treatments and was followed by H_6 (8.33). The least number of leaves was observed in H_2 (5.00) which was on par with H_3 (5.00), H_8 (5.33) and H_1 (6.67).

In an experiment to find best pre-germination method to enhance the germination in *P. edulis* var. *flavicarpa* seeds, it was found that number of leaves were 11.20 and 3.53 (Ghosh *et al*., 2017). This agrees with the results of the present study, since the number of leaves ranged between 5.00 and 10.33.

4.2.1.5 Total leaf area

Total leaf area revealed significant difference among the hybrids. Maximum total leaf area was exhibited by H_4 (181.17 cm^2) which was on par with H_6 (170.83 cm^2). The lowest total leaf area was observed in H_3 (100.83 cm^2) which was on par with H_2 (103.67 cm^2), H_1 (106.17 cm^2), S_1 (111.83 cm^2) and H_8 (123.83 cm^2) (Table 20).

The significant variations in total leaf area could be due to the differences observed in number of leaves. The hybrids H_5 and H_7 which had more number of leaves, 10.33 and 8.33 respectively recorded the highest leaf area, since leaf area is dependent on number of leaves.

4.2.1.6 Seedling height

Seedling height of different hybrids varied significantly. Seedling height was maximum in H_4 (18.00 cm) which was on par with H_6 (16.83 cm), H_7 (16.50 cm), H_5 (16.17 cm), H_8 (15.33 cm) and H_3 (14.83 cm). H_2 recorded the lowest seedling height of 11.00 cm, which was on par with S_1 (11.67 cm) and H_1 (12.33 cm) (Table 20).

In a study conducted to evaluate the seed viability and germination characteristics of passion fruit seedlings, Gurung *et al.* (2014) recorded a seedling height of 13.10 cm in the control treatment. Ghosh *et al.* (2017) also reported a seedling height of 15.88 cm in passion fruit seedling in the control treatment when conducted a pre germination study in passion fruit. The present results are in accordance with these findings.

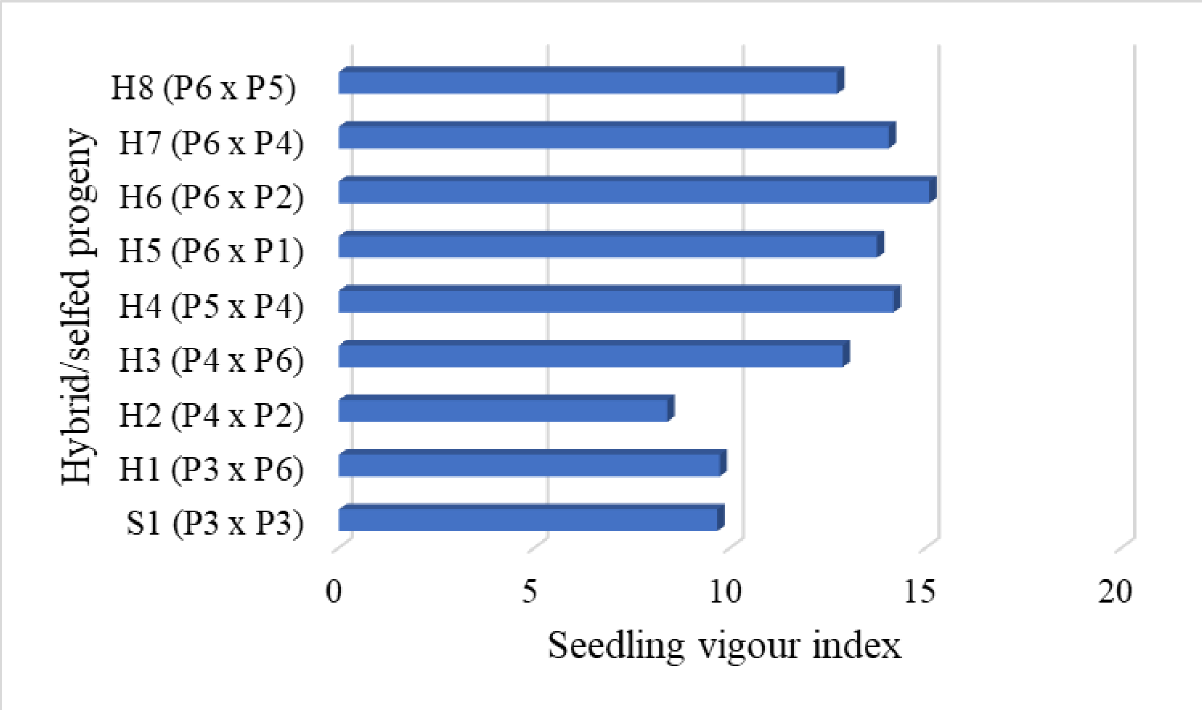


Figure 9. Seedling vigour index of passion fruit hybrids and selfed progeny

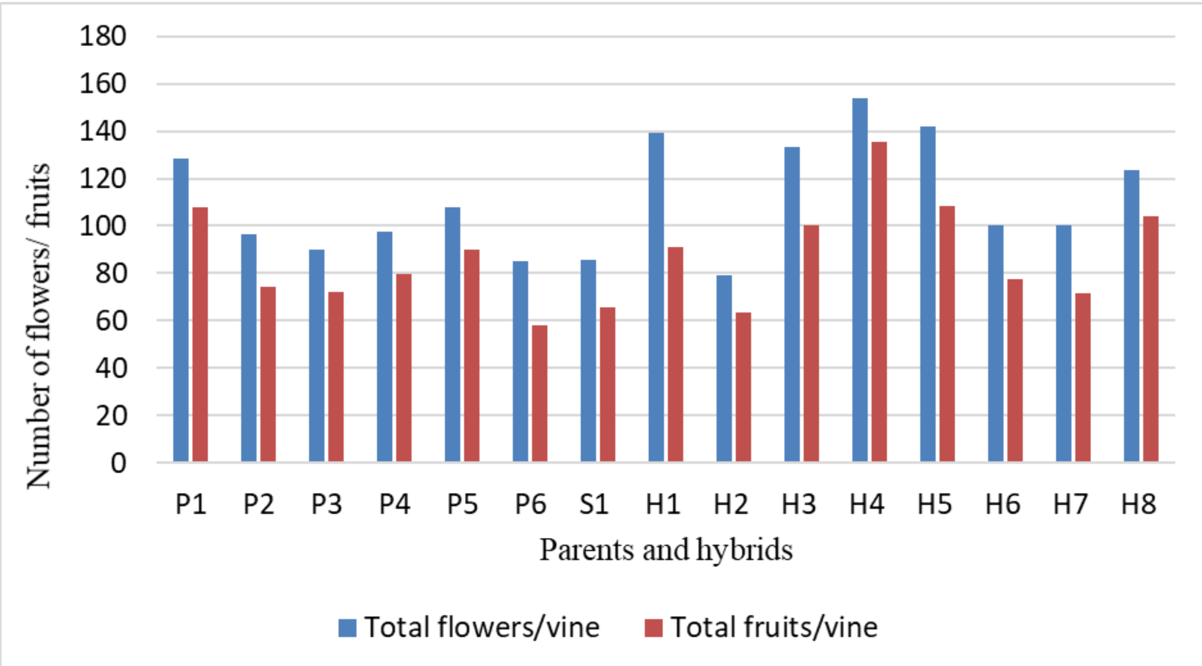


Figure 10. Total number of flowers and fruits per vine of passion fruit parents, hybrids and selfed progeny

4.2.1.7 Seedling girth

Seedling girth of different hybrids did not vary significantly. It was in the range of 0.57 cm (S_1 and H_1) to 1.20 cm in H_4 (Table 20).

Similar studies in passion fruit hybrid seedlings were reported earlier. Commercially passion fruit plants are propagated by seeds, however, irregular germination and heterozygous nature results in lack of uniformity in progeny. The germination characteristics of any plant are directly linked to the genotype. Souto *et al*. (2017) evaluated the germination and early growth characters of passion fruit hybrid seedlings. They reported significant variation in germination and seedling characters like time taken for germination, emergence speed index, seedling height, length of shoots and roots, and the individual seedling dry matter (root + shoot). They recommended HB2 as a genotype with good potential for breeding programs since it showed superior germination and seedling characters. In the present experiment also, significant differences could be observed among the hybrid/selfed seedlings with respect to seed germination, seedling height, leaf number and leaf area, which is in agreement with the report of Souto *et al*. (2017). In the present study, hybrids like H_6 (P_6 x P_2) with highest values for seed germination per cent (90.12 %), seedling vigour index (15.09) and comparatively higher leaf area (170.83 cm^2) and seedling height (16.83 cm) and seedling girth (0.80 cm) as well as hybrid H_4 (P_5 x P_4) with highest values for leaf area (181.17 cm^2), seedling height (18.00 cm) and with comparatively higher seedling vigour index can be considered superior in seedling characters.

II. Field evaluation of parents and hybrids/selfed seedlings

Results and discussion on flower, fruit and yield characters of the parental accessions along with the developed hybrids/selfed progeny are presented here under.

4.2.2 VEGETATIVE CHARACTERS OF HYBRIDS/SELFED AND PARENTS

Vegetative characters of parents and hybrids/selfed progeny are presented in Table 21.

4.2.2.1 Stem girth (cm)

Stem girth of hybrids and parents did not vary significantly. It ranged from 8.50 cm in P_1 and P_3 to 11.75 cm in H_6 (Table 21).

Table 21. Vegetative characters of different parents and hybrids /selfed progeny of passion fruit at 12 MAP

Parent/ hybrid/selfed	Stem girth (cm)	No. of branches
P_1	8.50	8.50
P_2	10.00	6.50
P_3	8.50	7.25
P_4	9.50	7.00
P_5	9.50	7.00
P_6	9.25	7.50
S_1 (P_3 x P_3)	10.00	6.15
H_1 (P_3 x P_6)	10.00	7.50
H_2 (P_4 x P_2)	9.75	7.85
H_3 (P_4 x P_6)	11.25	6.50
H_4 (P_5 x P_4)	10.50	8.50
H_5 (P_6 x P_1)	9.50	7.50
H_6 (P_6 x P_2)	11.75	8.75
H_7 (P_6 x P_4)	11.00	6.00
H_8 (P_6 x P_5)	10.50	8.00
CD (0.05)	NS	NS

4.2.2.2 Number of branches

Number of branches did not vary significantly among different parents and hybrids/selfed progeny. It varied from 6 in H_7 to 8.75 in H_6 (Table 21).

4.2.3 FLOWER CHARACTERS OF HYBRIDS AND PARENTS

Flower characters of parents and hybrids/selfed progenies are represented in Table 22.

Studying the flowering behavior is very much important in the breeding program which is directly connected to the yield also. Data on flower characters of parents and hybrids/selfed progeny are presented in Table 22.

4.2.3.1 Time of anthesis (H)

Anthesis time of hybrids and parents was in the range of 12.52 in P_6 to 14.05 in H_7 (Table 22).

4.2.3.2 Flower bud initiation to anthesis (days)

Days taken from flower bud initiation to anthesis did not vary significantly among the treatments. It was in the range of 16 days (H_5) to 24 days (P_2 and H_1) (Table 22).

Banu *et al*. (2009) reported that passion fruit required 10.00 to15.00 days from flower bud initiation to flower opening at different seasons. According to PRS (2015) it was 10-14 days among the passion fruit accessions evaluated. Montero *et al*. (2013) observed that *Passiflora edulis* took 12-15 days from flower bud initiation to anthesis. The present observation on days from flower bud initiation to anthesis is in agreement with the findings of these earlier researchers. These might be due to the genotypic difference in the hybrids.

4.2.3.3 Anthesis to fruit set (days)

Days taken from anthesis to fruit set did show significant variation among the treatment plants, which ranged from 2.00 days (P_2) to 3.50 days (H_5) (Table 22).

Table 22. Flower characters of different parents and hybrids/selfed progeny of passion fruit

Parent/ hybrid no.	Time of anthesis	Flower bud initiation to anthesis (days)	Anthesis to fruit set (days)	Fruit set (%)	Pollen viability (%)	Stigma receptivity
P_1	12.53 p.m.	23.50	2.50	84.10	89.50	Receptive
P_2	01.08 p.m.	24.00	2.00	76.54	92.00	Receptive
P_3	01.05 p.m.	22.00	3.00	80.02	89.00	Receptive
P_4	01.35 p.m.	21.00	3.00	81.54	91.00	Receptive
P_5	01.18 p.m.	19.50	2.50	82.90	87.50	Receptive
P_6	12.52 p.m.	21.50	2.50	68.49	89.67	Receptive
S_1 (P_3 x P_3)	01.45 p.m.	20.00	3.00	75.79	85.50	Receptive
H_1 (P_3 x P_6)	02.19 p.m.	24.00	2.50	66.39	87.38	Receptive
H_2 (P_4 x P_2)	01.25 p.m.	17.00	2.50	80.25	89.44	Receptive
H_3 (P_4 x P_6)	01.29 p.m.	18.50	2.50	74.93	89.50	Receptive
H_4 (P_5 x P_4)	01.13 p.m.	16.50	2.50	87.99	88.00	Receptive
H_5 (P_6 x P_1)	01.10 p.m.	16.00	3.50	76.65	89.50	Receptive
H_6 (P_6 x P_2)	01.53 p.m.	19.00	2.50	76.78	87.00	Receptive
H_7 (P_6 x P_4)	01.05 p.m.	20.00	2.50	71.57	88.00	Receptive
H_9 (P_6 x P_5)	01.28 p.m.	17.50	3.00	84.42	88.50	Receptive
CD (0.05)	-	NS	NS	NS	NS	-

4.2.3.4 Fruit set (%)

Per cent of fruit set did not vary significantly among the treatments. It varied from 71.57 per cent in H_7 to 87.99 per cent in H_4 (Table 22).

4.2.3.5 Pollen viability (%)

Pollen viability per cent of different treatment plants did not show significant variation. The pollen viability ranged from 85.50 per cent in S_1 to 92.00 per cent in P_2 (Table 22).

4.2.3.6 Stigma receptivity

Stigma was receptive at the time of anthesis in all passion fruit hybrids/selfed progeny and parents. Ruberté-Torres and Martin (1974) produced 6 new hybrids from 42 cross combinations among 7 passion fruit species, demonstrating the possibility of cross breeding among passion fruit species to enhance characters of edible passion fruit. When used as female parents, they showed enough fertility to permit seed production.

4.2.4 PHENOLOGICAL CHARACTERS OF PASSION FRUIT PARENTS AND HYBRIDS/SELFED PROGENY

Duration for first flowering, first fruiting and flowering to harvest of passion fruit parents and hybrids/selfed progeny are represented in Table 23.

4.2.4.1 Days taken for first flowering

Days taken for first flowering varied significantly among the parents and hybrids. The minimum number of days for flowering was observed in H_5 (200.00 days) which was on par with P_1 (200.50 days). The maximum days to first flowering was observed in P_6 (295.00 days) which was on par with H_6 (273.50 days), H_3 (271.50 days), P_4 (268.50 days), S_1 (268.00 days), P_2 (261.50 days), H_1 (259.50 days) and P_5 (259.50 days) (Table 23).

Montero *et al*. (2013) reported that the first flowering in *Passiflora edulis* was noticed in 34 weeks (238 days) after transplanting. According to Rao *et al.* (2013), hybrid Kaveri took 263.75 days to first flowering. In a study conducted by PRS (2015) on blooming pattern of fifty passion fruit accessions, it was revealed that

Kaveri, which is a hybrid, came to flower early, which took 222.47 days and the last accession to produce flower was VP which took 287.50 days to flower. So, a difference of 65.03 days was observed in the inception of flowering of various accessions. On an average different accession took an average of 252.86 days for first flowering.

In the present experiment also, the minimum number of days to first flowering was observed in H_5 which took 200 days and maximum number of days was observed in P_6 (295.00 days) during the first year of flowering. This is in line with the findings of PRS (2015). There was a difference of 95 days between accessions in the inception of flowering. The early flowering group consisted of H_5 (200.00 days) and P_1 (200.50 days). The late flowering types consisted of P_6 (295.00 days), H_6 (273.50 days), H_2 (271.50 days), P_4 (268.50 days), S_1 (268.00 days), P_2 (261.50 days), H_1 and P_5 (259.50 days). The hybrids which took minimum number of days for flowering can be grouped as early flowering types for getting early yields.

4.2.4.2 Days taken for first fruiting

Days taken for first fruiting revealed significant variation among different parents and hybrids. Minimum number of days to first fruiting was recorded in H_5 (205.00 days) which was on par with P_1 (206.00 days), H_3 (230.00 days) and H_4 (237.00 days). The time for first fruiting was maximum in P_6 (298.50 days) (Table 23). The variation in days taken for first flowering would have contributed to the significant changes in days taken for first fruiting.

4.2.4.3 Flowering to harvest duration (days)

Total number of days taken from flowering to harvest varied significantly among the parents and hybrids. Minimum number of days from flowering to harvest was observed in P_2 (58.50 days), which was on par with H_3 (59.00 days), H_2 (61.00 days), S_1 (66.00 days), P_3 (66.00 days), P_1 (67.00 days) and H_5 (67.50 days). Maximum days from flowering to harvest was observed in H_8 (85.00 days). However, there was no significant difference between H_8, H_7, H_4, H_1, P_4, P_5 and P_6 (Table 23).

Table 23. Phenological characters of passion fruit parents, selfed and hybrid progenies

Parent/ hybrid/selfed	Duration (days)		
	First flowering	First fruiting	Flowering to harvest
P_1	200.50	206.00	67.00
P_2	261.50	266.00	58.50
P_3	250.00	253.00	66.00
P_4	268.50	271.50	75.00
P_5	259.50	263.00	80.50
P_6	295.00	298.50	81.50
S_1 (P_3 x P_3)	268.00	270.00	66.00
H_1 (P_3 x P_6)	259.50	262.50	74.00
H_2 (P_4 x P_2)	271.50	274.50	61.00
H_3 (P_4 x P_6)	215.50	230.00	59.00
H_4 (P_5 x P_4)	233.50	237.00	76.50
H_5 (P_6 x P_1)	200.00	205.00	67.50
H_6 (P_6 x P_2)	273.50	278.50	72.50
H_7 (P_6 x P_4)	244.50	250.50	82.00
H_8 (P_6 x P_5)	235.00	266.50	85.00
CD (0.05)	41.81	42.85	11.01

The variations observed in flowering to harvest duration might be due to its dependency on genetic makeup of the genotypes. Deshmukh *et al.* (2017) reported a flowering to harvest duration of 80-90 days. According to Tripathi (2018), 60 to 70 days were required from flowering to harvest in passion fruit. The present findings are comparable with these earlier reports by scientists.

4.2.5 YIELD CHARACTERS OF PASSION FRUIT PARENTS AND HYBRIDS/ SELFED PROGENY

4.2.5.1 Flower production of passion fruit parents and hybrids at monthly intervals

The monthly flower production of passion fruit hybrids/selfed and parents are presented in Table 24.

Flower production was non-significant in all the months studied, except in the month of May (Table 24).

Flower production in December was the highest in H_5 (3.50), while there was no flower production in most of the hybrids and parents (Table 24).

In the month of January, flower production was the highest in H_4 (23.00). There was no flower production in P_4, P_5, P_6, S_1, H_2 and H_6. In February, flower production was in the range of 9.00 in H_6 to 41.00 in H_4. Flower production in March, varied from 17.00 in P_6 to 53.50 in H_5 (Table 24). Production of flowers in the month of April was in the range of 18.00 in P_3 to 34 in P_1. Flower production in May showed significant variation among the parents and hybrids (Table 24).

The maximum flower production was observed in P_6 (32.00) which was on par with P_5 (29.00) and S_1 (26.00). Minimum flowers were produced in P_3 (17.00) which was on par with H_4 (17.50), P_2 and H_3 (18.00), H_2 and H_8 (18.50), P_1 (22.00), H_7 (22.50), P_4 and H_6 (23.00) (Table 24).

4.2.5.2 Total flower production per vine per year

Total flower production in different parents and hybrids did not show significant difference and it was in the range of 79.00 in H_3 to 154.00 in H_4 (Table 24, Figure 10).

According to Ulmer and Macdougal (2004), passion fruit flowers throughout the year and has abundant blooms. Ullah *et al*. (2009) reported that passion fruit is photosensitive in nature, characterized as a long day plant which required a day length of 10.50 h for flowering. The pattern of flower initiation and flower opening directly influence the fruiting pattern. Hence, studying the flowering pattern helps in identifying the fruiting pattern.

According to the reports of PRS (2015), on an average, the flowering started in March slowly increasing from April and peak flowering was noticed in June. In most of the accessions, flowering exhibited a declining pattern progressively during July-November months. Slight differences from this common trend was observed in certain genotypes in the blooming patterns, might be due to the genotypic character.

Among parents, P_1 and among hybrids, H_3 (P_4 x P_6), H_5 (P_6 x P_1) and H_7 (P_6 x P_4) started flowering in December and showed a progressive trend till March. All these parents and hybrids showed longer period of flower production which directly influence the yield. All the parents and hybrids started flowering at least by March (Table 24).

Based on monthly flower production, profused flowering was observed in hybrid, H_5 (P_6 x P_1), which had 53.50 flowers in March, followed by H_4 (P_5 x P_4) which had 46.50 flowers (Table 24).

Ruberté-Torres and Martin (1974) produced 6 new hybrids from 42 cross combinations among 7 passion fruit species, demonstrating the possibility of cross breeding among passion fruit species and most of the hybrids obtained were vigorous with slight variations in the flowering behaviour. This in support with the variations in flowering observed in the present experiment.

According to the reports of PRS (2015) from March-November profuse flowering was noted in Kaveri (100.32) and least flowers in 143P (25.38). In the present experiment from a period from December to May the highest number of flowers was observed in H_4 (P_5 x P_4) which produced 154 flowers and the lowest flower production was noted in H_2 (P_4 x P_2) (79 flowers). The variations in flower production may be due to the differences in fertilizers applied, climate, soil factors and the particular genetic constitution of different types. Kishore *et al.* (2010) found that different species of cultivated *Passiflora* spp. responded differently in different environments. Das *et al*. (2013) also reported variations in blooming pattern of passion fruit under varied flashes in Bangladesh. This is also supported by the finding of PRS (2015) who reported that the passion fruit types evaluated revealed differences and some amount of similarities in their flowering behavior. The present findings are in line with these earlier reports.

4.2.5.3 Peak flowering month

Peak flowering month was identified as March in all passion fruit parents and hybrids, except in P_6 and S_1 (P_3 x P_3) where peak flowering was observed in May (Figure 11). So, it could be inferred that peak flowering month is a character associated with the genotype. Kishore *et al.* (2010) reported peak flowering period of March-June whereas, PRS (2015) reported June-August as peak flowering period. The difference might be due to the variations in planting time and inherent character of the genotypes.

4.2.5.4 Fruit production of passion fruit hybrids and parents at monthly interval

Fruit production of different passion fruit hybrids and parents are given in Table 25.

Fruit production in December did not show significant variation among different hybrids and parents. Only one fruit was observed in P_1, H_3, H_5 and H_7. Other parents and hybrids did not produce fruits (Table 25).

In the month of January, flower production showed significant difference among the hybrids and parents evaluated. The highest fruit production was recorded in H_8 (20.00) which was on par with H_4 (19.50) and H_3 (16.50). H_2, S_1, P_6, P_5, P_4, H_1 and H_6 did not produce fruits (Table 25).

Fruit production in February did not vary significantly even though it was highest in 37.50 in H_4. P_6 did not produce any fruits during February (Table 25).

There was no significant difference in fruit production during March and it ranged from 10.00 in P_6 to 41.50 in H_4 (Table 25).

In the month of April also fruit production did not vary significantly and it was in the range of 15.00 in P_3 to 27.50 in P_1 and H_9 (Table 25).

Table 24. Flower production in passion fruit hybrids and parents

Parent/ hybrid no.	Flower production (Number/vine)						
	December '19	January '20	February '20	March '20	April '20	May '20	Total flowers
P_1	2.50	12.00	20.00	38.00	34.00	22.00	128.50
P_2	0.00	7.00	18.00	27.50	26.00	18.00	96.50
P_3	0.00	8.50	18.00	28.50	18.00	17.00	90.00
P_4	0.00	0.00	12.50	35.00	27.00	23.00	97.50
P_5	0.00	0.00	16.00	34.00	29.00	29.00	108.00
P_6	0.00	0.00	10.00	17.00	26.00	32.00	85.00
S_1 (P_3 x P_3)	0.00	0.00	12.50	22.50	24.50	26.00	85.50
H_1 (P_3 x P_6)	0.00	22.00	31.00	41.00	20.00	25.00	139.00
H_2 (P_4 x P_2)	0.00	0.00	13.50	24.50	22.50	18.50	79.00
H_3 (P_4 x P_6)	2.00	21.50	36.50	32.00	23.50	18.00	133.50
H_4 (P_5 x P_4)	0.00	23.00	41.00	46.50	26.00	17.50	154.00
H_5 (P_6 x P_1)	3.50	17.00	20.00	53.50	24.00	24.00	142.00
H_6 (P_6 x P_2)	0.00	0.00	9.00	41.50	27.00	23.00	100.50
H_7 (P_6 x P_4)	1.50	3.50	19.00	25.50	28.00	22.50	100.00
H_8 (P_6 x P_5)	0.00	22.50	30.00	21.50	31.00	18.50	123.50
CD (0.05)	NS	NS	NS	NS	NS	6.35	NS

Table 25. Fruit production in passion fruit parents and hybrids

Parent/ hybrid no.	Fruit production (Number/vine)						
	December ‘19	January ‘20	February ‘20	March ‘20	April ‘20	May ‘20	Total fruits
P_1	1.00	10.00	17.50	33.50	27.50	18.50	108.00
P_2	0.00	4.00	14.00	22.00	20.00	14.00	74.00
P_3	0.00	4.50	15.00	21.50	15.00	16.00	72.00
P_4	0.00	0.00	7.00	30.00	24.00	18.50	79.50
P_5	0.00	0.00	12.00	29.00	24.00	25.00	90.00
P_6	0.00	0.00	0.00	10.00	20.50	27.50	58.00
S_1 (P_3 x P_3)	0.00	0.00	8.50	20.00	18.00	19.00	65.50
H_1 (P_3 x P_6)	0.00	0.00	21.00	35.50	15.00	19.50	91.00
H_2 (P_4 x P_2)	0.00	0.00	11.00	20.00	18.50	14.00	63.50
H_3 (P_4 x P_6)	1.00	16.50	26.00	27.00	17.50	12.50	100.50
H_4 (P_5 x P_4)	0.00	19.50	37.50	41.50	21.50	15.50	135.50
H_5 (P_6 x P_1)	1.00	11.50	15.00	40.00	21.50	19.50	108.50
H_6 (P_6 x P_2)	0.00	0.00	1.00	31.00	23.50	22.00	77.50
H_7 (P_6 x P_4)	1.00	2.50	5.50	22.50	23.00	17.00	71.50
H_8 (P_6 x P_5)	0.00	20.00	19.50	22.00	27.50	15.00	104.00
CD (0.05)	NS	4.81	NS	NS	NS	5.40	39.48

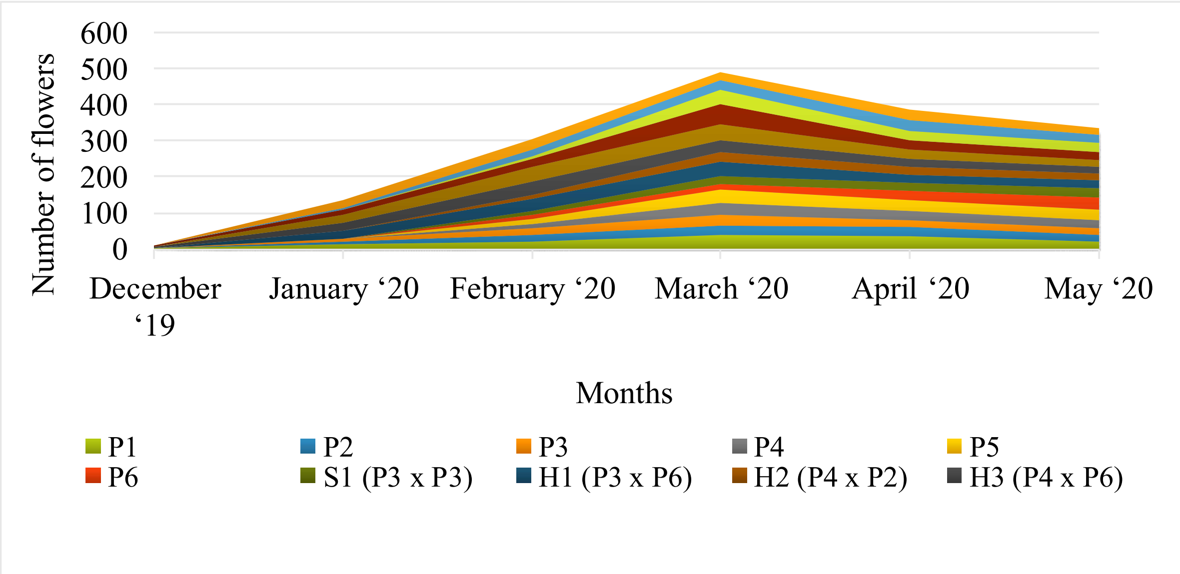


Figure 11. Monthly flowering in passion fruit parents, hybrids and selfed progeny

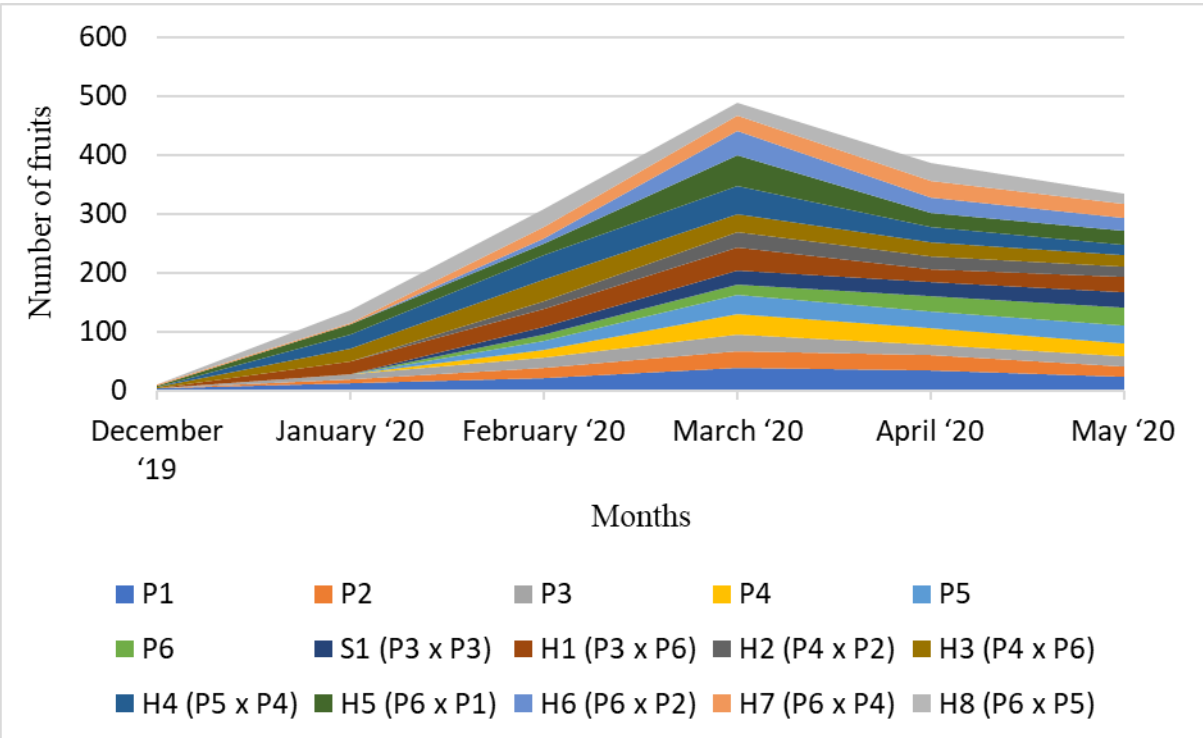


Figure 12. Monthly fruiting in passion fruit parents, hybrids and selfed progeny

During May, fruit production varied significantly among different parents and hybrids studied. The highest fruit production was shown by P_6 (27.50) which was on par with P_5 (25.00). H_3 showed the lowest fruit production of 12.50, which was on par with H_1 and P_2 (14.00), H_4 (15.50), P_3 (16.00) and H_7 (17.00) (Table 25).

4.2.5.5 Total fruit production per vine per year

Total fruit production per vine showed significant variation among the passion fruit parents and hybrids. The highest fruit production was observed in H_4 (135.00) which was on par with H_5 (108.50), P_1 (108.00), H_8 (104.00) and H_3 (100.50). The lowest flower production was observed in P_6 (58.00) (Table 25, Figure 10).

According to the reports of Rao *et al.* (2013) hybrid Kaveri produced 166.71 fruits per plant per year, which is in accordance with the present finding.

The significant variations in fruit production might be due to the specific combining ability of parents used in the hybridization studies which ultimately influenced the vigor and thereby fruit production of passion fruit hybrids (Souto *et al*., 2017).

Carpenter bees (*Xylocopa* sp.) are the main pollinators of passion fruit which are large solitary bees. Reduction in pollinators results in reduction in yield of passion fruit. Pollinator enhancement promoted production of a bigger and sweeter fruits (Junqueira and Augusto, 2017). So, the reduction in yield in hybrids and parents may be due to decreased number of pollinators.

4.2.5.6 Peak fruiting month

In all most all parents and hybrids, peak fruiting month was observed in March, while in Parent 6, peak fruiting was observed in May. In hybrids, H_7 (P_6 x P_4) and H_8 (P_6 x P_5) peak fruiting was observed in April (Figure 12).

4.2.6 FRUIT CHARACTERS OF PASSION FRUIT PARENTS AND HYBRIDS

Fruit characters of passion fruit hybrids and parents recorded in the present experiment are given in Table 26 and 27. Fruits from different passion fruit parents and hybrids are shown in Plate 33.

4.2.6.1 Fruit diameter (cm)

Fruit diameter of passion fruit hybrids and parents varied significantly. The maximum fruit diameter of 7.00 cm was observed in H_6, which was on par with P_6 (6.85 cm), H_3 (6.69 cm), H_4 (6.68 cm), H_2 (6.62), P_4 (6.61 cm), H_8 (6.56 cm), H_7 (6.46 cm) and P1 (6.44 cm). The minimum fruit diameter was reported in P3 (5.65 cm) which was on par with S1 (5.73 cm), H1 (5.92 cm) and P5 (6.13 cm) (Table 26).

In a study for evaluating promising passion fruit accessions at CHES, Chettalli variations in fruit diameter has been reported by Tripathi *et al.* (2014). He reported fruit diameter variation in the range of 5.03 cm in CHES PF-2-11 to 7.08 cm in CHES PF-7, which is in conformity with the observed values of fruit diameter in the present study.

4.2.6.2 Fruit girth (cm)

Fruit girth of parents and hybrids exhibited a similar trend as that of fruit diameter, which varied significantly. The maximum fruit girth of 22.00 cm was observed in H_6, which was on par with P_6 (21.50 cm), H_3 & H_4 (21.00 cm), P_4 (20.75 cm), H_8 (20.60 cm) and H_7 & H_2 (20.30 cm). The minimum fruit girth was recorded in P_3 (17.75 cm) which was on par with S_1 (18.00 cm), H_1 (18.60 cm) and P_5 (19.25 cm) (Table 26, Figure 13).

The variations in fruit girth can be attributed to the variation in fruit diameter. From the data (Table 26), it can be concluded that fruit girth is a factor contributing to fruit weight and heavier the fruit the fruit girth would be more.

4.2.6.3 Fruit weight (g)

Fruit weight of passion fruit parents and hybrids varied significantly. The maximum fruit weight was observed in H_6 (117.75 g) which was on par with P_6 (106.00 g). P_6 was on par with H_3 (91.50 g) which was again on par with H_4 (89.50 g), P_4 (85.28 g), H_7 (85.00 g), P_1 (81.50 g), H_8 (80.85 g), P_2 (79.25 g) and H_2 (77.95 g). The lowest fruit weight of 57.75 g was recorded in S_1 which was on par with H_1 (62.50 g), P_3 (63.25g), H_5 (68.00 g) and P_5 (70.83 g) (Table 26, Figure 14).

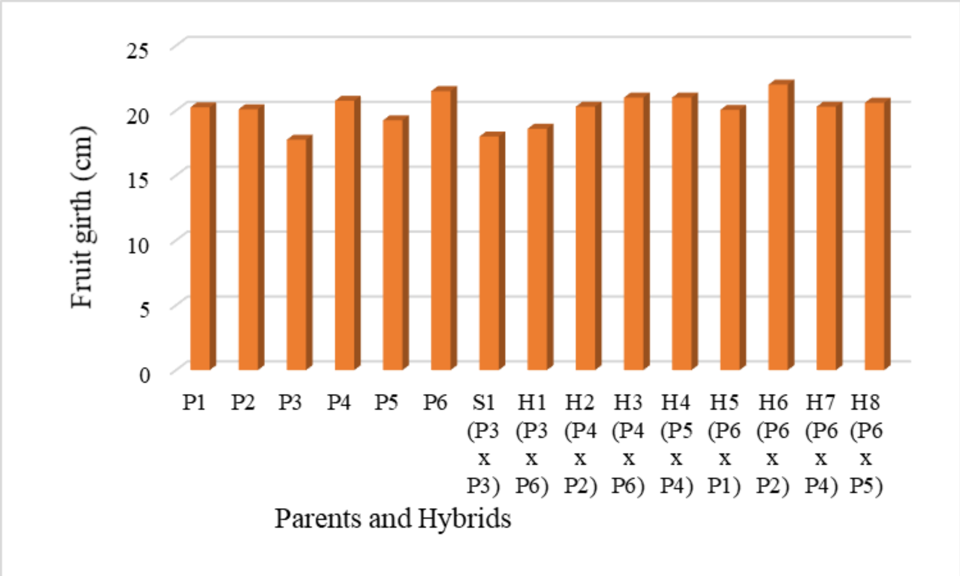


Figure 13. Fruit girth of passion fruit parents, hybrids and selfed progeny

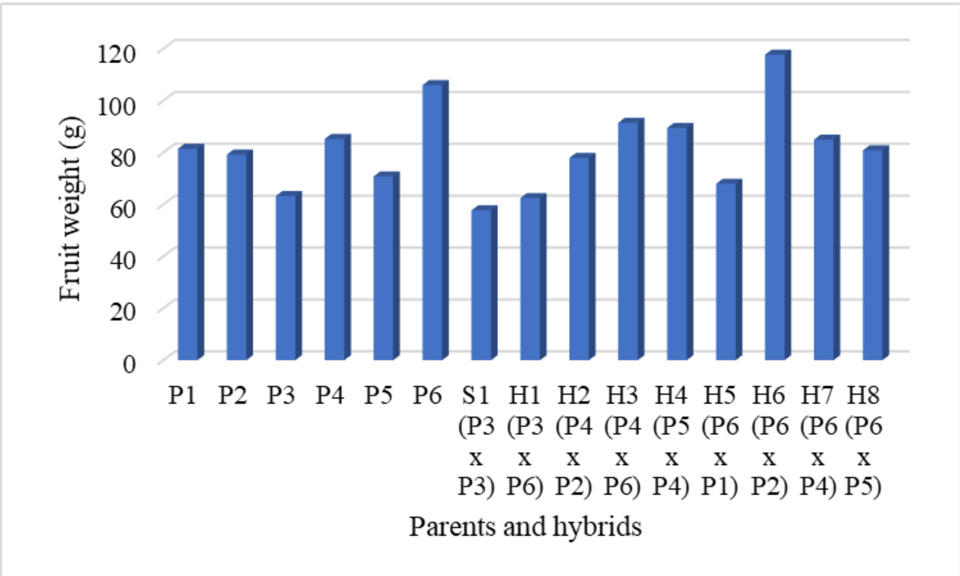


Figure 14. Fruit weight of passion fruit parents, hybrids and selfed progeny

Plate 33. Variaton in fruits of passion fruit parents, hybrids and selfed progeny

According to Beena and Beevi (2016) considerable variations were observed in fruit weight among the wild and cultivated *Passiflora* species studied, *viz*., *P. foetida and P. edulis*. According to Souto *et al*. (2017) the significant variations in fruit weight might be due to the specific combining ability of parents used in the hybridization studies which ultimately influenced the size of passion fruit hybrids. So, selection of paternal and maternal parents with superior characters is an important factor in hybridization programme.

4.2.6.4 Pulp weight (g)

Parents and hybrids of passion fruit showed significant difference in pulp weight. The highest pulp weight was recorded in H_6 (52.75 g) which was on par with H_3 (51.50 g), H_4 (46.50 g), P_6 (46.00 g), H_2 (45.95 g), H_8 (43.60 g) and H_7 (43.00 g). The lowest pulp weight was recorded in H_1 (27.60 g) which was on par with S_1 (28.50 g) and P_3 (30.25 g) (Table 26).

In a study evaluating promising passion fruit accessions at CHES, Chettalli variations in pulp weight has been reported by Tripathi *et al.* (2014). He reported pulp weight variation in the range of 13.10 g in CHES PF-2-11 to 50.10 g in CHES PF-3, which is in consonance with the observed values of pulp weight in the present study. From the data (Tabled 26) it can also be inferred that fruit weight and pulp weight is directly linked. The parent or hybrid with heavier fruits recorded high pulp weight.

4.2.6.5 Rind weight

Rind weight of parents and hybrids of passion fruit varied significantly. The highest rind weight was recorded in H_6 (65.00 g) which was on par with P_6 (60.00 g). The lowest rind weight was recorded in H_5 (29.00 g) which was on par with S_1 (29.25 g), H_2 (32.00 g), P_5 (32.50 g), P_3 (33.00 g) and H_1 (34.90 g) (Table 26).

The variations in rind weight may be due to the inherent character of the genotype. From the data it can also be inferred that those parents and hybrids with more rind weight has more fruit weight. Hence, it could be concluded that fruit weight is highly dependent on rind weight.

4.2.6.6 Seed weight

Seed weight of passion fruit hybrids and parents did not vary significantly. It ranged from 6.00 g in H_3 to 9.50 g in H_6 (Table 26).

4.2.6.7 Rind thickness

Significant variation was revealed in rind thickness of passion fruit parents and hybrids. The maximum rind thickness of 0.94 cm was observed in H_6, which was on par with P_6 (0.92 cm) and P_4 (0.86 cm). P_4 was in turn on par with H_8 (0.83 cm). The lowest rind thickness was observed in P_5 (0.48 cm) which was on par with H_4 and S_1 (0.48 cm) and P_2 (0.50 cm) (Table 27).

Among the passion fruit parents and hybrids wide variation with respect to rind thickness of fruit was recorded. The differences in rind thickness may be attributed to the individual genotypic constitution. Variation in rind thickness was also observed by Charan *et al.* (2018). From the data it can also be inferred that the hybrids or parents with more rind thickness has more fruit weight. So, we can conclude that rind thickness contributes to the fruit weight.

4.2.6.8 Shelf life

There was no significant variation with respect to shelf life of fruits among the parents and hybrids, which ranged from 13.00 days (P_3, P_5, S_1 and H_4) to 14.50 days (P_6 and H_6) (Table 27).

4.2.6.9 Rind colour

Rind colour was yellow with white specks in P_6, while it was purple with white specks in all others (Table 27).

In the hybridization work by Ruberté-Torres and Martin (1974) the cross between *Passiflora edulis* f. *flavicarpa* x *P. alata* produced fruits superior to the parent species. In the present experiment fruit characters like fruit girth, fruit diameter, fruit weight, rind thickness, rind weight, pulp weight, seed weight of the hybrid H_7 (P_6 x P_2) were superior to that of both the parents. Hybridization might have resulted in heterosis.

Table 26. Fruit characters of passion fruit parents, selfed and hybrid progenies

Treatment	Fruit girth (cm)	Fruit diameter (cm)	Fruit weight (g)	Pulp weight (g)	Rind weight (g)	Seed weight (g)
P_1	20.25	6.44	81.50	39.25	42.25	6.75
P_2	20.10	6.40	79.25	38.75	40.50	6.50
P_3	17.75	5.65	63.25	30.25	33.00	9.00
P_4	20.75	6.61	85.28	41.78	43.50	7.75
P_5	19.25	6.13	70.83	38.33	32.50	8.00
P_6	21.50	6.85	106.00	46.00	60.00	9.25
S_1 (P_3 x P_3)	18.00	5.73	57.75	28.50	29.25	7.50
H_1 (P_3 x P_6)	18.60	5.92	62.50	27.60	34.90	7.75
H_2 (P_4 x P_2)	20.30	6.62	77.95	45.95	32.00	6.25
H_3 (P_4 x P_6)	21.00	6.69	91.50	51.50	40.00	6.00
H_4 (P_5 x P_4)	21.00	6.68	89.50	46.50	43.00	7.25
H_5 (P_6 x P_1)	20.05	6.39	68.00	39.00	29.00	8.50
H_6 (P_6 x P_2)	22.00	7.00	117.75	52.75	65.00	9.50
H_7 (P_6 x P_4)	20.30	6.46	85.00	43.00	42.00	8.50
H_8 (P_6 x P_5)	20.60	6.56	80.85	43.60	37.25	6.50
CD (0.05)	1.73	0.57	14.88	10.71	8.23	NS

Table 27. Fruit characters of passion fruit parents, selfed and hybrids progenies

Parent/ hybrid no.	Rind thickness (cm)	Shelf life (days)	Rind colour	Pulp colour
P_1	0.71	14.00	Purple with white specks	Yellowish orange
P_2	0.50	13.25	Purple with white specks	Yellowish orange
P_3	0.59	13.00	Purple with white specks	Yellowish orange
P_4	0.88	13.50	Purple with white specks	Deep yellow
P_5	0.48	13.00	Purple with white specks	Yellowish orange
P_6	0.92	14.50	Yellow with white specks	Yellowish orange
S_1 (P_3 x P_3)	0.48	13.00	Purple with white specks	Deep yellow
H_1 (P_3 x P_6)	0.64	13.50	Purple with white specks	Yellowish orange
H_2 (P_4 x P_2)	0.75	14.00	Purple with white specks	Yellowish orange
H_3 (P_4 x P_6)	0.59	14.00	Purple with white specks	Deep yellow
H_4 (P_5 x P_4)	0.48	13.00	Purple with white specks	Yellowish orange
H_5 (P_6 x P_1)	0.63	13.50	Purple with white specks	Yellowish orange
H_6 (P_6 x P_2)	0.94	14.50	Purple with white specks	Yellowish orange
H_7 (P_6 x P_4)	0.68	13.50	Purple with white specks	Yellowish orange
H_8 (P_6 x P_5)	0.83	14.00	Purple with white specks	Yellowish orange
CD (0.05)	0.11	NS	-	-

4.2.6.10 Pulp colour

As evidenced from Table 27, pulp colour was deep yellow in P_4, S_1 and H_3, while it was yellowish orange in all passion fruit parents and hybrids.

4.2.7 QUALITY CHARACTERS OF PASSION FRUIT HYBRIDS AND PARENTS

Quality characters of passion fruit hybrids and parents are presented in Table 28. Among the quality characters of passion fruit hybrids and parents, only TSS showed significant difference. Quality of any produce is determined by factors like genetics of the variety, environmental conditions, interaction between genotype and environment and crop management practices as reported by Wyckhuys *et al.* (2012).

4.2.7.1 TSS (° Brix)

TSS of passion fruit parents and hybrids exhibited significant variation. The highest TSS was observed in P_4 (17.53 °Brix) which was on par with H_6 (17.50 °Brix), S_1 (17.30 °Brix), H_5 (17.00 °Brix), H_8 (16.93 °Brix), H_1 (16.79 °Brix), P_5 (16.50 °Brix), P_1 (16.25 °Brix), H_4 (16.20 °Brix) and P_3 (15.75 °Brix). The lowest TSS was recorded in H_3 (13.90 °Brix) which was on par with P_6 (14.25 °Brix), H_7 (15.13 °Brix) and P_3 (15.75 °Brix) (Table 28).

From the qualitative parameters studied, only TSS showed significant variation among different parents and hybrids. The highest TSS was observed in P_4 (17.53 °Brix) and the lowest TSS of 13.90 °Brix in H_3 (P_4 x P_6), these slight variations observed may be due to the individual genotypic constitution influencing the TSS quality. A TSS range of 15 °Brix 16 °Brix was noticed in passion fruit hybrids developed at Brazil (Meletti *et al*., 2000).

4.2.7.2 Titrable acidity (%)

Acidity of passion fruit did not show significant variation among the parents and hybrids. It varied from 2.40 per cent in H_2 to 3.42 per cent in P_6 (Table 28).

4.2.7.3 Total sugar (%)

Total sugar per cent also did not vary significantly which was in the range of 7.88 per cent in P_2 to 13.31 per cent in H_1 (Table 28).

4.2.7.4 Reducing sugar (%)

Passion fruit parents and hybrids did not show significant variation with respect to reducing sugar content. It ranged from 4.69 per cent in P_2 to 9.10 per cent in H_4 (Table 28).

4.2.7.5 Non reducing sugar (%)

Non reducing sugar content in different passion fruit parents and hybrids did not vary significantly. It varied from 2.29 per cent in P_5 to 7.33 per cent in H_2 (Table 28).

4.2.7.6 Sugar/ acid ratio

Sugar acid ratio of different passion fruit parents and hybrids did not exhibit significant variation. It varied from 2.30 in P_5 to 5.13 in H_8 (Table 28).

4.2.7.7 Ascorbic acid (mg 100g^{-1})

Ascorbic acid content of passion fruit parents and hybrids/selfed progeny did not vary significantly. It was in the range of 14.03 mg 100g^{-1} (H_4) to 25.27 mg 100g^{-1} (P_2) (Table 28).

4.2.7.8 Total carotenoids (mg 100g^{-1})

Total carotenoid content in passion fruit parents and hybrids/selfed progeny did not show significant variation. The total carotenoid content varied from 1.31 mg 100g^{-1} in P_4 to 2.45 mg 100g^{-1} in H_2 (Table 28).

4.2.8 ORGANOLEPTIC ANALYSIS OF PASSION FRUIT HYBRIDS AND PARENTS

Data corresponding to the organoleptic analysis of passion fruit hybrids and parents are presented in Table 29. Highest score for appearance was recorded in fruits of parents 1, 2 and 6 (6.70). For flavour P_2 recorded the highest score of 6.50. P_3 and P_5 recorded the highest score for texture. For taste (7.20) and after taste (6.40) S_1 recorded the highest score. The highest score for odour 6.80 was recorded by H_2. The highest score for overall acceptability was recorded in H_6.

Table 28. Quality characteristics of passion fruit parents, selfed progeny and hybrids

Parent/ hybrid no.	TSS (° Brix)	Acidity (%)	Total sugar (%)	Reducing sugar (%)	Non reducing sugar (%)	Sugar/ acid ratio	Ascorbic acid (mg $100g^{-1}$)	Total carotenoids (mg $100g^{-1}$)
P_1	16.25	3.24	13.15	7.25	5.90	4.14	21.05	2.10
P_2	16.50	2.53	7.88	4.69	3.19	2.99	25.27	1.83
P_3	15.75	2.94	12.50	7.73	4.78	4.36	15.54	1.79
P_4	17.53	2.93	10.13	5.90	4.23	3.61	16.23	1.31
P_5	16.50	3.38	7.53	4.84	2.29	2.30	17.69	1.88
P_6	14.25	3.42	9.29	7.52	2.35	2.74	14.58	1.93
S_1 (P_3 x P_3)	17.30	2.98	11.20	6.13	5.07	4.03	14.74	1.33
H_1 (P_3 x P_6)	16.79	3.49	13.31	5.98	7.33	3.98	14.79	2.45
H_2 (P_4 x P_2)	16.40	2.40	10.75	5.25	5.50	4.57	20.69	1.70
H_3 (P_4 x P_6)	13.90	3.30	12.35	9.10	3.25	3.75	14.03	1.11
H_4 (P_5 x P_4)	16.20	2.95	8.24	5.02	3.22	2.79	14.13	1.83
H_5 (P_6 x P_1)	17.00	3.00	13.18	9.70	3.48	4.39	14.82	1.40
H_6 (P_6 x P_2)	17.50	2.80	11.46	8.30	3.17	4.14	20.08	1.36
H_7 (P_6 x P_4)	15.13	2.65	12.64	8.37	5.57	5.13	14.58	1.47
H_8 (P_6 x P_5)	16.93	3.14	11.06	7.33	3.73	3.92	17.20	1.40
CD (0.05)	1.87	NS	NS	NS	NS	NS	NS	NS

Table 29. Organoleptic analysis of passion fruit parents, selfed and hybrids

Treatment	Appearance	Colour	Texture	Flavour	Taste	After taste	Odour	Overall acceptability
P_1	6.70	6.50	6.40	6.50	6.50	6.20	6.30	6.70
P_2	6.70	6.30	6.30	6.70	6.40	6.20	5.90	6.30
P_3	6.50	6.40	6.50	6.20	6.80	6.20	6.20	6.20
P_4	6.20	6.40	6.40	5.90	6.40	6.20	6.50	6.10
P_5	6.20	6.40	6.50	6.00	6.60	6.00	6.10	5.90
P_6	6.70	6.20	6.40	6.10	6.70	6.00	6.10	6.20
S_1 (P_3 x P_3)	6.60	6.10	6.40	6.30	7.20	6.40	6.10	6.40
H_1 (P_3 x P_6)	6.40	6.30	6.40	6.30	6.90	6.50	6.40	6.10
H_2 (P_4 x P_2)	6.40	6.10	6.30	6.20	6.80	6.10	6.80	6.50
H_3 (P_4 x P_6)	6.00	6.00	6.10	6.10	6.50	6.10	6.50	6.60
H_4 (P_5 x P_4)	6.10	6.00	6.10	6.20	5.90	6.30	6.10	6.30
H_5 (P_6 x P_1)	6.30	6.20	5.80	6.00	5.90	6.10	6.20	5.80
H_6 (P_6 x P_2)	6.40	6.10	5.90	5.80	7.20	6.20	6.40	6.90
H_7 (P_6 x P_4)	6.20	6.10	6.20	5.70	6.20	5.70	6.50	6.10
H_8 (P_6 x P_5)	6.30	6.10	6.30	5.90	6.40	6.40	6.60	6.20
K W value	10.25	6.49	5.97	11.82	19.52	4.80	8.59	8.15

Eventhough, certain unique characteristics were observed in hybrids it could be observed that most of the characters were intermediate to parent species particularly flower and fruit characters, which is in line with the results of the study by Ruberte-Torres and Martin (1974) wherein they reported intermediate values for the observed characters.

There are several reports on successful interspecific hybridization in passion fruit. Ruberté-Torres and Martin (1974) conducted hybridization using *P. edulis* and *P. incarnata* as the parents, to develop a group of fertile plants of interspecific hybrid origin, which can function as perennial fruit crop cultivars in temperate areas where purple and yellow passion fruits were not adapted. A tetraploid hybrid group of four seedling progenies with some cross-compatibility has been produced from the colchicine-treated plants that had been converted to amphiploids. In 1971, a clone of *Passifora incarnata* was crossed with *P. cincinnati* Masters and the F1 hybrid named 'Incense', released in 1973 by U. S. Dept. of Agriculture, continues to be sold in the nursery trade. 'Incense' has the characteristics ornamental value of its pollen parent and the ability of *P. incarnata* to resist temperate zone winters (Knight, 1991).

4.2.9 RELATIVE HETEROSIS AND HETEROBELTIOSIS FOR ECONOMIC CHARACTERS OF PASSION FRUIT HYBRIDS

According to Hathcock and Daniel (1973) expression of heterosis, even to a small degree, for an individual component character is essential. In the present study, cross combinations derived from genetically divergent parents were estimated for the mid-parent and better parent heterosis. Average or mid-parent or relative heterosis (RH) is the superiority of F_1 hybrid over mid-parental value *i.e.,* average of two parents. Heterobeltiosis (HB) is the superiority of F_1 hybrid over the better parent or superior parent out of the two parents involved in the cross. If the values of ‘RH and HB’ are positive, hybrid value is better than mid-parent value and better parent value respectively. If the values of ‘RH and HB’ are negative, mid-parent value and better parent value are better than the hybrid value. The heterotic effect of passion fruit hybrids was estimated with respect to mid parental values (relative heterosis) and better parental values (heterobeltiosis) for fruit number and yield per vine per year and the results are presented in Table 30 and 31. The hybrids P_5 x P_4 and P_6 x P_2 exhibited significant level of heterosis, therefore superior in performance. The relative heterosis and heterobeltiosis analysis have revealed that hybrids P_5 x P_4 and P_6 x P_2 are superior in yield characters, hence can be recommended for further evaluation.

Assessment of relative heterosis and heterobeltiosis was done to compare the performance of hybrids with their parents in many crops. Verma and Behera (2007) reported high relative heterosis and heterobeltiosis for hybrids of bottle gourd for yield per vine. Sukartini *et al*. (2012) reported higher mean value of relative heterosis and heterobeltiosis for fruit characters like fruit length and fruit diameter for F1 hybrids of mango. Significant and desirable standard heterosis has been reported in tomato hybrids by Garg *et al*. (2013). Cardoso *et al.* (2014) evaluated heterosis in heterotic intragroup hybrids of papaya. Among the Formosa intragroup of papaya hybrids, two hybrid combinations (MR x J4 and MR x SK) showed heterosis for all traits, as well as good average total fruit production. Among the cocoa hybrids developed at Cocoa Research Centre, Kerala Agricultural University, Thrissur, relative heterosis and heterobeltiosis were worked out by Sujith and Minimol (2016). The results revealed that the three hybrids CCRP 8, 9 and 10 showed significant heterobeltiosis and relative heterosis for the characters studied, *ie,* for fresh and dry bean weight per tree per year. Among the three hybrids, CCRP 8 and 10 were superior in performance compared to CCRP 9, based on values of relative heterosis and heterobeltiosis. According to Janaranjani (2016) in bottle gourd the hybrid from the cross 'Pusa Naveen × NDBG-164' had high heterosis for yield and yield attributes days to first male flower anthesis, fruit length, number of harvests, and yield per plant. Thangamani (2013) also reported heterosis in bottle gourd.

The negative mid-parent heterosis and heterobeltiosis was reported for bunch weight, berry weight and juice recovery in grape by Sahoo *et al*. (2017). The above findings are in line with the results of the present study.

4.3 Standardization of nutrient requirement in passion fruit

Balanced application of nutrients is crucial for crop growth and development and also to balance the soil fertility status. Judicious management of resources is essential to maintain profitability to the farmer, of which fertilization is an important aspect. Proper fertilization is needed for any fruit crop, which otherwise will adversely affect yield and quality of fruits. Nitrogen, phosphorus and potassium being the major nutrients, are taken up by plants in large quantities. Amount of nutrients required vary with crops and cultivars, rather than the physical and chemical composition of soil and availability of nutrients (Kumar *et al*., 2008). Passion fruit is a highly nutrient responsive crop. The influence of different NPK treatments on biometric parameters, yield, fruit characters including quality attributes of passion fruit was studied. The results of the experiment on standardization of nutrient management technique in passion fruit are presented and discussed hereunder.

4.3.1.1 Stem girth (cm)

Stem girth at 12 MAP varied significantly among different treatments (Table 32). Maximum girth was observed in T_4 (12.00 cm), which was significantly superior to all other treatments. This was followed by T_3 (9.13 cm), which was on par with T_2 (8.88 cm), T_1 (8.75 cm) and T_5 (7.00 cm). It is evident that higher doses of nutrients (NPK @ 50:20:50 g vine^{-1}) resulted in the increased stem girth of plants.

According to Geetha (1998), increasing levels of N applied in banana up to 190 g plant^{-1} significantly increased plant girth. In the present study, stem girth increased with the application N which might be due to the role of N in imparting vigorous vegetative growth as reported by Das *et al.* (2013).

4.3.1 RESPONSE OF VEGETATIVE PARAMETERS TO NPK FERTILIZATION IN PASSION FRUIT

Observations on vegetative parameters, girth of stem (cm) and number of branches were recorded, analysed and the results are presented in Tables 32.

Mehta *et al*. (2016), also reported that higher doses of NPK increased the girth of stem in passion fruit. The maximum value for girth was recorded by application of 300:150:150 g NPK compared to the absolute control. More nutrition might have resulted in meeting the requirement of vines, which in turn contributed to the better growth.

Table 30. Relative heterosis and heterobeltiosis for total number of fruits

Hybrids	Mid Parent	RH (%)	Better Parent	HB (%)
P3 x P6	65.00	40.00	72.00	26.39
P4 x P2	76.75	-17.26	79.50	-20.13
P4 x P6	68.75	46.18	79.50	26.42
P5 x P4	84.75	59.88*	90.00	50.56*
P6 x P1	83.00	30.72	108.00	0.46
P6 x P2	66.00	17.42	74.00	4.73
P6 x P4	68.75	4.00	79.50	-10.06
P6 x P5	74.00	40.54	90.00	15.56
S. E	15.94		18.41	
CD (0.05)	2.14		2.14	

Table 31. Relative heterosis and heterobeltiosis for yield per vine per year

Hybrids	Mid parent	RH (%)	Better Parent	HB (%)
P3 x P6	5331.38	5.09	6128.00	-8.58
P4 x P2	6344.24	-22.15	6776.73	-27.12
P4 x P6	6452.36	39.69*	6776.73	33.00
P5 x P4	6570.13	84.73*	6776.73	79.10*
P6 x P1	7472.00	-1.10	8816.00	-16.18
P6 x P2	6019.88	51.98*	6128.00	49.30*
P6 x P4	6452.36	-6.31	6776.73	-10.80
P6 x P5	6245.76	33.67	6363.53	31.19
S. E	1115.98		1288.62	
CD (0.05)	2.14		2.14	

RH- Relative heterosis, HB- Heterobeltiosis

4.3.1.2 Number of branches

Number of branches per vine, as shown in Table 32, varied significantly with respect to fertilizer treatments. Mean number of branches per vine was the maximum in T_1 (10.75), which was superior to all other treatments. It was followed by T_4 (9.25) having the higher fertilizer doses, which was on par with T_2 (8.75). The least number of branches was observed in T_5 (5.50), followed by T_3 (7.25).

According to Mehta *et al*. (2016) number of secondary branches varied significantly with different doses of nutrients. They reported that higher doses of NPK increased the number of branches. At 390 DAT, the maximum number of secondary branches, 15.98, was recorded in the treatment with 300:150:150 NPK g vine^{-1}. While the minimum value of 12.20, was recorded in absolute control.

According to Aular *et al*. (2014) characteristic response of passion fruit depends on species and amount and type of fertilizer applied. The amount and type of fertilizers applied might be the reason for variation in number of branches observed in the present experiment.

4.3.2 EFFECT OF NPK FERTILIZATION ON PHENOLOGICAL CHARACTERS OF PASSION FRUIT

Observations on days taken for first flowering, days taken for first fruiting and flowering to harvest duration (days) were recorded, analysed and the results are presented in Table 33.

4.3.2.1 Days taken for first flowering

Days taken for first flowering, which indicate the duration of vegetative phase, did not vary significantly among the accessions (Table 33). However, the minimum days to flowering, 197.75 days, was observed in T_2 and maximum days for first flowering was observed in T_5 (206.50 days).

4.3.2.2 Days taken for first fruiting

The statistical analysis of the data for days taken for first fruiting did not reveal significant difference among the treatments (Table 33). However, the minimum days for first fruiting was found in T_1 and T_2 (201.00 days) and the maximum time for first fruiting was observed in T_5 (217.50 days).

4.3.2.3 Flowering to harvest duration

Results indicated that the duration from flowering to harvest varied significantly among various treatments (Table 33). Shortest duration from flowering to harvest was noticed in T_5 (59.75 days), which was on par with T_1 (63.50 days) and T_2 (64.50 days). The longest duration from flowering to harvest was observed in T_4 (75.50 days), which was on par with T_3 (72.50 days).

In an experiment to study the effect of increased doses of phosphatic fertilizers, Kondo and Higuchi (2013) revealed that days from the day of pollination to harvest varied from 73.40 to 75.50 days and the results of the present study are comparable with these findings.

4.3.3 EFFECT OF NPK FERTILIZERS ON YIELD PARAMETERS IN PASSION FRUIT

Observations on yield parameters *viz*., number of flowers/vine/month, total flower production/vine, peak flowering month, number of fruits/vine/month, total fruit production/vine, peak fruiting month *etc.* were recorded, analysed and the results are presented in Tables 34 and 35.

4.3.3.1 Flower production per vine at monthly interval

The data on monthly flower production as influenced by different fertilizer treatments are presented in Table 34 and Figure 15.

Table 32. Effect of different levels of N, P and K on vegetative parameters of passion fruit at 12 MA

Treatments	Stem girth (cm)	No. of branches
T_1 (12.5 N: 5 P_2O_5: 12.5 K_2O (g vine $^{-1}$))	8.75	10.75
T_2 (25 N: 10 P_2O_5: 25 K_2O (g vine $^{-1}$))	8.88	8.75
T_3 (37.5 N: 15 P_2O_5: 37.5 K_2O (g vine $^{-1}$))	9.13	7.25
T_4 (50 N: 20 P_2O_5: 50 K_2O (g vine $^{-1}$))	12.00	9.25
T_5 (Absolute control)	7.00	5.50
CD (0.05)	2.60	1.24

Table 33. Effect of different levels of N, P and K on phenological characters in passion fruit

Treatments	Duration (days)		
	First flowering	First fruiting	Flowering to harvest
T_1 (12.5 N: 5 P_2O_5: 12.5 K_2O (g vine $^{-1}$))	198.25	201.00	63.50
T_2 (25 N: 10 P_2O_5: 25 K_2O (g vine $^{-1}$))	197.75	201.00	64.50
T_3 (37.5 N: 15 P_2O_5: 37.5 K_2O (g vine $^{-1}$))	202.00	208.00	72.50
T_4 (50 N: 20 P_2O_5: 50 K_2O (g vine $^{-1}$))	199.75	203.25	75.50
T_5 (Absolute control)	206.50	217.50	59.75
CD (0.05)	NS	NS	10.77

Data on flower production per vine during May did not show significant difference among the treatments (Table 34). The highest flower production was observed in T_2 (4.00) and the lowest flower production was observed in T_3 (1.50).

Data depicted in Table 34 regarding flower production per vine in the month of June, clearly indicate significant difference among the treatments**.** Flower production was the maximum in T_4 (26.75), which was significantly superior to all other treatments. T_3 (18.75), T_5 (16.50), T_1 (14.00) and T_2 (13.50) were on par with one another with respect to flower production in the month of June.

Flower production in July exhibited significant variation (Table 34). The highest flower production was recorded in T_4 (35.50), which was superior to all other treatments. It was followed by T_3 (29.25) which was on par with T_2 (27.25) and T_1 (25.00). The lowest flower production was observed in T_5 (19.50).

Data on flower production during August varied significantly among different treatments as depicted in Table 34. It was the maximum in T_4 (41.25), which was on par with T_1 (36.50) and T_3 (32.50). The minimum flower production was found in T_5 (19.75), which was on par with T_2 (29.25).

Significant variation could not be observed in flower production per vine during the month of September as shown in Table 34. However, the highest flower production was observed in T_4 (38.25) and the lowest flower production in T_5 (35.75). Flower production in the month of October did not vary significantly among the different treatments, it was in the range of 27.25 (T_5) – 36.00 (T_3). The data on flower production in November did not show significant variation among the treatments and it ranged from 11.00 in T_2 to 24.25 in T_4. Monthly flower production varied significantly during June, July and August (Table 34).

4.3.3.2 Peak flowering month

Peak flowering was observed in the month of August in T_4, profuse flowering was recorded in September in T_1, T_2 and T_5. Peak flowering in T_3 was recorded in October (Table 34, Figure 15).

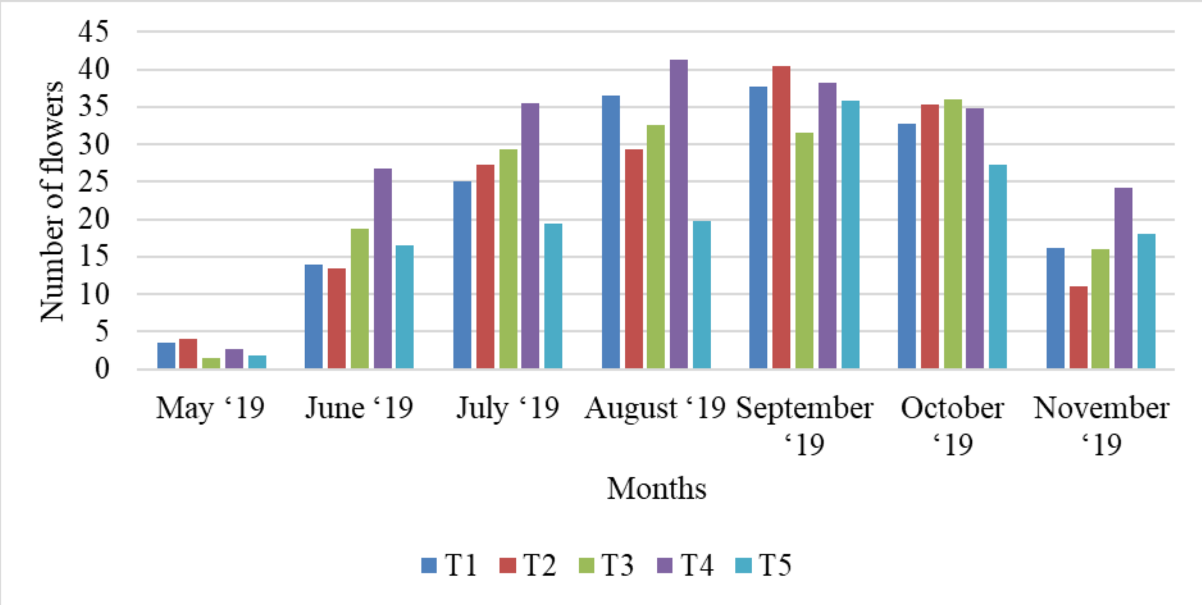


Figure 15. Monthly flowering in passion fruit with different levels of fertilizers

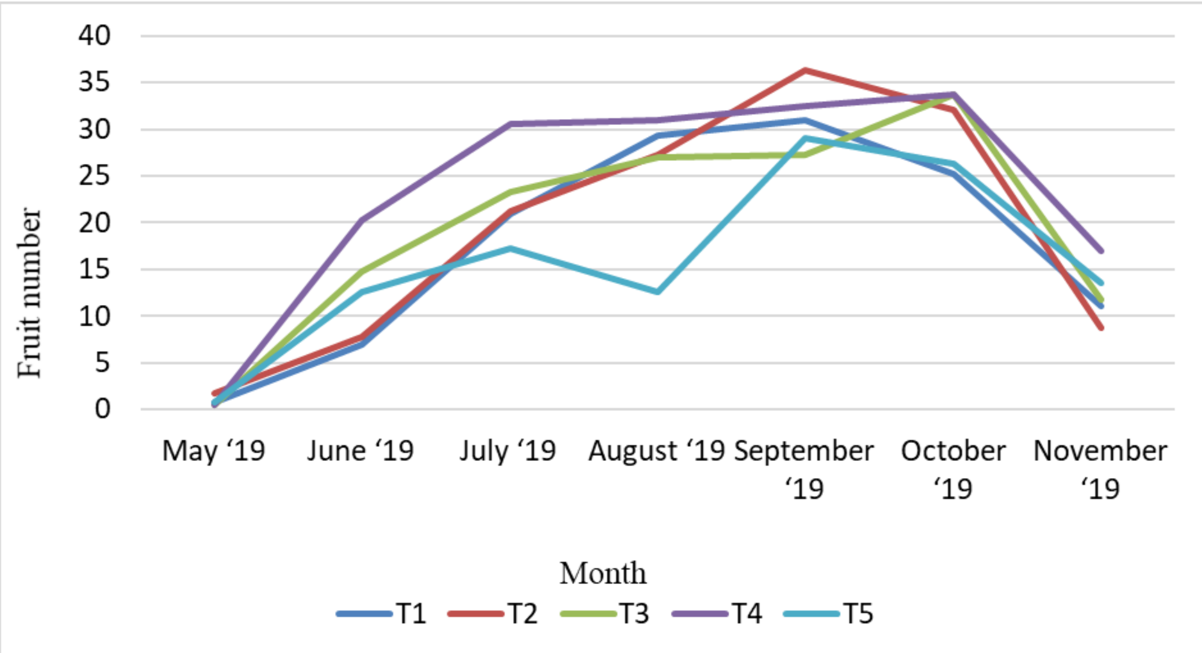


Figure 16. Monthly fruiting in passion fruit with different levels of fertilizers

(T1-12.5: 5:12.5; T2-25:10: 25; T3-37.5:15: 37.5; T4- 50: 20: 50) (N, P_2O_5, K_2O g $vine^{-1}$)

T5 - Absolute control

4.3.3.3 Total flower production per vine per year

Data on total flower production per vine showed significant variation among the treatments (Table 34, Figure 17). Highest flower production was recorded in T_4 (203.50), which was significantly superior to all other treatments. T_4 was followed by T_1 (165.75), which was on par with T_3 (165.50) and T_2 (160.75). The lowest flower production was observed in T_5 which is the absolute control (138.50).

The higher photosynthetic rate due to more vegetative growth imparted by the high application of fertilizers in T_4 might have resulted in more number of flowers in this treatment.

4.3.3.4 Fruit production per vine at monthly interval

The data on monthly fruit production as influenced by different fertilizer treatments are depicted in Table 35 and Figure 16.

Fruit production during the month of May did not show significant variation among treatments which ranged from 0.50 in T_3 and T_4 to 1.75 in T_2 (Table 35).

Fruit production per vine in June showed significant difference among the treatments. The highest fruit production was recorded in T_4 (20.25), which was on par with T_3 (14.75) (Table 36). The lowest fruit production was observed in T_1 (7.00) which was on par with T_2 (7.75) and T_5 (12.50).

Fruit production per vine in July showed significant variation among treatments (Table 35). The highest fruit production was observed in T_4 (30.50) which was significantly superior to all other treatments. It was followed by T_3 (23.25) which was on par with T_2 (21.25) and T_1 (21.00). The lowest fruit production was observed in T_5 (17.25).

Data on fruit production per vine in August showed significant variation among the treatments (Table 35). Fruit production was the maximum in T_4 (31.00), which was on par with T_1 (29.25), T_2 (27.25) and T_3 (27.00). The lowest fruit production was recorded in T_5 (12.50), which was significantly lower than all other treatments.

Fruit production per vine in September did not show significant difference among the treatments as shown in Table 35. Fruit production varied from 27.25 in T_3 to 36.25 in T_2.

The data on fruit production per vine in October did not show significant variation among the treatments (Table 35). It ranged from 25.25 in T_1 to 33.75 in T_3 and T_4.

Fruit production per vine in November did not vary significantly (Table 35) and the production varied from 8.75 in T_2 to 17.00 in T_4.

Significant variation was observed in monthly fruit production during the months of June, July and August (Table 35).

4.3.3.5 Peak fruiting month

In T_1, T_2 and T_5 peak fruiting was recorded in September, whereas in T_3 and T_4, peak fruiting was observed in the month of October (Table 35, Figure 16).

4.3.3.6 Total fruit production per vine per year

Total fruit production per vine per year showed significant difference among the treatments (Table 35, Figure 17). Highest fruit production per vine per year was observed in T_4 (165.50), which was on par with T_3 (138.25), T_2 (135.00). The lowest fruit production was observed in T_5 (111.75), which was on par with T_1 (125.25). T_4 also had the highest B:C ratio of 2.53.

The increased production of fruits in T_4 (treatment with highest dose of NPK) might be due to increased availability of nutrients, which might have resulted in increased vegetative growth and higher photosynthetic activity.

In an experiment to study effect of irrigation and mulching on growth, yield and quality of passion fruit, Rao *et al*. (2013) reported 166.71 number of fruits per plant per year in Kaveri, and the value observed in the present experiment, is comparable with the research finding.

Vegetative growth and yield were higher in passion fruit when leaf K content was in the range of 2.00-3.00 per cent (Menzel *et al*., 1993). In the present study the leaf K content (2.72 %) was highest in T_4, which might have contributed to the higher fruit yield.

Spironello *et al.* (2004) reported that high yield in pineapple was closely related to N and K supply. In the present study, T_4 and T_3 with high N and K supplementation produced more number of fruits. They also reported that effects of N and K were normally synergistic for fruit yield. The effects of N and K were normally synergistic for yield and fruit size.

According to Kumar *et al*. (2008) in a study conducted in guava, treatment combinations with high nitrogen levels had the highest yield and fruiting compared to lower N levels. In the present study also, T_4, which was given the highest amount of nitrogenous fertilizers produced more number of fruits. The enhanced vegetative growth, by the application of high levels of nitrogen might have led to increased photosynthesis, enhancing the fruit production along with adequate amount of phosphorus and potassium.

Cerutti and Delatorre (2013) reported that there was a strong correlation between N and P contents, both elements interacting in a synergistic way. Adequate doses of both N and K enhance each other's absorption, while absorption is hindered when these are applied in excessive amounts. In the present study the increased number of fruits in the higher doses of NPK might be due to the enhanced absorption of N and P.

4.3.4 INFLUENCE OF NPK ON FRUIT CHARACTERS OF PASSION FRUIT

Various observations on fruit characters *viz.,* rind color, pulp color, girth (cm), diameter (cm), fruit weight (g), pulp weight (g), rind weight (g), seed weight (g), rind thickness (cm) were recorded, analyzed and data are presented in Table 36. Fruits from different treatments are shown in Plate 34.

Table 34. Effect of different levels of N, P and K on flower production

Treatment	Flower production (Number/ vine)							
	May ‘19	June ‘19	July ‘19	August ‘19	September ‘19	October ‘19	November ‘19	Total flowers
T_1	3.50	14.00	25.00	36.50	37.75	32.75	16.25	165.75
T_2	4.00	13.50	27.25	29.25	40.50	35.25	11.00	160.75
T_3	1.50	18.75	29.25	32.50	31.50	36.00	16.00	165.50
T_4	2.75	26.75	35.50	41.25	38.25	34.75	24.25	203.50
T_5	1.75	16.50	19.50	19.75	35.75	27.25	18.00	138.50
CD (0.05)	NS	7.16	6.09	10.65	NS	NS	NS	32.86

Table 35. Effect of different levels of N, P and K on fruit production in passion fruit

Treatment	Fruit production (Number/vine)								B:C ratio
	May '19	June '19	July '19	August '19	September '19	October '19	November '19	Total fruits	
T_1	0.75	7.00	21.00	29.25	31.00	25.25	11.00	125.25	1.18
T_2	1.75	7.75	21.25	27.25	36.25	32.00	8.75	135.00	1.43
T_3	0.50	14.75	23.25	27.00	27.25	33.75	11.75	138.25	1.64
T_4	0.50	20.25	30.50	31.00	32.50	33.75	17.00	165.50	2.53
T_5	0.75	12.50	17.25	12.50	29.00	26.25	13.50	111.75	0.93
CD (0.05)	NS	7.00	5.56	11.23	NS	NS	NS	31.06	-

4.3.4.1 Fruit girth (cm)

Fruit girth varied significantly among different treatments. The highest fruit girth was recorded in T_4 (22.88 cm), which was significantly superior to all other treatments (Table 36, Figure 18). This was followed by T_3 (20.35cm), which was on par with T_2 (19.85 cm) and T_1 (19.75 cm).

Spironello *et al.* (2004), reported that fruit size in pineapple was closely related to N and K concentrations in the leaves. In the present study also fruit girth which determines the fruit size showed an increasing trend as N and K concentration in the leaves increased.

4.3.4.2 Fruit diameter (cm)

Fruit diameter showed significant difference among the treatments (Table 36). T_4 had the highest fruit diameter of 7.28 cm, which was significantly superior to all other treatments. This was followed by T_3 (6.48 cm), which was on par with T_2 (6.32 cm) and T_1 (6.29 cm).

According to Borges *et al*. (2007) potassium deficiency resulted in the reduction of fruit size. Fruit diameter which is a factor contributing to fruit size was lowest in the absolute control and increased as the levels of nutrients increased. This might be due to the increasing levels of K which contributed to the enhanced fruit size as reported by Borges *et al*. (2007).

4.3.4.3 Fruit weight (g)

Application of different levels of N, P and K had significant effect on fruit weight (Table 36). Among the different treatments, T_4 recorded the maximum fruit weight of 114.75 g, which was on par with T_3 (89.13 g). The lowest average fruit weight was noted in T_5 (53.65 g), which was on par with T_1 (70.45 g) and T_2 (79.40 g).

As per the reports of Kondo and Higuchi (2013), fruit weight and juice content increased with increased application of P. According to Mehta *et al*. (2016), among the two doses of NPK, 250:125:125 g vine^{-1} resulted in the maximum fruit weight of 69.13 g, compared to higher dose of NPK, 300:150:150 g vine^{-1}. They also recorded the minimum fruit characters in the case of absolute control. Fruit weight of 72.63 g was observed with the application NPKB 250:125:120:1.2 g vine^{-1} and was on par with NPKS 250:125:125:24 g vine^{-1}. The lowest fruit weight was observed in absolute control. Here increased dose of 300:150:150 NPK g vine^{-1} along with B and S resulted in lower fruit weight which might have been the indication that 250:125:125 NPK g vine^{-1} would be the maximum limit of fertilizer applied to a passion fruit vine to get highest fruit weight (Mehta and Prasad, 2018), which might be due to climatic and genetic factors. But the maximum fruit weight observed in present experiment is much higher compared to the fruit weight noted by Mehta and Prasad (2018).

According to Mehta and Prasad (2018), the possible reason behind increasing fruit weight might be due to hormone mediated direct transport, accumulation and balanced partitioning of photosynthetic assimilates to the developing fruit than by enabling the shoot to meet the nutritional requirement of fruits throughout their development.Studies by Olermo *et al*. (2017) has also reported the highest fruit weight with fertilization of 250-50-80 N-P_2O_5-K_2O kg ha^{-1}, which was the highest level of fertilizer combination among the different treatments.

4.3.4.4 Pulp weight (g)

Application of graded doses of N, P and K significantly influenced pulp weight (Table 36, Figure 19). Maximum pulp weight was recorded in T_4 (51.25 g), which was on par with T_3 (44.00 g). The lowest pulp weight was recorded in T_5 (27.13 g), which was on par with T_1 (35.75 g).

In the present experiment the highest pulp content was observed in T_4, which was supplied with highest level of P. This is in agreement with the reports of Kondo and Higuchi (2013), who reported that juice content increased with increased application of P. Olermo *et al*. (2017) reported that the best value of fruit juice and number of seeds were obtained with fertilizer rate of 250 N-50 P_2O_5- 80 K_2O kg ha^{-1}, which might be due to the relative importance of the macronutrients in passion fruit production. The result of the present study, where pulp weight (the juice and seed weight added together) had recorded the maximum value in T_4, with the highest level of NPK fertilizers, which is in line with the finding of Olermo *et al.* (2017).

Table 36. Effect of different levels of N, P and K on fruit characters

Treatment	Fruit girth (cm)	Fruit diameter (cm)	Fruit weight (g)	Pulp weight (g)	Rind weight (g)	Rind thickness (cm)	Seed weight (g)	Rind colour	Pulp colour
T_1	19.75	6.29	70.45	35.75	34.70	0.45	7.50	Purple with white specks	Yellowish orange
T_2	19.85	6.32	79.40	40.53	38.88	0.45	7.75	Purple with white specks	Yellowish orange
T_3	20.35	6.48	89.13	44.00	45.13	0.45	7.75	Purple with white specks	Yellowish orange
T_4	22.88	7.28	114.75	51.25	63.50	0.48	7.88	Purple with white specks	Deep yellowish orange
T_5	18.18	5.79	53.65	27.13	26.53	0.46	7.38	Purple with white specks	Yellowish orange
CD (0.05)	2.07	0.66	26.48	10.44	17.92	NS	NS	-	-

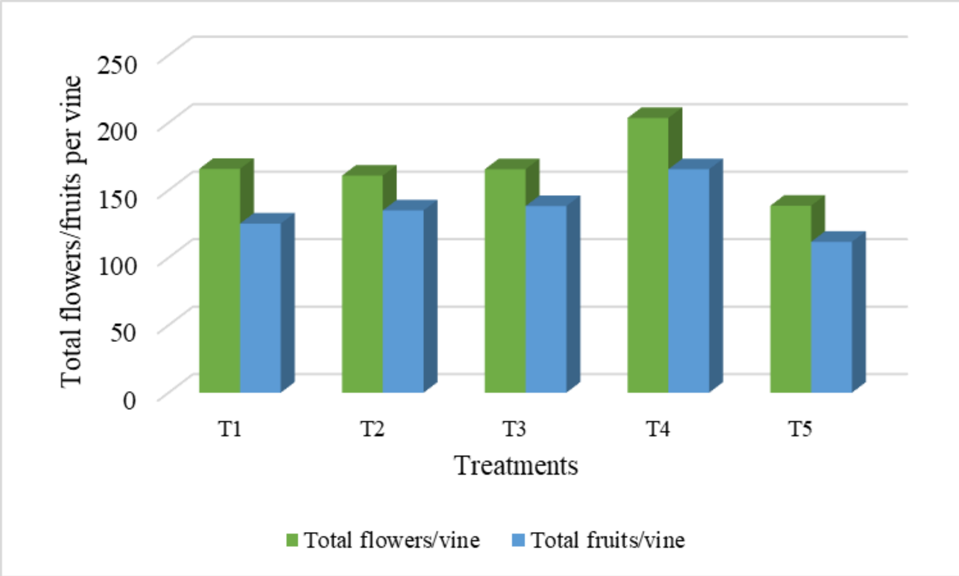


Figure 17. Total flowers and fruits per vine with different levels of fertilizers

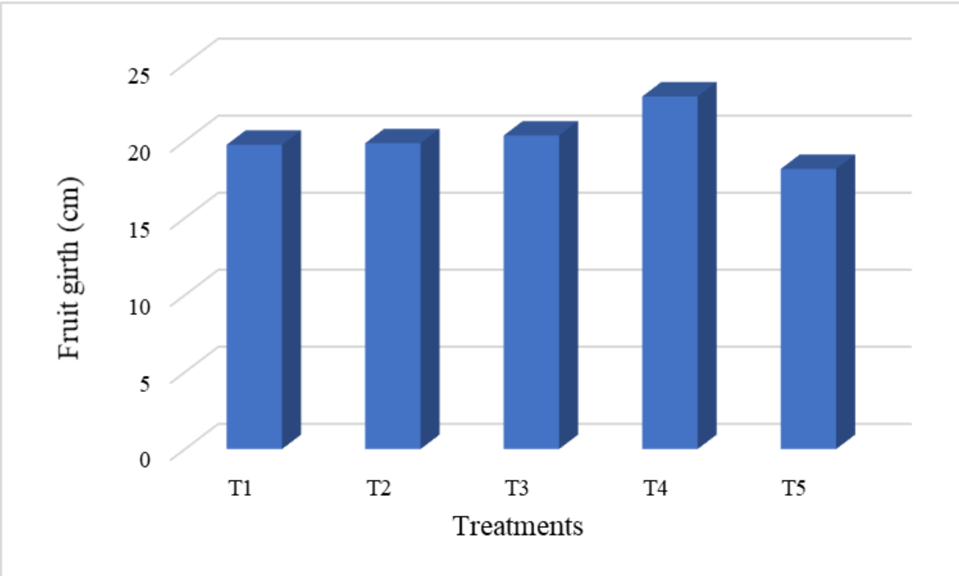


Figure 18. Fruit girth of passion fruit with different levels of fertilizers

(T1-12.5: 5:12.5; T2-25:10: 25; T3-37.5:15: 37.5; T4- 50: 20: 50) (N, P_2O_5, K_2O g $vine^{-1}$), T5 - Absolute control

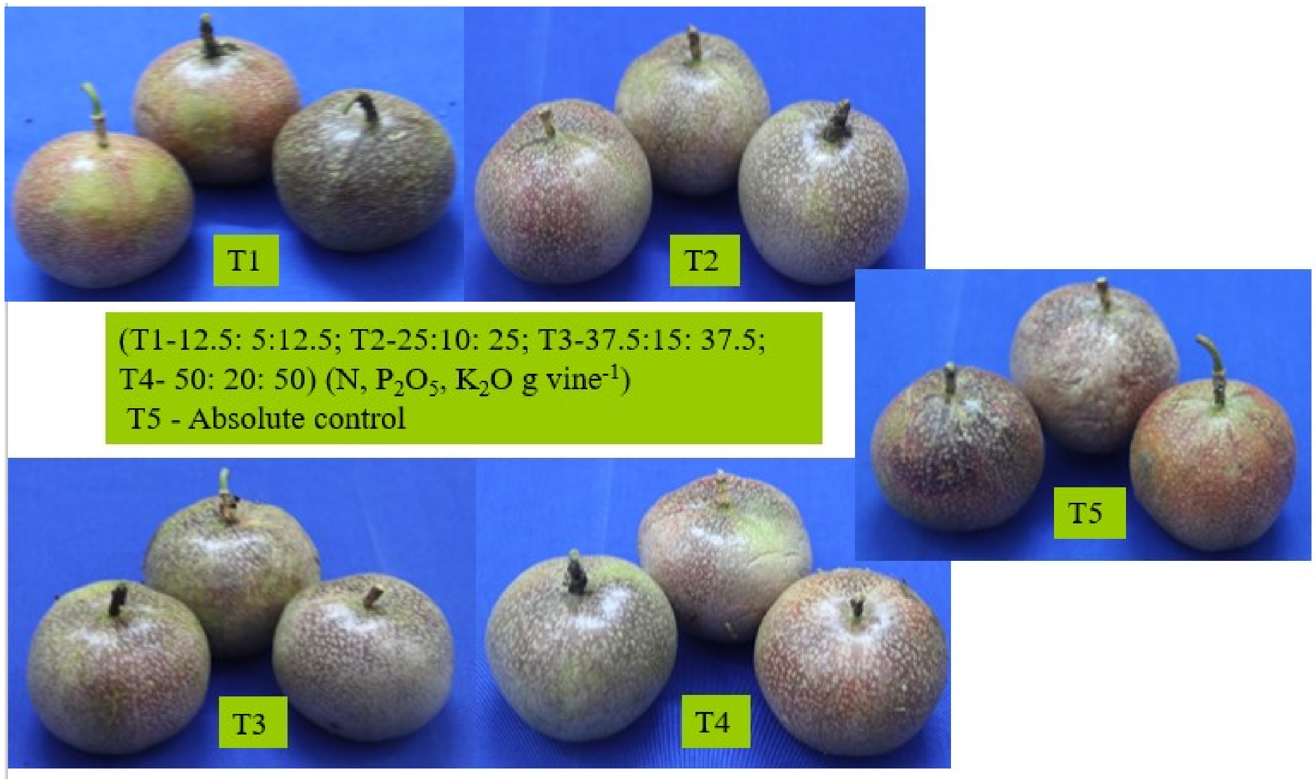


Plate 34. Passion fruits from different fertilizer treatments

4.3.4.5 Rind weight (g)

Significant difference was observed in rind weight of fruits in different treatments (Table 36). Maximum rind weight was observed in T_4 (63.50 g), which was significantly superior to all other treatments. This was followed by T_3 (45.13 g) which was on par with T_2 (38.88 g) and T_1 (34.70 g). The least rind weight was observed in T_5 (26.53 g), which was on par with T_1 and T_2.

The best value for fruit weight was obtained with the highest fertilizer rate of 250-50-80 N-P_2O_5- K_2O kg ha^{-1} among the different treatments (Olermo *et al.*, 2017). In the present experiment also the rind weight, which is an important factor contributing to fruit weight was found to be highest in T_4 (50 N: 20 P_2O_5: 50 K_2O g $vine^{-1}$), which could be attributed to the relative significance of primary nutrients in passion fruit production.

4.3.4.6 Rind thickness (cm)

Statistically analyzed data on rind thickness did not show significant difference with respect to treatments (Table 36). It ranged from 0.45 cm (T_1, T_2 and T_3) to 0.48 cm (T_4).

4.3.4.7 Seed weight (cm)

Application of different levels of N, P and K did not significantly influence seed weight which varied from 7.38 g in T_5 to 7.88 g in T_4 (Table 36).

4.3.4.8 Rind colour

Rind colour did not show any variation with respect to fertilizer treatments; it was purple with white specks for all the treatments (Table 36).

4.3.4.9 Pulp colour

Pulp colour was deep yellowish orange in T_4 and yellowish orange in all other treatments (Table 36).

4.3.5 EFFECT OF DIFFERENT LEVELS OF NPK ON PASSION FRUIT QUALITY PARAMETERS

Different factors affect the passion fruit quality, some of the factors include irrigation, climate, fertilization dose and methods *etc*. Mineral nutrition enhances fruit quality in passion fruit (Aular *et al*., 2014).

Observations on fruit quality parameters *viz.,* TSS (° Brix), titrable acidity (%), total sugar (%), reducing sugar (%), non reducing sugar (%), sugar/ acid ratio, ascorbic acid (mg $100g^{-1}$), total carotenoids (mg $100g^{-1}$) and shelf life (days) were recorded and analyzed (Table 37). The results of the experiment are furnished and discussed hereunder.

4.3.5.1 TSS (° Brix)

Different levels of N, P and K had significant effect on the TSS (Table 37). The highest TSS was observed in T_4 (19.15 °Brix), which was superior compared to all other treatments. It was followed by T_3 (17.90 °Brix), which was on par with T_2 (17.25 °Brix), T_5 (17.05 °Brix) and T_1 (16.88 °Brix).

The highest TSS may be due to application of higher levels of N, P and K as reported by Oliveira *et al*. (2015) in passion fruit and Pengrin *et al*. (2014) in pineapple. Potassium has a positive effect on TSS content of passion fruit as reported by Spironello *et al.* (2004). In the present experiment, T_4, with highest level of K, reported to have the highest TSS. Correlation studies in mango has shown that TSS content was significantly and positively correlated to total sugar content (Rani *et al.*, 2020). In the present experiment also, the treatments with highest total sugar content had the highest TSS.

4.3.5.2 Titrable acidity (%)

Acidity was not influenced significantly by different NPK treatments (Table 37); it varied from 2.50 in T_1 to 2.77 per ccent in T_4.

Table 37. Effect of different levels of N, P and K on quality parameters of passion fruit

Treatment	TSS (° Brix)	Acidity (%)	Total sugar (%)	Reducing sugar (%)	Non reducing sugar (%)	Sugar/ acid ratio	Ascorbic acid (mg $100g^{-1}$)	Total carotenoids (mg $100g^{-1}$)	Shelf life (days)
T_1	16.88	2.50	10.26	6.37	3.89	4.60	19.40	1.33	14.25
T_2	17.25	2.56	12.60	9.17	3.44	5.06	20.67	1.82	15.75
T_3	17.90	2.55	12.70	8.32	4.38	4.72	19.89	2.03	15.75
T_4	19.15	2.77	13.38	8.76	4.62	4.42	19.99	2.19	15.00
T_5	17.05	2.54	9.76	5.81	3.96	4.43	19.39	1.53	15.75
CD (0.05)	1.16	NS	1.48	1.77	NS	NS	NS	NS	NS

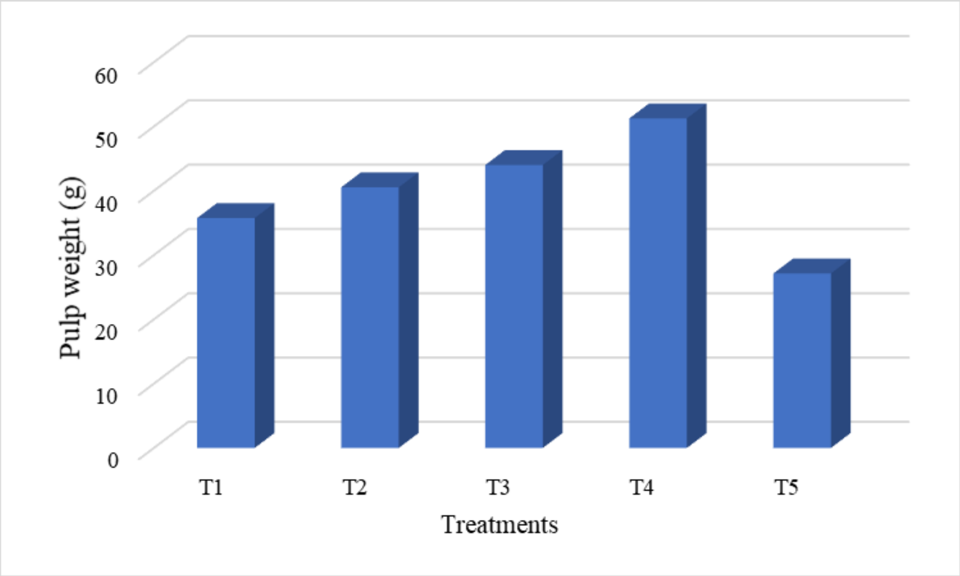


Figure 19. Pulp weight of passion fruit with different levels of fertilizers

(T1-12.5: 5:12.5; T2-25:10: 25; T3-37.5:15: 37.5; T4- 50: 20: 50) (N, P_2O_5, K_2O g $vine^{-1}$), T5 - Absolute control

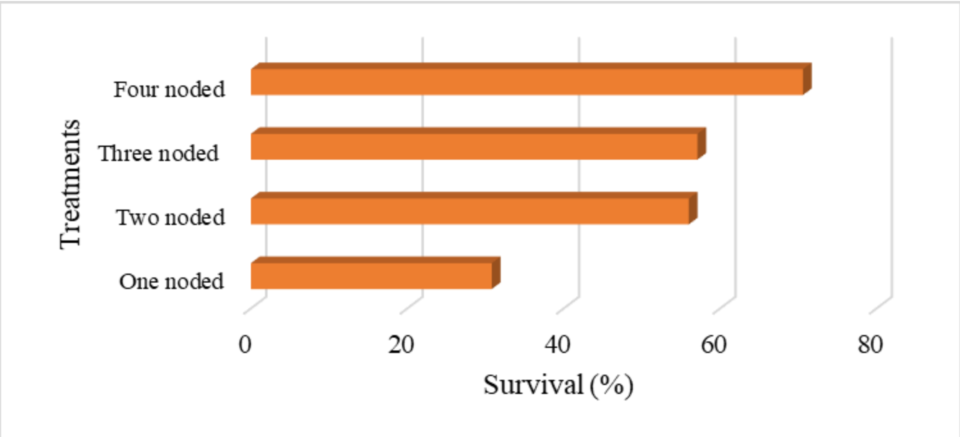


Figure 20. Survival per cent in different noded cuttings

4.3.5.3 Total sugars (%)

Application of different levels of nutrients exhibited significant effect on total sugar content of passion fruits (Table 38). The highest total sugar content was observed in T_4 (13.38 %) which was on par with T_3 (12.70 %) and T_2 (12.60 %). The lowest total sugar content was noted in T_5 (9.76 %) which was on par with T_1 (10.26 %).

According to Kumar *et al*. (2008) in a study conducted in guava, treatment combinations with high potassium levels had the highest sugar content. Present results are also in line with the above finding that high sugar content was observed in treatment combination with the highest potassium level. According to Mehta and Prasad (2018) application of NPKB (250:150:150:1.2 g/vine/year), have stimulated synthesis of enzymes affecting the physiological process, which in turn hydrolysed starch and helped in metabolic level in regulating vital physiological and biochemical processes which ultimately enhanced quality characters in fruits.

4.3.5.4 Reducing sugar (%)

Reducing sugar varied significantly depending on different NPK levels (Table 37). The highest reducing sugar content was observed in T_2 (9.17 %) which was on par with T_4 (8.76 %) and T_3 (8.32 %). The lowest reducing sugar content was observed in T_5 (5.81 %) which was on par with T_1 (6.37 %).

In an experiment in guava conducted by Kumar *et al*. (2008) the highest values of reducing sugar was observed in the treatment combination with highest N, P, K levels (150 N:100 P_2O_5:150 K_2O g plant^{-1}. They also observed minimum values of reducing sugar in the control treatment. The results of the present study are in line with the above finding.

4.3.5.5 Non reducing sugar (%)

Application of different levels of N, P and K had no significant effect on the non reducing sugar content of passion fruits. The variation was observed in the range of 3.44 per cent (T_2) - 4.62 per cent (T_4) (Table 37).

4.3.5.6 Sugar/ acid ratio

Influence of different levels of N, P and K on sugar/acid ratio of fruits was found to be non-significant, with values ranging from 4.42 (T_4) to 5.06 (T_2) (Table 37).

4.3.5.7 Ascorbic acid (mg 100g^{-1})

Application of different levels of nutrients had no significant effect on ascorbic acid content of fruits which ranged from 19.39 mg 100g^{-1} (T_5) to 20.67 mg 100g^{-1} (T_2) (Table 37).

4.3.5.8 Total carotenoids (mg 100g^{-1})

There was no significant effect on total carotenoid content of the fruits due to the application of different levels of N, P and K. The values ranged from 1.33 mg 100g^{-1} (T_1) to 2.19 mg 100g^{-1} (T_4) (Table 37).

4.3.5.9 Shelf life (days)

Shelf life of fruits was not significantly affected by different levels of N, P and K. Minimum shelf life of 14.25 days was noticed in T_1 and maximum of 15.75 days in T_2, T_3 and T_5 (Table 37).

4.3.5.10 Organoleptic analysis

Data corresponding to the organoleptic evaluation of passion fruits grown under different fertilizer treatments are presented in Table 38.

Sensory qualities are very important from the consumer's point of view. It depends on characters like appearance, colour, flavour, texture, odour, taste, after taste and overall acceptability. Among the five treatments, T_4 (7.40) recorded highest score for appearance and lowest score was recorded by T_5 (6.20). The maximum score for colour was observed in T_3 (7.80) and the minimum in T_5 (6.70). Score for texture was the maximum in T_3 (7.80) and the minimum in T_5 (6.70). For flavour, maximum score was recorded in T_3 (7.40) and minimum score in T_5 (6.30). The highest score for taste was recorded in T_3 (7.10) and the lowest score for T_4 (6.40). For after taste, T_3 (7.60) recorded the highest score and T_5 (6.10) the lowest. In case of odour, T_3 (7.20) recorded the maximum score and minimum in T_4 (6.50). The overall acceptability score was the highest in T_3 (7.50) and the lowest in T_5 (6.30). The highest overall score for all the sensory evaluation characters was recorded by T_3 (37.5:15:37.5 NPK g vine^{-1}). In case of overall acceptability, T_3 had the highest score of 7.50. So T_3 can be considered as the best treatment with regard to sensory characters.

4.3.6 SOIL NUTRIENT ANALYSIS

Soil properties *viz.,* pH, electrical conductivity, and organic carbon as well as nutrient like N, P, K, Ca and Mg were analysed before and after the experiment. The results are shown in Tables 39 and 40.

4.3.6.1 Soil pH

Soil samples collected from the experimental site before planting of the crop recorded a pH of 4.50 (Table 39). After the final harvest, T_4 recorded the highest pH of 4.43 which was followed by T_1 (4.34), T_3 (4.30), T_5 (4.28) and T_2 (4.24) (Table 40).

Among the different treatments, the application of NPK 150: 20: 50 g vine^{-1} recorded the highest pH of 4.34. In all the treatments, pH was low compared to initial value. In all the treatments, except for absolute control, the reduction in pH might be due to application chemical fertilizers and organic matter in the form of FYM.

According to the reports of Seng *et al.* (2006), liming did not show any advantage in increasing the soil pH. Crop response to liming is mainly due to the neutralizing of Al toxicity. Excess of Al in soil solution have adverse effect on root growth and retards the uptake of nutrients and water by plants.

4.3.6.2 Soil EC

Before planting, the EC recorded was 0.04 dSm^{-1} (Table 39) and after the final harvest highest EC was noted for T4 (0.13 dSm^{-1}) which was followed by T3 (0.12 dSm^{-1}), T2 (0.08 dSm^{-1}), T1 (0.05 dSm^{-1}) and T5 (0.04 dSm^{-1}) (Table 40).

Soil EC showed an increasing trend with increasing level of fertilizers applied. This might be due to the increased ions released to the soil from the fertilizers applied.

Table 38. Organoleptic evaluation of passion fruits from different fertilizer treatments

Treatment	Appearance	Colour	Texture	Flavour	Taste	After taste	Odour	Overall acceptability
T_1	6.70	7.00	6.90	6.70	6.50	6.50	7.10	7.30
T_2	7.20	7.50	7.00	6.80	6.80	6.80	7.00	6.80
T_3	7.30	7.80	7.80	7.40	7.10	7.60	7.20	7.50
T_4	7.40	7.50	7.20	6.60	6.40	6.70	6.50	6.60
T_5	6.20	6.70	6.70	6.30	5.60	6.10	6.60	6.30
K W value	3.11	3.35	4.83	2.89	5.44	4.52	3.91	3.79

4.3.6.3 Organic carbon

Before planting, the organic carbon content of the soil was 1.07 per cent (Table 39). After the final harvest, the highest organic carbon content was recorded in T_2 (1.26 %), which was followed by T_4 (1.20 %), T_1 (1.15 %), T_3 (1.09 %) and T_5 (1.06 %) (Table 40).

Organic carbon content of all the treatments, except for the absolute control, increased compared to the organic carbon content of the soil before starting the experiment. This might be due to the application of FYM @10 kg per plant and subsequent decomposition of organic matter present in the FYM (Poojashree, 2019).

4.3.6.4 Available Nitrogen

Before the experiment, the nitrogen content was 300.34 kg ha^{-1} (Table 39). After the final harvest, the highest N content was observed in T_2 (337.30 kg ha^{-1}), which was followed by T_4 (325.64 kg ha^{-1}), T_1 (315.90 kg ha^{-1}), T_3 (304.22 kg ha^{-1}) and T_5 (298.39 kg ha^{-1}) as given in Table 40.

The nitrogen content in the soil increased in all the treatments, except for the absolute control. This might be due to the increased application of nitrogenous fertilizers. Improvement of available nitrogen content with higher NPK doses has been reported by Peters (1997) in banana. The present study finding is in line with the results of Rajees (2003), who reported an increase in available N content after the experiment with increased levels of NPK on oriental pickling melon.

Highest nitrogen content in T_2 might be due to high soil organic carbon which is the major reservoir of soil nitrogen. The humic substances, a colloidal fraction of the soil organic matter, are responsible for much of the cation adsorption on the surface horizon (Oliver *et al*., 2013).

According to Bhindhu (2017) with soil pH nearing to neutrality which increases the bacterial activity, especially nitrifying bacteria and improves the mineralization of organic matter and release of elements like N, P and S into soil solution.

4.3.6.5 Available Phosphorous

Before planting, the available phosphorous content of the soil was 26.04 kg ha^{-1} (Table 39). After the final harvest, the highest available P content was in T_4

(29.16 kg ha^{-1}), which was followed by T_3 (27.76 kg ha^{-1}), T_2 (23.75 kg ha^{-1}), T_1 (22.47 kg ha^{-1}) and T_5 (19.11 kg ha^{-1}) (Table 40).

Only two treatments T_4 (50 N: 20 P_2O_5: 50 K_2O g $vine^{-1}$) and T_3 (37.5 N: 15 P_2O_5: 37.5 K_2O g $vine^{-1}$) showed increased phosphorus content compared to initial phosphorus levels. This reveals that in other treatments phosphorus applied was not adequate which resulted in a decrease in available phosphorus content.

The reduced values of P, even with the application of phosphatic fertilization may be due to the high phosphoric fixing capacity of the lateritic soil. According to Sureshkumar *et al.* (2018), when phosphatic fertilizers are added to soil water, soluble phosphorus enters the soil solution and forms compounds with Al, Fe, Mn, Ca *etc*. The Ca-P and soluble P are the forms of P available to plants. The products of P fixation are sparingly soluble to insoluble, therefore only small quantities of P will be available for plants at a particular time. This might be the reason for the reduced value of P in those treatments.

With soil pH nearing to neutrality which increases the bacterial activity, especially nitrifying bacteria, and improves the mineralization of organic matter and release of P into soil solution (Bhindhu, 2017). In the present experiment, available P was highest in T_4 (29.16 kg ha^{-1}) which had the higher pH.

As per the reports of Frageria and Santos (2008), with increasing soil pH, available P content also increased linearly in Brazilian oxisols.

4.3.6.6 Available Potassium

An available potassium content of 170.54 kg ha^{-1} was recorded in soil before planting (Table 39). After the final harvest, the highest available K content was recorded in T_4 (242.87 kg ha^{-1}) which was followed by T_3 (231.24 kg ha^{-1}), T_2 (223.33 kg ha^{-1}), T_1 (222.34 kg ha^{-1}) and T_5 (139.95 kg ha^{-1}) (Table 40).

The highest available potassium content recorded higher values compared to the initial potassium content, except in absolute control. This might be due to the increased application of potassium fertilizers. According to Indira (2003), an increase in available potassium content in soil was observed, with application of higher rates of N and K in a study conducted in banana.

Table 39. Chemical properties of soil at experimental site before planting

Parameters	Content in the soil
pH	4.50
EC	0.04 dS m^{-1}
Organic carbon	1.07 %
Available N	300.34 kg ha^{-1}
Available P	26.04 kg ha^{-1}
Available K	170.54 kg ha^{-1}
Available Ca	129.05 mg kg^{-1}
Available Mg	92.83 mg kg^{-1}

Table 40. Chemical properties of soil at experimental site after the harvest

Treatment	pH	EC (dSm^{-1})	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available Ca (mg/kg)	Available Mg (mg/kg)
T_1	4.34	0.05	1.15	315.90	22.47	222.34	136.33	84.38
T_2	4.24	0.08	1.26	337.30	23.75	223.33	145.63	74.24
T_3	4.30	0.12	1.09	304.22	27.76	231.24	140.00	72.48
T_4	4.43	0.13	1.20	325.64	29.16	242.87	148.75	86.25
T_5	4.28	0.04	1.06	298.39	19.11	139.95	124.95	70.50

The present results are also in conformity with the results of Rajees (2003) who reported an increase in available K after the harvest with higher supply of NPK in oriental pickling melon.

4.3.6.7 Available Calcium

Available calcium before the experiment was 129.05 mg kg^{-1} (Table 39). After the final harvest, available Ca was highest in T_4 (148.75 mg kg^{-1}), followed by T_2 (145.63 mg kg^{-1}), T_3 (140.00 mg kg^{-1}), T_1 (136.33 mg kg^{-1}) and T_5 (124.95 mg kg^{-1}) (Table 40).

In the absolute control, where no lime was applied, calcium content was slightly lower than the initial calcium level. While, in all other treatments, calcium content slightly increased compared to initial value, which might be due to the application of lime.

4.3.6.8 Available Magnesium

Available magnesium content before planting was 92.83 mg kg^{-1} (Table 39). After the final harvest available Mg was highest in T_4 (86.25 mg kg^{-1}), followed by T_1 (84.38 mg kg^{-1}), T_2 (74.24 mg kg^{-1}), T_3 (72.48 mg kg^{-1}) and T_5 (70.50 mg kg^{-1}) (Table 40).

All the treatments showed a reduction in available magnesium level compared to the initial magnesium content in the soil. The absorption of available magnesium by the plant might have resulted in the reduction in soil Mg level, since there was no addition of Mg during the experimental period.

4.3.7 PLANT NUTRIENT ANALYSIS

The effects of treatments on the plant N, P, K, Ca and Mg are presented in Table 41.

4.3.7.1 Nitrogen

Application of different levels of NPK had no significant effect on N content of the plant which varied from 3.65 per cent (T_4 and T_5) to 3.96 per cent in T_3 (Table 41).

4.3.7.2 Phosphorous

Application of different levels of NPK had no significant effect on P content of the plant, which ranged between 0.22 per cent in T_1 to 0.29 per cent in T_4 (Table 41).

4.3.7.3 Potassium

Application of different levels of NPK had significant effect on plant K content (Table 41). T_4 (2.72 %), recorded the highest plant K content, which was on par with T_2 (2.49 %). T_2 was on par with T_3 (2.41 %) and T_1 (2.23 %). T_5 (2.12 %) had the lowest plant K content, which was on par with T_3 and T_1.

The difference in potassium content in plant might be due to the different levels of potassium applied. According to Priya *et al.* (2007), application of higher levels of potassium fertilizers restrict the activity of iron and manganese, thereby, increasing K uptake. The lowest content of K (2.12 %) in the absolute control might be due to the absence of liming. Liming acid soils is a must in the case of acid soils, otherwise K uptake will be antagonized (Sureshkumar *et al*., 2018).

In a study conducted by Rajees (2003) in oriental pickling melon revealed that leaf K content increased significantly with increase in NPK levels. With increase in the levels of application of nutrients, there was a trend to absorb and accumulate more nutrients in the leaves. But, the rate of increase of nutrients in leaves due to increasing levels of NPK was comparatively lesser. Vegetative growth and yield of passion fruit was higher when leaf K content was in the range of 2.00 to 3.00 per cent (Menzel *et al.,* 1993), which supports the findings in present study. According to Kondo and Higuchi (2013) application of lower doses of K resulted in lower K concentration. This is also in agreement with the results of the present study.

4.3.7.4 Calcium

Application of different treatments had no effect on plant Ca content, which varied from 1.5 per cent in T_5 to 2.83 per cent in T_3 (Table 41).

4.3.7.5 Magnesium

Application of different treatments did not have significant effect on plant Mg content (Table 41). It ranged from 0.30 per cent in T_3 and T_4 to 0.40 per cent in T_2.

Table 41. Plant nutrient analysis after final harvest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T_1	3.66	0.22	2.23	2.73	0.37
T_2	3.95	0.28	2.49	2.61	0.40
T_3	3.96	0.27	2.41	2.83	0.30
T_4	3.65	0.29	2.72	2.82	0.30
T_5	3.65	0.24	2.12	1.51	0.35
CD (0.05)	NS	NS	0.30	NS	NS

Table 42. Effect of different noded cuttings on survival per cent, shoot and root parameters

Treatment	Days to sprout	Survival (%)	No. of leaves	Total leaf area (cm^2)	Shoot length (cm)	Root length (cm)
One noded (N_1)	20.00	30.80	4.80	71.61	17.60	9.75
Two noded (N_2)	18.00	56.00	6.10	82.84	21.63	9.95
Three noded (N_3)	17.70	57.10	6.70	142.29	24.62	13.55
Four noded (N_4)	17.80	70.60	7.70	166.15	28.75	14.25
CD (0.05)	1.54	2.27	1.00	5.10	1.89	1.59

Pacheco *et al*. (2017) found that the external and internal characteristics of passion fruit is influenced by fertilization, along with other factors. Different levels of NPK significantly influenced biometric parameters, yield and fruit characters and to a less extent qualitative parameters. Passion fruit is considered as a soil exhaustive crop. Therefore, passion fruit cultivation may lead to severe depletion of nutrients from the soil. So, additional supply of nutrients to soil is highly essential.

4.3.8 PEST AND DISEASE INCIDENCE

A few pests like scale and stem borer as well as diseases like fungal wilt were noticed which could be controlled by pesticides and fungicides.

4.4 Standardization of propagation through stem cutting in passion fruit

The results and discussion of the experiment propagation studies in passion fruit are presented here.

4.4.1 EFFECT OF DIFFERENT NODED STEM CUTTINGS ON PROPAGATION OF PASSION FRUIT

Effect of different noded cuttings on days to sprout, survival per cent, shoot and root parameters are given in Table 42. Significant influence was noticed with respect to survival per cent, shoot and root characteristics at 90 DAP by using different noded cuttings.

4.4.1.1 Effect of different noded cutting on days to sprout

The number of days to sprout varied significantly among different noded cuttings of passion fruit (Table 42). The least days to sprout (17.70 days) was recorded in three noded cutting, which was on par with four noded cutting (17.80 days) and two noded cutting (18.00 days). The longest days to sprout was observed in one noded cutting (20.00 days).

4.4.1.2 Effect of different noded cutting on survival per cent

Survival per cent (70.60) was also the highest in the four noded cuttings (N_4), which was superior to all other treatments (Table 42, Figure 20). This was followed by three noded cuttings (N_3), which was on par with two noded cutting (N_2) and the lowest survival per cent was obtained in single noded cuttings (N_1).

4.4.1.3 Effect of different noded cutting on number of leaves

Number of leaves (7.70) was highest in four noded cuttings (N_4), which was on par with three noded cuttings with 6.70 number of leaves (Table 42). It was on par with two noded cutting with 6.10 number of leaves and one noded cutting with 4.80 number of leaves.

4.4.1.4 Effect of different noded cutting on total leaf area

Total leaf area also exhibited a similar trend. Total leaf area (166.15 cm^2) was highest in four noded cuttings (N_4), which was superior to all other treatments (Table 42). It was followed by three noded cutting, two noded cutting and one noded cutting with 142.29 cm^2, 82.84 cm^2 and 71.61 cm^2 respectively.

4.4.1.5 Effect of different noded cutting on shoot length

Shoot length observed also varied significantly with respect to the number of nodes present in the cuttings and shoot length (28.75 cm) was the highest in four noded cutting (N_4), which was superior to all other treatments (Table 42). It was followed by three noded (N_3), two noded (N_2) and one noded cuttings (N_1).

4.4.1.6 Effect of different noded cutting on root length

Root length also showed the same trend and four noded cuttings (N_4) had the highest root length (14.25 cm), which was on par with three noded cuttings (N_3) (Table 42). This was followed by two noded cutting (N_2) which was on par with the single noded cuttings (N_1).

For all the parameters studied, except for days to sprout, four noded cuttings (N_4) exhibited the highest values, which may be due to the increased carbohydrate reserve present in them. This might be due to the low reserve of carbohydrates in the single noded cuttings since it had the minimum size among the treatments. According PRS (2015) in a propagation study using two to five noded cuttings, it was found that three to four noded cuttings gave the maximum success and buds started sprouting after 21 days of planting. On an average, stem cuttings started rooting in twenty to thirty days. But all the sprouted buds were not successful in sustaining the growth and majority of the sprouts died later, showing a reduction in survival per cent with the passage of time. The highest number of sprouts was recorded on the 28^{th} day after planting, which decreased slowly. After 36 days of planting, the final survival per cent was 46.60. Regular irrigation to maintain 100 per cent relative humidity is important because there is a rapid loss of water from the vine cuttings. So, in the case of state like Kerala, propagation using vine cuttings can be done during the monsoon season, when there is required relative humidity.

In a similar study conducted by Bemkaireima *et al*. (2012) number of leaves (6.53), total leaf area (55.9 cm^2) and survival per cent (45) were highest in four noded cuttings and the values of the present study are comparable with those results. Zimmerman and Hitchcock (1935) reported that higher number of nodes in the cuttings of vine crops resulted in higher root production, which agrees with the present results. Basu and Ghosh (1974) reported that superiority in root length could be due to higher C: N ratio in the tissues of cuttings and higher food reserves in the cuttings. Longer shoot length, higher number of leaves and higher survival per cent in four noded cuttings might be due to the longer roots which resulted in better root development, helping in more absorption of nutrients and water. Therefore, considering survival per cent, total leaf area and shoot length four noded cutting is superior. But, based on days to sprout, number of leaves and root length, three noded cuttings are preferable.

4.4.2 EFFECT OF NAA CONCENTRATIONS ON ROOTING OF STEM CUTTINGS OF PASSION FRUIT

Effect of NAA concentration on days to sprout, shoot and root parameters and survival per cent are shown in Table 43. NAA concentration had significant effect on different characters studied.

4.4.2.1 Effect of NAA concentration on days to sprout

Days to sprout varied significantly among different treatments (Table 43). The shortest days to sprout of 17.38 days was observed with use of 800 ppm NAA, which was on par with 17.88 days with use of NAA 600 ppm, 18.00 days with the use of NAA 200 ppm and 18.13 days with the use of 400 ppm NAA. The longest days to sprout of 20.50 days was observed in the control treatment.

4.4.2.2 Effect of NAA concentration on survival per cent of stem cuttings

Survival per cent (64.50 %) was the highest when NAA 800 ppm was used, which was superior to all other treatments (Table 43, Figure 21). The least survival per cent of 39.25 was observed in the control treatment.

4.4.2.3 Effect of NAA concentration on number of leaves

Maximum number of leaves (7.00) was observed in the treatment NAA 800 ppm, which was on par with treatments using NAA 400 and 600 ppm (Table 43). Minimum number of leaves of 5.63 was recorded with the use of 200 ppm NAA.

4.4.2.4 Effect of NAA concentration on total leaf area

Total leaf area was significantly influenced by NAA concentrations and the maximum leaf area of 164.38 cm^2 was observed with 800 ppm NAA, which was superior to all other treatments (Table 43). It was followed by 139.69 cm^2, 115.01 cm^2, 94.11 cm^2 and 65.42 cm^2 with the use of 600 ppm, 400 ppm, 200 ppm NAA and control treatment respectively.

4.4.2.5 Effect of NAA concentration on shoot length

Shoot length varied significantly and was higher in all the NAA concentrations used when compared with the control (14.34 cm) (Table 43). The highest shoot length (27.94 cm) was observed NAA 800 ppm (A_5) which was on par with NAA 600 ppm (A_4).

4.4.2.6 Effect of NAA concentration on root length

NAA concentrations significantly influenced the root length after 90 days of planting (Table 43). The highest root length (14.56 cm) was recorded in treatment with higher NAA concentration, of 800 ppm, which was superior to all other treatments. It was followed by A_4 with 12.70 cm, which was on par with 12.25 cm in A_3 (400 ppm NAA) and 11.25 cm in A2 (200 ppm NAA). The least root length was observed in the control treatment (8.61 cm).

The beneficial effect of growth hormones on the rooting of cuttings have been reported earlier in many crops. Higher survival per cent and shoot parameters might be due to the stimulated cambial activity resulting from the application of auxin like hormones which increased the mobilization of reserve food materials to the site of root initiation as reported by Gurumurthy *et al.* (1984). According to Tripathi *et al.* (2014) root characters were significantly influenced by higher level of NAA concentration and were found superior over control. Pandey *et al*. (1983) reported that root initiation and root characters were influenced by the optimum concentrations of exogenous auxins which caused the mobilization and utilization of carbohydrates and nitrogen, along with the presence of cofactors at the cut portion. In a study conducted in pomegranate cuttings by Rajamanickam and Balamohan (2019), it was found that the concentration of IBA increased number of leaves, shoot length, root length and survival per cent. The use of 800 ppm NAA by quick dip method promoted survival per cent, leaf area and root length. NAA 600 ppm can also be considered, based on days to sprout, number of leaves and shoot length.

4.4.3 EFFECT OF DIFFERENT NODED CUTTINGS AND NAA CONCENTRATION ON PROPAGATION OF PASSION FRUIT

The effect of different noded cuttings and NAA concentration on days to sprout, shoot and root parameters and survival per cent at 90 DAP was studied. The results are shown in Table 44 and discussed hereunder.

4.4.3.1 Effect of number of nodes and NAA concentration on days to sprout

The number of days to sprout varied significantly among different treatments (Table 44). The shortest days to sprout (15) was observed in T_{15} (three noded + 800 ppm NAA), which was on par with T_{10} (two noded with 800 ppm NAA) and T_{19} (four noded along with 600 ppm NAA) each with 16.00 days to sprout, T_{12} and T_{18} (16.50 days), T_7, T_8 and T_{13} (17.50 days) and T_{17} (18.00 days). The longest days to sprout (21.00 days) was recorded in T_{11} (three noded without NAA) and T_1 (one noded without NAA).

4.4.3.2 Effect of number of nodes and NAA concentration on survival per cent

Survival per cent among different treatments varied significantly ranging from 21 to 81 per cent (Table 44, Figure 22). The maximum survival percentage of 81 was recorded in T_{20} (four noded + 800 ppm NAA), which was on par with T_{19} (four noded + 600 ppm NAA). The lowest survival per cent of 21 per cent was recorded in T_1 (one noded without NAA).

4.4.3.3 Effect of number of nodes and NAA concentration on number of leaves

Significant variation in number of leaves was observed among the treatments and it varied from 4 (Treatment 1) to 8.50 (Treatment 20) (Table 44). T_{20} (four noded + 800 ppm NAA) was on par with T_9 (two noded + 600 ppm NAA), T_{10} (two noded + 800 ppm NAA), T_{11} (three noded without NAA), T_{13} (three noded + 400 ppm NAA), T_{14} (three noded + 600 ppm NAA), T_{15} (three noded + 800 ppm NAA), T_{16} (four noded without NAA), T_{17} (four noded + 200 ppm NAA), T_{18} (four noded + 400 ppm NAA) and T_{19} (four noded + 600 ppm NAA).

4.4.3.4 Effect of number of nodes and NAA concentration on total leaf area

Statistical analysis showed that leaf area also varied significantly among the treatments (Table 44). Leaf area, which is major contributing factor towards photosynthesis, was highest in Treatment 15 (three noded + 800 ppm NAA), with leaf area of 237.50 cm^2, which was superior to all other treatments. The lowest leaf area of 32.25 cm^2 was observed in Treatment 1 (one noded without NAA).

Table 43. Effect of NAA concentration on shoot and root characteristics and survival per cent

Treatment	Days to sprout	Survival (%)	No. of leaves	Shoot length (cm)	Total leaf area (cm^2)	Root length (cm)
Control (A_1)	20.50	39.25	5.88	14.34	65.42	8.61
NAA 200 ppm (A_2)	18.13	44.38	5.63	22.74	94.11	11.25
NAA 400 ppm (A_3)	18.00	58.13	6.63	24.72	115.01	12.25
NAA 600 ppm (A_4)	17.88	61.88	6.50	26.00	139.69	12.70
NAA 800 ppm (A_5)	17.38	64.50	7.00	27.94	164.38	14.56
CD (0.05)	1.72	2.53	1.11	2.11	5.70	1.77

Table 44. Effect of different noded cuttings and NAA concentrations on days to sprout, shoot and root parameters and survival per cent

Treatment	Days to sprout	Survival (%)	No. of leaves	Shoot length (cm)	Total leaf area (cm^2)	Root length (cm)	B: C ratio
T_1	21.00	21.00	4.00	8.25	32.25	6.25	0.35
T_2	20.50	27.00	4.50	15.50	56.75	9.75	0.45
T_3	20.50	33.00	6.00	20.75	73.30	8.75	0.51
T_4	18.50	32.00	4.50	20.75	97.25	11.00	0.51
T_5	19.50	41.00	5.00	22.75	98.50	13.00	0.67
T_6	20.50	29.00	5.50	12.38	42.00	6.95	0.48
T_7	17.50	45.00	5.50	21.75	81.20	8.75	0.70
T_8	17.50	64.00	6.00	23.25	81.75	11.50	0.54
T_9	18.50	73.00	6.50	24.50	103.75	10.80	0.59
T_{10}	16.00	69.00	7.00	26.25	105.50	11.75	0.56
T_{11}	21.00	52.00	7.00	16.00	87.68	11.25	0.86
T_{12}	16.50	41.50	5.00	25.70	108.25	13.00	0.70
T_{13}	17.50	62.50	7.00	26.38	136.00	13.75	0.99
T_{14}	18.50	62.50	7.00	26.75	142.00	13.00	0.96
T_{15}	15.00	67.00	7.50	28.25	237.50	16.75	1.02
T_{16}	19.50	55.00	7.00	20.75	99.75	10.00	0.90
T_{17}	18.00	64.00	7.50	28.00	130.25	13.50	1.05
T_{18}	16.50	73.00	7.50	28.50	169.00	15.00	1.21
T_{19}	16.00	80.00	8.00	32.00	215.75	16.00	1.27
T_{20}	19.00	81.00	8.50	34.50	216.00	16.75	1.31
CD (0.05)	3.44	5.07	2.23	4.23	11.40	3.55	-

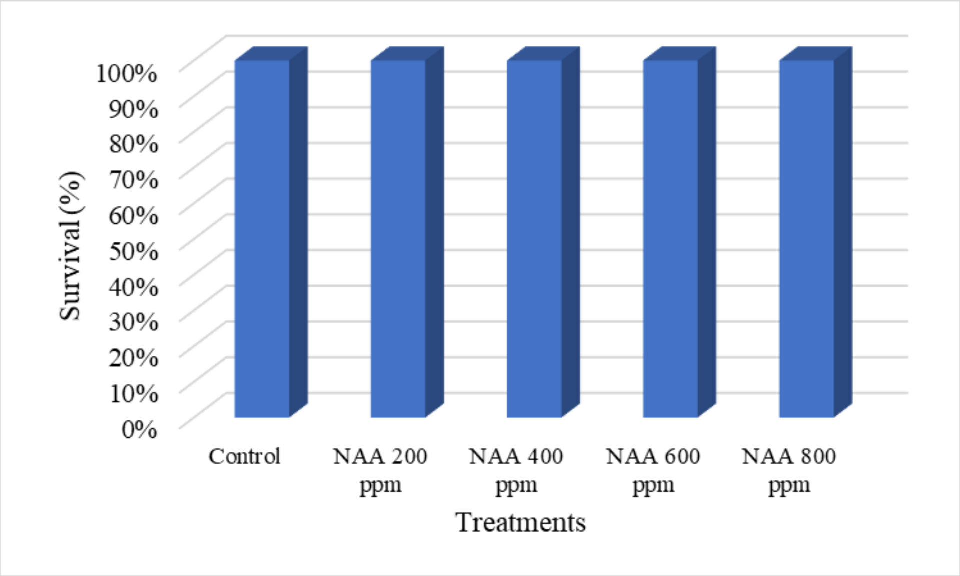


Figure 21. Survival per cent with different NAA concentrations

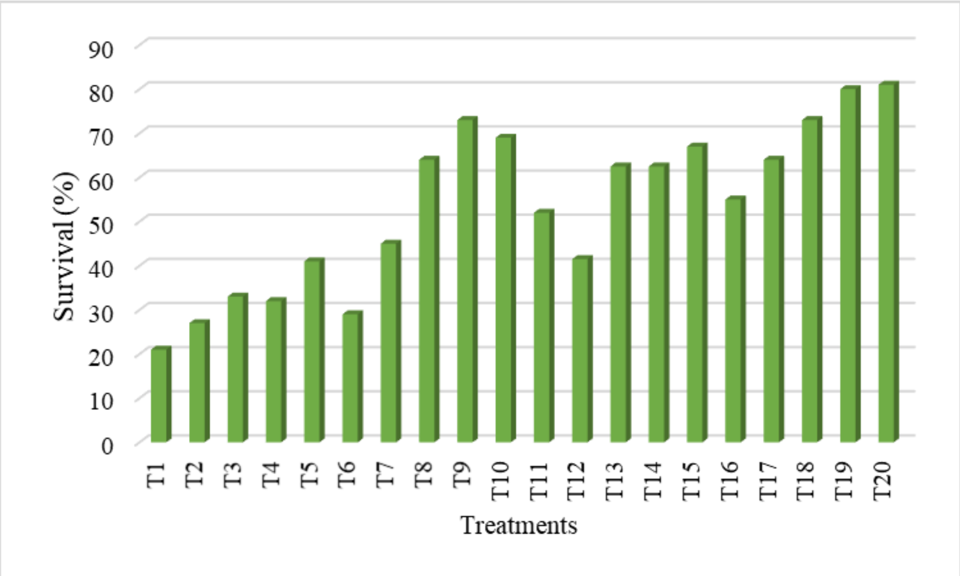


Figure 22. Survival per cent in different treatment combinations

4.4.3.5 Effect of number of nodes and NAA concentration on shoot length

Shoot length of passion fruit cuttings varied significantly (Table 44) and was the highest in T_{20} (34.50 cm), which was on par with T_{19} (four noded + 600 ppm NAA), with 32.00 cm. While the lowest shoot length of 8.25 cm was observed in Treatment 1(one noded without NAA).

4.4.3.6 Effect of number of nodes and NAA concentration on root length

The study also revealed that root length varied significantly with respect to different treatments (Table 44). Root length was lowest in Treatment 1 (6.25 cm) and highest in Treatment 15 and Treatment 20 (16.75 cm). Treatments 15 and 20 were on par with T_{19} (16.00 cm), T_{18} (15.00 cm), T_{13} (13.75 cm) and T_{17} (13.50 cm).

Therefore, combined effect of number of nodes and NAA concentration has shown that T_{15} (three noded + 800 ppm NAA) is preferable in terms of total leaf area, root length, days to sprout and number of leaves. While, based on survival per cent and shoot length T_{20} (four noded + 800 ppm NAA) and T_{19} (four noded + 600 ppm NAA) were on par and superior to T_{15}. T_{20} also had the highest B:C ratio of 1.31.

According to Bemkaireima *et al*. (2012), interaction effect of four noded cuttings treated with IBA showed superiority with respect to survival per cent, which is in line with the present results. The high success rate in T_{15}, T_{19} and T_{20} may be due to optimum concentration of NAA and carbohydrate reserve present in the cuttings. Singh and Singh (1972) reported that the combination of four noded cuttings and 800 ppm NAA was superior over other treatments because of the rooting cofactor in its stem or due to the inherent rooting capacity of the species. The favourable interaction effect between the number of nodes in the cuttings and NAA concentration might have led to the high success in three noded along with 800 ppm NAA, four noded cutting using 600 ppm and 800 ppm NAA.

From the present study, it could be concluded that among the different noded cuttings, four noded cutting was superior in all the characteristics studied. As the number of nodes per cutting increased survival per cent, shoot and root parameters also got enhanced. NAA was found to increase the growth of passion fruit cuttings and the highest concentration of NAA used, 800 ppm, resulted in high values for different parameters studied. The interaction effect between number of nodes per cutting and NAA concentration showed that four noded cutting treated with 600 ppm

NAA and 800 ppm NAA were on par and recorded the higher values for different characters studied. Thus, four noded cuttings dipped in 600 ppm NAA can be used effectively for the large scale multiplication of passion fruit plants for commercial cultivation thereby ensuring true to type plants which in turn helps to get uniform crop with high returns.

Summary

5. SUMMARY

The experiment on 'Production technology and crop improvement of passion fruit (*Passiflora edulis* Sims.)' was conducted during 2018-2020 under the humid agroclimatic conditions of Thrissur. The salient findings of the study are presented in this chapter.

Eight accessions of passion fruit collected from different locations of Kerala were evaluated for their performance. Among the vegetative characters studied, stem girth varied from 7.83 cm in Accession 5 to 13.83 cm in Accession 2. Highest stem girth was observed in Accession 2 which was significantly superior to all other accessions.

Slight variation was observed in the time of anthesis, which varied from 01.03 pm in Accession 3 to 01.42 pm in Accession 2. Per cent fruit set did not show significant difference among the accessions which ranged from 73.45 per cent in Accession 8 to 83.22 per cent in Accession 1. Stigma was receptive at the time of anthesis in all the accessions evaluated. Pollen storage studies revealed that passion fruit pollen could be stored in desiccator under refrigerated condition at 4°C, up to 72 hours after anthesis, with 50.88 per cent viability.

Time taken for first flowering and first fruiting and the duration from flowering to harvest varied significantly among different accessions. The least number of days to flowering of 157.33 days was observed in Accession 7 which was on par with Accession 5 (160.33 days), Accession 6 (165.00 days), Accession 4 (169.33 days) and Accession 1 (171.00 days). The least number of days for first fruiting was found in Accession 7 with 159.67 days, which was on par with Accession 5 (163.33 days), Accession 6 (168.00 days), Accession 4 (172.33 days) and Accession 1 (173.33 days). Flowering to harvest duration was the least in Accession 4 (59.33 days) which was on par with Accession 1 (59.67 days), Accession 7 (63.00 days), Accession 5 (67.00 days), and Accession 2 (68.00 days).

Data on flower production from February to September revealed that significant variation was observed in the months of February, March, April, May and June. Peak flowering was recorded in September in Accessions 1, 2, 4, 5, 6, 7 and 8. In Accession 3, August was found to be the peak flowering month. Total flower production per vine varied significantly among the accessions. The highest flower production was recorded in Accession 4 (190.67), which was on par with Accession 2 (181.67) and Accession 6 (180.33). Accession 4 (190.67), Accession 2 (181.67) and Accession 6 (180.33) can be considered superior in terms of flower production.

Fruit production from February to September revealed that significant variation observed only in the months of March and May. Peak fruiting month was found to be September in all accessions, except for Accession 3 which had the peak fruit production in the month of August. In the case of Accession 4, July was the peak fruiting month, while in Accession 2, June and September were the peak fruiting months. June - September can be considered as peak fruiting months in the plains of Thrissur. Highest fruit production per vine per year was observed in Accession 4 (155.33 nos.), which was on par with Accession 2 (149.33 nos.) and Accession 6 (146.67 nos.).

Fruit characters of different accessions varied significantly. The highest fruit weight was observed in Accession 3 (120.33 g), which was superior to all other accessions. The highest fruit girth was observed in Accession 3 (23.30 cm), which was on par with Accession 4 (23.00 cm), Accession 2 (22.67 cm) and Accession 8 (22.37 cm). Fruit diameter also exhibited a similar trend. Pulp weight was highest in Accession 3 (52.00 g), which was on par with Accession 4 (48.17 g) and Accession 2 (46.67 g). The maximum juice weight was recorded for Accession 4 (43.30 g), which was on par with Accession 3 (42.33 g), Accession 2 (38.50 g) and Accession 8 (37.00 g). Rind thickness, which is a contributing factor towards shelf life of various accessions varied significantly and highest rind thickness was recorded in Accession 3 (0.91 cm) which had a shelf life of 15.67 days, which was on par with Accession 5 (0.78 cm) with a shelf life of 15.33 days.

Different accessions have shown significant effect on physical components, *viz*., juice per cent, rind per cent and per cent of seed. High juice recovery is of importance in the processing industry and value addition. Juice per cent recorded was the maximum in Accession 4 (39.34 %), which was on par with Accession 2 (39.00 %), Accession 8 (37.48 %) and Accession 5 (37.19 %). The lowest rind per cent was observed in Accession 5 (52.55 %), which was on par with Accession 2 (52.61 %), Accession 4 (53.14 %) and Accession 8 (56.38 %).

Accessions like 3 (yellow) and 4 (purple) with superior fruit characters like fruit girth, fruit diameter, fruit weight, pulp weight and juice weight could be used for commercial cultivation as well as crop improvement programmes. Accessions like Accession 4, 2, 8 and 5 which are having highest juice recovery with the lower rind percentage may be exploited for processing industries, for the preparation of value added products and beverages.

All the quality parameters studied varied significantly among the accessions. The highest TSS of 18.33 °Brix was recorded in Accession 4, which was on par with Accession 8 (17.80 °Brix), Accession 2 (17.45 °Brix) and Accession 5 (17.33 °Brix). The lowest acidity was recorded in Accession 2 (2.37 %). Total sugar per cent was highest in Accession 5 (13.55 %), which was on par with Accession 4 (12.32 %). The highest reducing sugar was recorded in Accession 4 (10.34 %), which was superior to all other accessions. Accession 5 recorded the highest non reducing sugar per cent of 5.92, which was superior to all other accessions. The highest sugar/acid ratio was recorded in Accession 5 (4.97), which was significantly superior to all others. Maximum ascorbic acid content was observed in Accession 4 (31.15 mg $100g^{-1}$). The highest total carotenoid content was found in Accession 7 (3.38 mg $100g^{-1}$), which was significantly superior to all other accessions. From the organoleptic analysis, it was found that overall acceptability score was the highest in Accession 4 (7.60). The Accession 4 (purple type) with highest TSS (18.33 °Brix), higher total sugar (12.32 %), highest reducing sugar (10.34 %) and highest ascorbic acid (31.15 mg $100g^{-1}$) can be selected as a superior accession based on quality parameters.

Different accessions showed differences in physicochemical characters. Accession 4, which was early in flowering and fruiting, superior in yield as well as fruit characters can be considered superior and can be used for commercial cultivation and crop improvement programmes. Due to low levels of acidity and high TSS purple type was found to be sweeter and have good flavour compared to yellow accessions. Accessions like 4, 2, 8 and 5 which were having high juice recovery with the lower rind per cent may be exploited for processing industries.

Biometric characters of hybrid seedlings *viz.*, days for germination, seed germination per cent, seedling vigour index, number of leaves, total leaf area and seedling height showed significant variations. The least number of days for germination, 13.00 days, was observed in H_5 (P_6 x P_1). The highest seed germination percentage of 90.12 per cent, was recorded in H_6 (P_6 x P_2) which was on par with H_3 (86.74 %), H_7 (85.45 %) and H_5 (85.04 %). The highest seedling vigour index of 15.09 was exhibited by H_6 (P_6 x P_2) which was on par with H_4 (14.17), H_7 (14.05), H_5 (13.75), H_3 (12.87) and H_8 (12.73). The highest number of leaves (10.33) was recorded in H_4 (P_5 x P_4), which was superior to all other treatments. The highest total leaf area (181.17 cm^2) was exhibited by H_4 which was on par with H_6 (170.83 cm^2). Seedling height was maximum in H_4 (18.00 cm) which was on par with H_6 (16.83 cm), H_7 (16.50 cm), H_5 (16.17 cm), H_8 (15.33 cm) and H_3 (14.83 cm).

In the comparative study of hybrids and parents, minimum number of days to first fruiting was recorded in H_5 (205.00 days) which was on par with P_1 (206.00 days), H_3 (271.50 days) and H_4 (263.00 days). Minimum number of days from flowering to harvest was observed in P_2 (58.50 days), which was on par with H_3 (59.00 days), H_2 (61.00 days), S_1 (66.00 days), P_3 (66.00 days), P_1 (67.00 days) and H_5 (67.50 days). Hybrid, H_5 which took the least number of days to first flowering, first fruiting and flowering to harvest can be regarded as early type.

While observing the flower production from December to May, significant variation was noticed only in the month of May. Peak flowering month was identified as March in all passion fruit parents and hybrids, except in P_6 and S_1 (P_3 x P_3) where peak flowering was observed during May.

Fruit production was evaluated from December to May and fruit production varied significantly in the months of May and December. In all most all parents and hybrids, peak fruiting month was observed in March, while in Parent 6, peak fruiting was observed in May. In hybrids, H_7 (P_6 x P_4) and H_8 (P_6 x P_5) peak fruiting was observed in April. The highest fruit production was observed in H_4 (135.00) which was on par with H_5 (108.50), P_1 (108.00), H_8 (104.00) and H_3 (100.50). Hybrids, H_4, H_5, H_8 and H_3 were superior in terms of fruit production.

The maximum fruit diameter and fruit girth (7.00 cm and 22.00 cm respectively) were observed in H_6. The fruit diameter in H_6 was on par with P_6 (6.85 cm), H_3 (6.69 cm), H_4 (6.68 cm), H_2 (6.62), P_4 (6.61 cm), H_8 (6.56 cm), H_7 (6.46 cm) and P_1 (6.44 cm). The maximum fruit girth observed in H_6, was on par with P_6 (21.50 cm), H_3 and H_4 (21.00 cm), P_4 (20.75 cm), H_8 (20.60 cm) and H_7 & H_2 (20.30 cm). The highest fruit weight was also observed in H_6 (117.75 g) which was on par with P_6 (106.00 g). Parents and hybrids of passion fruit showed significant difference in pulp weight. The highest pulp weight was recorded in H_6 (52.75 g) which was on par with H_3 (51.50 g), H_4 (46.50 g), P_6 (46.00 g), H_2 (45.95 g), H_8 (43.60 g) and H_7 (43.00 g). The lowest rind weight was recorded in H_5 (29.00 g) which was on par with S_1 (29.25 g), H_2 (32.00 g), P_5 (32.50 g), P_3 (33.00 g) and H_1 (34.90 g). Significant variation was revealed in rind thickness of passion fruit parents and hybrids. The maximum rind thickness of 0.94 cm was observed in H_6, which was on par with P_6 (0.92 cm) and P_4 (0.86 cm). Based on fruit characteristics, H_6, with highest fruit weight, fruit girth, fruit diameter and pulp weight can be considered as a superior hybrid.

Among the quality characteristics of passion fruit hybrids and parents, only TSS showed significant variation. The highest TSS was observed in P_4 (17.53 °Brix) which was on par with H_6 (17.50 °Brix), S_1 (17.30 °Brix), H_5 (17.00 °Brix), H_8 (16.93 °Brix), H_1 (16.79 °Brix), P_5 (16.50 °Brix), P_1 (16.25 °Brix), H_4 (16.20 °Brix) and P_3 (15.75 °Brix).

In the experiment for the standardization of fertilizer requirement in passion fruit, vegetative characters like stem girth and number of branches varied significantly. Maximum girth was observed in T_4 (12.00 cm), which was significantly superior to all other treatments. Number of branches per vine varied significantly with respect to fertilizer treatments and mean number of branches per vine was the maximum in T_1 (10.75), which was superior to all other treatments. Shortest duration from flowering to harvest was noticed in T_5 (59.75 days), which was on par with T_1 (63.50 days) and T_2 (64.50 days).

From the monthly flower production observed during May to November, significant variation was observed during June, July and August. Peak flowering was observed in the month of August in T_4, profuse flowering was recorded in September in T_1, T_2 and T_5. Peak flowering in T_3 was recorded in October. Highest flower production (203.50 nos.) was recorded in T_4 (50 N: 20 P_2O_5: 50 K_2O (g vine $^{-1}$)), which was significantly superior to all other treatments.

Significant variation was observed in monthly fruit production during the months of June, July and August. Peak fruiting was observed in the month of September in all treatments, whereas in T_3 and T_4 peak fruiting was recorded in October. Highest fruit production per vine per year was observed in T_4 (165.50), which was on par with T_3 (138.25), T_2 (135.00). The highest fruit diameter and fruit girth (7.28 cm and 22.88 cm) were recorded in T_4 which was significantly superior to all other treatments. T_4 recorded the maximum fruit weight and pulp weight of 114.75 g and 51.25 g respectively, which was on par with T_3 with 89.13 g and 44.00 g fruit weight and pulp weight respectively. The least rind weight was observed in T_5 (26.53 g), which was on par with T_1 and T_2.

Different levels of N, P and K had significant effect on fruit quality parameters like TSS, total sugars and reducing sugars. The highest TSS was observed in T_4 (19.15 °Brix), which was superior to all other treatments. The highest total sugar content was observed in T_4 (13.38 %) which was on par with T_3 (12.70 %) and T_2 (12.60 %). The highest reducing sugar content was observed in T_2 (9.17 %) which was on par with T_4 (8.76 %) and T_3 (8.32 %). Organoleptic analysis revealed that T_3 had the highest score of 7.50 in overall acceptability.

Soil samples were collected from the experimental site before planting of the crop and it recorded a pH of 4.50. After the final harvest, T_4 recorded the highest pH of 4.43 which was followed by T_1 (4.34), T_3 (4.30), T_5 (4.28) and T_2 (4.24). Before planting, the EC recorded was 0.04 dSm^{-1} and after the final harvest highest EC was noted for T_4 (0.13 dSm^{-1}) which was followed by T_3 (0.12 dSm^{-1}), T_2 (0.08 dSm^{-1}), T_1 (0.05 dSm^{-1}) and T_5 (0.04 dSm^{-1}).

Before planting, the organic carbon content of the soil was 1.07 %. After the final harvest, the highest organic carbon content was recorded in T_2 (1.26 %), which was followed by T_4 (1.20 %), T_1 (1.15 %), T_3 (1.09 %) and T_5 (1.06 %). Before the experiment, the nitrogen content was 300.34 kg ha^{-1}. After the final harvest, the highest N content was observed in T_2 (337.30 kg ha^{-1}), followed by T_4 (325.64 kg ha^{-1}), T_1 (315.90 kg ha^{-1}), T_3 (304.22 kg ha^{-1}) and T_5 (298.39 kg ha^{-1}).

Before planting, the available phosphorous content of the soil was 26.04 kg ha^{-1}. After the final harvest, the highest available P content was in T_4 (29.16 kg ha^{-1}), which was followed by T_3 (27.76 kg ha^{-1}), T_2 (23.75 kg ha^{-1}), T_1 (22.47 kg ha^{-1}) and T_5 (19.11 kg ha^{-1}). An available potassium content of 170.54 kg ha^{-1} was recorded in soil before planting. After the final harvest, the highest available K content was recorded in T_4 (242.87 kg ha^{-1}) followed by T_3 (231.24 kg ha^{-1}), T_2 (223.33 kg ha^{-1}), T_1 (222.34 kg ha^{-1}) and T_5 (139.95 kg ha^{-1}).

Available calcium before the experiment was 129.05 mg/kg. After the final harvest, available Ca was highest in T_4 (148.75 mg kg^{-1}), followed by T_2 (145.63 mg kg^{-1}), T3 (140.00 mg kg^{-1}), T_1 (136.33 mg kg^{-1}) and T_5 (124.95 mg kg^{-1}). Available magnesium content before planting was 92.83 mg kg^{-1}. After the final harvest available Mg was highest in T_4 (86.25 mg kg^{-1}), followed by T_1 (84.38 mg kg^{-1}), T_2 (74.24 mg kg^{-1}), T_3 (72.48 mg kg^{-1}) and T_5 (70.50 mg kg^{-1}).

Among the different plant nutrients analyzed, only plant K content varied significantly by the application of different levels of NPK T_4 (2.72 %) recorded the highest plant K content, which was on par with T_2 (2.49 %).

In the experiment carried out for the standardization of propagation technique, different noded cuttings were found to have significant effect on number of days for sprouting, survival percentage, number of leaves, shoot length, total leaf area and root length. Survival per cent (70.60 %), total leaf area (166.15 cm^2) and shoot length (28.75 cm) were highest in four noded cuttings which was superior to all other treatments. Number of leaves (7.70) and root length (14.25 cm) were also highest in the four noded cuttings, which was on par with three noded cuttings (number of leaves 6.70 and root length 13.55 cm). The least number of days for sprouting (17.70 days) was recorded in three noded cuttings, which was on par with four noded cuttings (17.80 days) and two noded cuttings (18.00 days).

Different concentrations of NAA had significant effect on success rate of cuttings. The minimum days to sprout (17.38 days) was observed with 800 ppm NAA, which was on par with NAA 600 ppm (17.88 days), NAA 200 ppm (18.00 days) and 400 ppm NAA (18.13 days). Maximum number of leaves (7.00) was observed in the treatment NAA 800 ppm, which was on par with treatments with NAA 400ppm and 600 ppm. The highest shoot length (27.94 cm) was observed in NAA 800 ppm which was on par with NAA 600 ppm.

The interaction effect of NAA and number of nodes was significant with respect to the success rate of passion fruit cuttings. The least number days to sprout (15 days) was observed in T_{15} (three noded cutting + 800 ppm NAA), which was on par with T_{10} (two noded cutting with 800 ppm NAA) and T_{19} (four noded cutting along with 600 ppm NAA), each with 16.00 days to sprout, T_{12} and T_{18} (16.50 days), T_7, T_8 and T_{13} (17.50 days) and T_{17} (18.00 days). The maximum survival of 81 per cent was recorded in T_{20} (four noded cutting + 800 ppm NAA), which was on par with T_{19} (four noded cutting + 600 ppm NAA). T_{20} (four noded cutting + 800 ppm NAA) with 8.50 leaves was on par with T_9, T_{10}, T_{11}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}, T_{18} and T_{19}. Leaf area, which is major contributing factor towards photosynthesis, was highest in Treatment 15 (three noded cutting + 800 ppm NAA), with leaf area of 237.50 cm^2, which was superior to all other treatments. The highest shoot length was observed in T_{20} (34.50 cm), which was on par with T_{19} (four noded + 600 ppm NAA), with a shoot length of 32.00 cm. Root length was highest in treatments 15 and 20 (16.75 cm each) which were on par with T_{19} (16.00 cm), T_{18} (15.00 cm), T_{13} (13.75 cm) and T_{17} (13.50 cm).

Combined effect of number of nodes and NAA concentration has shown that T_{15} (three noded + 800 ppm NAA) was superior in terms of total leaf area, root length, days to sprout and number of leaves. Based on survival per cent and shoot length T_{20} (four noded + 800 ppm NAA) and T_{19} (four noded + 600 ppm NAA) were superior and on par.

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PRODUCTION TECHNOLOGY AND CROP IMPROVEMENT OF PASSION FRUIT (*Passiflora edulis* Sims.)

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Passion fruit (*Passiflora edulis* Sims.) belonging to the family *Passifloraceae* is most accepted for fresh consumption and for various processed products. Passion fruit cultivation is gaining popularity among farmers due to its adaptability under humid tropical conditions and presence of nutritional and therapeutic components. The present study was undertaken in passion fruit with the objectives to evaluate performance of different genotypes, hybridization for development of superior types, standardize the nutrient requirement and propagation method through stem cuttings.

Eight passion fruit accessions collected from different locations of Kerala were evaluated for vegetative, flower, yield and fruit characters. Flower characters did not show significant variation, while, the yield and fruit characters exhibited variations among the eight accessions evaluated. Pollen storage studies conducted revealed that passion fruit pollen can be stored over calcium chloride in a desiccator under refrigerated condition for 72 hours with 50.88 per cent pollen viability. Accessions 7 and 5, which were early to flower (157.33 days and 160.33 days), early to fruit (159.67 days and 163.33 days) and early to harvest (63 days and 67 days) were identified as early bearing types. The number of fruits per vine per year recorded was maximum in Accession 4 (155.33), which was on par with Accession 2 (149.33) and Accession 6 (146.67). Peak fruiting was observed from the month of June to September. Accession 3 (yellow) and Accession 4 (purple) were found to be superior in fruit characters. Accessions 2, 4, 5 and 8 with high juice content and thin rind can be utilized for processing and value addition. Accession 5 with improved quality parameters like high non-reducing sugar (5.92 %), sugar acid ratio (4.97), TSS (17.33 °Brix), total sugars (13.55 %) and lower acidity (2.73 %) was identified as a superior selection based on quality parameters. Correlation studies showed that yield/vine had significant and positive correlation with fruit diameter, fruit girth, fruit weight, pulp weight and juice weight. Rind thickness was found to have significant positive correlation with shelf life. The study revealed that considerable variability existed among the different accessions of passion fruit. The accessions which recorded high yield *viz*., Accession 2, 4 and 6 can be used for further crop improvement programmes to develop superior passion fruit varieties.

Hybridization work was carried out using six selected superior accessions maintained at Malanadu passion fruit plantation, Idukki, which resulted in the development of one selfed progeny and 8 hybrids. The hybrids and selfed progeny were evaluated for three months at nursery stage and in the field in the college orchard, COH, Vellanikkara for one year. Peak flowering and fruiting periods were observed during March - May. Maximum number of fruits were recorded in hybrids *viz.*, H_3 (P_4 x P_6), H_4 (P_5 x P_4), H_5 (P_6 x P_1) and H_8 (P_6 x P_5). With regard to fruit characters, hybrid H_6 (P_6 x P_2), was observed to be the best, with highest fruit weight, fruit girth, fruit diameter and pulp weight, which also had maximum overall acceptability in sensory evaluation.

Fertilizer trial was conducted at four different levels of NPK in the variety 134P. Among the phenological characters, duration of flowering to harvest varied significantly. Higher number of fruits per vine (165.50) was recorded with application of 50 N: 20 P_2O_5: 50 K_2O g $vine^{-1}$ (T_4), which was on par with the treatments applied with 37.5 N: 15 P_2O_5: 37.5 K_2O g $vine^{-1}$ (T_3) and 25 N: 10 P_2O_5: 25 K_2O g $vine^{-1}$ (T_2). The treatment which received 50 N: 20 P_2O_5: 50 K_2O g $vine^{-1}$ was found to be significantly superior with respect to fruit diameter, fruit girth and rind weight. Application of 50 N: 20 P_2O_5: 50 K_2O g $vine^{-1}$ resulted in high TSS (19.15 °Brix), total sugars (13.38 %) and reducing sugars (8.76 %). In the organoleptic evaluation, maximum score was observed for the fruits from the plots which received fertilizers of 37.5 N:15 P_2O_5: 37.5 K_2O g $vine^{-1}$.

The presence of number of nodes in the stem cuttings, different concentrations of NAA and their interaction were found to have significant effect on the survival percentage and shoot and root parameters of the rooted cuttings. Four noded cutting recorded maximum survival per cent (70.60 %), total leaf area (166.15 cm^2) and shoot length (28.75 cm). Among the different concentrations of NAA, survival percentage, root length and total leaf area, NAA 800 ppm was found significantly superior. The study revealed that four noded cuttings dipped (quick dip method) in 600 ppm NAA could be used for the large scale multiplication of passion fruit plants for commercial cultivation.

Appendices

APPENDIX – I

Meteorological data-September 2018 to May 2020

	Temperature		RH (%)			Rainfall
Month	Max (°c)	Min (°c)	I	II	Mean	(mm)
Sep	32.2	22.5	91	60	75	29.0
Oct	32.8	22.9	90	62	76	393.0
Nov	32.7	23.3	82	54	68	66.6
Dec	33.0	22.5	78	47	63	0.0
2019						
Jan	32.9	20.4	71	38	55	0.0
Feb	35.3	23.4	77	41	59	0.0
Mar	36.8	24.8	85	45	65	0.0
Apr	36.1	25.5	86	54	70	76.4
May	34.6	24.9	89	59	74	48.8
Jun	32.2	23.5	93	73	83	324.4
Jul	30.4	22.8	95	76	85	654.4
Aug	29.5	21.9	96	82	89	977.5
Sep	31.2	22.0	95	75	85	419.0
Oct	32.4	21.4	91	68	79	418.4
Nov	32.9	21.7	83	60	71	205.0
Dec	32.3	22.1	73	52	63	4.4
2020						
Jan	34.1	22.4	78	43	60	0.0
Feb	35.5	23.2	71	37	54	0.0
Mar	36.4	24.4	85	46	65	33.4
Apr	36.4	24.7	86	55	71	44.7
May	35.0	25.2	90	63	77	59.6

APPENDIX - II

Score card for sensory evaluation of passion fruit pulp

9 Point hedonic scale

Treatments	Appearance	Colour	Texture	Flavour	Taste	After Taste	Odour	Overall acceptability

Note: you are provided with the samples of passion fruit pulp and are requested to rank them according to the scale given below as per your liking

Scale:

9 Like Extremely
8 Like Very Much
7 Like Moderately
6 Like Slightly
5 Neither like nor Dislike

4 Dislike Slightly
3 Dislike Moderately
2 Dislike Very Much
1 Dislike Extremely

Date:

Name:

Signature: