EFFECT OF GROWING ENVIRONMENT AND CLIMATE CHANGE ON PHYSIYOLOGY OF TOMATO (*Lycopersicon esculentum* Mill.)

By

RAJALAKSHMI RADHAKRISHNAN

(2010-20-101)

ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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THESIS

Submitted in partial fulfillment of the requirement

for the degree of

BSc-MSc Integrated Climate Change Adaptation

Faculty of Agriculture

Kerala Agricultural University, Thrissur

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DECLARATION

I hereby declare that the thesis entitled **"Effect of growing environment and climate change on physiology of tomato (*Lycopersicon esculentum*. Mill)"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **'Effect of Growing Environment and Climate Change on the Physiology of Tomato, *Lycopersicon Esculentum* Mill.'** is a record of research work done independently by Ms. Rajalakshmi Radhakrishnan. (2010-20-101) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

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We, the undersigned members of the advisory committee of **Ms. Rajalakshmi Radhakrishnan., (2010-20-101)** a candidate for the degree of **BSc-MSc (Integrated) Climate Change Adaptation**, agree that the thesis entitled **"Effect of Growing Environment and Climate Change on the Physiology of Tomato, *Lycopersicon Esculentum* Mill."** may be submitted by **Ms. Rajalakshmi Radhakrishnan.,** in partial fulfilment of the requirement for the degree.

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Introduction

1. INTRODUCTION

Lycopersicon esculentum Mill., commonly known as tomato belongs to the nightshade family, *Solanaceae*. The species originated in the South American Andes and its use as a food originated in Mexico. Tomato finds an important place as one of the three most important horticultural crops. In term of human health, tomato is a major component of daily meals in many countries and constitutes an important source of minerals, vitamins and antioxidant compound.

Global climate change is any significant long term change in expected patterns of weather over a region which may be naturally induced or anthropogenic, the major causes of which being increased industrialization, urbanization, deforestation, agriculture, change in land use patterns etc.

The effect of climate change on crop and terrestrial food production are evident in several regions of the world. Negative impacts of climate trends have been more common than positive ones. For the major crops (wheat, rice and maize) in tropical and temperate regions, climate change without adaptation will negatively impact production for local temperature increase of 2˚C or more above late 20th century level. Projected impacts vary across crops, regions and adaptation scenarios, with about 10 per cent and about 10 per cent of projection for the period 2030-2049 showing gains of more than 10 per cent and about 10 per cent of projections showing yield loss of more than 25 per cent compared to late 20th century (IPCC AR5, 2014). The impacts of climate change on agriculture are global concerns and for that matter India, where agriculture sector alone represents 17 per cent of India's Gross National Product (GNP) and the livelihood of nearly 70 per cent of the population is exposed to a great danger, as the country is one of the most vulnerable countries due to climate change. One of the most remarkable characteristics of climate change is the increase in temperature, so it has been mainly recognized as 'global warming'. This warming has been attributed to the enhanced greenhouse effect produced, among others, by the increased amounts of carbon dioxide from the burning of fossil fuel since the Industrial Revolution (Houghton, 2004).

Climate models predict that warmer temperatures and increase in the frequency of the drought during the 21st century will have net negative effects on agricultural productivity (Samuel *et al.*, 2010). Increase in the mean seasonal temperature can reduce final yield. Although tomato can grow under a wide range of temperatures, the fruit set occurs in narrow temperature range. Under the two projected climate scenarios namely, Canadian and Hadley scenario, reduction in tomato yield were in the range of 10-15 per cent in the former and 5 per cent range in the latter (Reilly *et al.*, 2001). Not only the yield and total productivity will be affected but also the qualitative or rather the nutrient aspect is also at threat. A considerable change in the climate will definitely bring about changes in the net photosynthetic rates, photosynthate assimilation and utilization, the stress proteins production, the pigments and carotenoid content, the vitamin C content etc. With such vagaries expected in the future climate, its daunting to simply rely on the present cultivation practices. New aspects of protected cultivation should come handy at this juncture.

Environmental stress is the primary cause of crop losses worldwide, reducing average yields for most major crops by more than 50 per cent (Boyer, 1982). Climatic changes will influence the severity of environmental stress imposed on vegetable crops. Moreover, increasing temperature, reduced rainfall and water availability, flooding and salinity associated with global climate change will be the major limiting factors in sustaining and increasing the vegetable productivity.

Growing the crops under a protected covering like greenhouses and rain shelter help reduce evapotranspiration, moderate soil temperatures, reduce soil runoff and erosion, protect fruits from direct contact with soil and minimize weed growth.

Greenhouse cultivation of vegetables offers distinct advantages of quality, productivity and favourable market price to the growers. Vegetable growers can substantially increase their income by greenhouse cultivation of vegetables in off season as the vegetable produced in normal season do not fetch good returns due to large availability of these vegetables in the market. Similarly, during the hot rainy season, vegetables such as tomato suffer from yield losses due to heavy rains. Simple, clear plastic rain shelters prevent water logging and rain impact damage on developing fruits with consequent increase in yields.

With a view to study the weather influence on tomato and to study the climate change impact, we have taken following objectives:

1. Study the effect of different growing environments and physiological traits of tomato.

2. Impact of projected climate change on the physiology of tomato.

Review of literature

2.1 PHENOLOGICAL CHARACTERS

2.1.2 Days to flower

Grimstad (1995) indicated that low temperature delayed flowering. Ho (1996) observed that under low light conditions, initiation of first inflorescence is delayed in tomato, as more leaves are initiated prior to the inflorescence. In an indeterminate plant, temperature affects floral initiation, floral development, fruit set and fruit growth simultaneously.

Ajithkumar (1999) found that morning and afternoon relative humidity during the first and second weeks after planting had positive effects on the days to flower. He also reported that it has a negative correlation with bright sunshine hours during first to second week after planting.

Anbarasan (2002) reported that *kharif* tomato took 60.71 days and summer tomato took 55.09 days for fifty per cent flowering in open field whereas it was 58.65 days and 59.40 days respectively for polyhouse crop. Vezhavendan (2003) observed earliest flowering of capsicum in rain shelter compared to open field condition.

ICAR (2004) observed significant difference with regard to earliness of tomato variety Anagha under rain shelter and open field during summer. But during rainy season, there was a significant difference. Open field crop flowered at 62.17 days after planting whereas under rain shelter with roof ventilation, it was 65.7 days.

2.1.3 Days to harvest

Slack and Calvert (1978) found a positive correlation in tomato between increasing night temperature and early fruit yield, but final; yield was negatively correlated to temperature. Gent (1988) found that under a day night temperature difference of 9°C, greenhouse tomato fruits grew and ripened quickly, resulting in greater yield.

Grimstad and Frimanslund (1993) reported that an average daily temperature of 15 to 25°C reduced the time to first cucumber harvest in greenhouse by 1.6d°C^{-1} (days per degree centigrade). Grimstad (1993) observed that low temperature resulted in a delayed harvesting of tomato in greenhouse.

Moccia *et al.* (1999) noted that determinate variety Lilliput of tomato exhibited early yield. Open crop of tomato took less number of days to maturity compared to crop under rainshelter (AVRDC, 2000). Study conducted by Arin and Ankara (2001) indicated that low tunnels are useful for promoting early harvesting and high total yield when compared with uncovered crop.

Vezhavendan (2003) noted that capsicum under rainshelter took less number of days to harvest than open crop in both *Rabi* and *Kharif* season in Kerala. Early flowering and fruiting were noticed in open field when compared to shade for different genotypes of tomato tried (Thangam *et al.* 2002). ICAR (2004) noted that tomato under rainshelter harvested earlier than open crop during *Rabi* but during rainy season, open field crop was harvested earlier than covered crop.

2.2 YIELD AND YIELD ATTRIBUTES

2.2.1 Fruit setting per centage

Ruchid *et al.* (1977) stated that even without pollination and fertilization, fruit set was noticed in tomato at higher temperature, which may be due to parthenocarpic nature. Shelby *et al.* (1973) reported that the fruit set could be governed by dominant genes with moderate heritability (broad sense) of 54 per cent. Picken (1984) reported that warm day and cool night temperature extremes in high tunnel could however interfere with flower development and fruit set.

Similar results were reported by Rao and Sreevijayapadma (1991). Under greenhouse in winter season, the number of fruit set decreased rapidly from the fifth cluster (Bertin and Gary, 1992). Gent (1992) reported that tomato plants set fruits during April and May, when air temperature varied from minimum near freezing to a maximum of 35-45°C.

Ercan and Vural (1994) reported that fruit setting ratio were relatively higher with 97.86 per cent in Cairo F1 and 98.08 under greenhouse condition. Temperature below 10°C or above 30°C (the exact value depending on the cv.) is detrimental to one or more of the processes leading to fruit set. Peet *et al.* (1996) reported that tomato fruit set and fruit weight per plant decreased as mean daily temperature increased from 25-29°C.

Empty flowers and persistent flowers without fruit set in the 35/20°C regime in tomato as observed by Lohar and Peet (1998). The effect of chronic, mild heat stress on fruit set release of pollen grains, photosynthesis, night respiration were examined under different temperature regimes, 28/22°C or 26/22°C (optimal temperature), 32/26°C using five cultivars. From this study Sato *et al.* (2000) suggested that number of pollen grains produced during photosynthesis and night respiration did not limit fruit set under chronic and mild heat stress.

2.2.2 Fruit weight

Lower sink activity of sweet pepper fruits at low temperature reduces the mean fruit weight (Bakker and Van Uffelen, 1988). Naniwal *et al.* (1992) observed a range of 44.4g in Pusa Ruby to 81.89g in MDT 21 for this trait. A range of 29.86 to 56.6g of fruit weight was observed in a study conducted by Bhardwaj and Thakur (1994) with 26 genotypes of tomato during summer season.

At higher temperature an almost similar amount of assimilates has to be distributed over a large number of fruits resulting in a lower average fruit weight. Thus the potential fruit weight at 23°C is about 40 per cent lower than at 17°C (De Konning, 1994).

Fruit weight of tomato was 38.3g under plastic shelter whereas it was 33.7g in open condition (AVRDC, 2000).

Cucumber under polyhouse gave 239g and all the plants in open field gave poor yield or got killed (Kanthaswamy *et al.* 2000). Fruits obtained from polyhouse crops gave higher mean of 26.56g as compred to 25.10g in open field during summer. During *Kharif* season, it was 27.74g and 22.19g respectively (Anbarasan, 2002).

ICAR (2004) recorded average fruit weight of 23.0g during *Rabi* and 39.1g during *Kharif* inside rainshelter in tomato whereas it was 17.5g and 43.1g respectively in open field. Hazarika and Phookan (2005) found that among different genotypes of tomato tried, cv. Yash recorded significantly higher individual fruit weight of 86.03g over most of the cultivars in polyhouse.

2.2.3 Yield per plant

Shelby *et al.* (1978) reported a slight but significant decline in pollen viability from plants subjected to high temperature. During winter in midhills of Uttar Pradesh, Bhatnagar *et al.* (1990) found that in the open field tomato plants were killed by frost. In greenhouse, a yield of 360 to 507 quintal per ha was obtained.

Dane *et al.* (1991) observed reduced pollen viability after prolonged period of higher temperatures in the field, which resulted I poor fruit yield. Stress during fruiting stage reduces productivity in tomato (Rao and Sreevijayapadma, 1991).

Isshiki (1994) observed a double yield of tomato in rain shelter than open field. Fonts *et al.* (1997) recorded average marketable fruit yield of 3.15 kg per plant in plastic tunnel, which was 141 per cent higher than in field grown plants with marketable fruits representing 94 and 71 per cent of total yield. He also noted that the average yield of marketable fruits of two tomato cv., Sunny and EF-50 in plastic tunnel was 51 per cent higher than that of field grown plants.

In an experiment with long life type salad tomato cultivars, Gualberto *et al.* (1998) reported that marketable fruit yield was 40 to 45 per cent higher in greenhouse than open field. Rain shelter cultivation of tomato at plastic culture development centre, Thavanur recorded a yield of 5 kg per m2 in open condition (KAU, 1999).

Arya *et al.* (2000) reported that plastic shelter increased tomato and capsicum production by 169 and 956 per cent without any us of pesticides. Chandra *et al.* (2000) recorded a higher yield of 110.51 t per ha with Pusa Hybrid 2 varieties of tomato inside polyhouse.

A study conducted in TNAU in naturally ventilated polyhouse with insect proof net and open field by Nagalakshmi *et al.* (2000) showed that S-41 under polyhouse was early in flowering and fruit set than open field and yield was double compared to open field. Srivastava (2000) obtained 60 to 70 per cent higher tomato yield under polyhouse in high rainfall areas of Jorhat, Assam. Dixit *et al.* (2002) found green leafy vegetables under greenhouse structure showed superior yield and yield attributing characters as compared to open field condition.

2.3 EFFECT OF WEATHER PARAMETERS

2.3.1 Air temperature

In Canada, Charles and Harris (1972) found low fruit set in tomato at 10°C and 12.8°C, which was primarily due to poor pollen viability and germination and to a lesser extent to a high stigma position in the antheridial cone. At 26.7°C, stigma height was the main factor reducing fruit set but low stigma receptivity was an important factor in some selections. Shvebs and Grudev (1972) revealed that during fruit formation the optimum day and night temperatures were above 16°C and l3°C respectively. In their study at Russia, a relationship between the sum of mean daily temperature and the duration of flowering was observed.

Friend and Helson (1976) suggested that high growth rate obtained under a high day temperature was the result of a high rate of net photosynthesis. Nilwik (1981) observed changes in RGR during seedling stage in response to temperature.

Rudich *et al.* (1977) observed that the higher temperature condition (39°C ± 2°C day and 22°C ± 2°C night) at Israel caused deficient fruit set in tomatoes. The impaired fruit set of Roma VF was found to be associated with pollen viability, style elongation, and lack of formation of the endothecium, which is essential to stamen and pollen thecae opening. Takahashi *et al, (*1977) in a study with the tomato cv. Fukuju-No.2, the highest number of flower buds/plant was obtained from plants receiving high NPK and grown at day/night temperature of 22/12°C.

Longuenesse (1978) grew tomato cv. Montfavet 63.5 in a glass house with a day temperature of 20°C and night temperature of 15°C or 11°C and he reported that, with the lower night temperature, flowering, fruit development and maturity were delayed, but without affecting the number of flowers and fruits resulting in higher fruit yield.

A high positive correlation (r =0.9) between the number of seeds/fruit and fruit size at a day temperature of 27°C was reported by Rylski (1979).

Papadopoulos and Tiessen (1981) reported that a low greenhouse air temperature of 19°C (day)/14°C (night) during the autumn, caused no reduction in yield when compared with the standard 22°C/17°C. An air temperature of 13°C/08°C during the spring markedly reduced yield compared with 19°C/14°C. Flowering of Ohio MR-13 in growth chambers was delayed significantly at 24 °C/08°C compared with 24°C/17°C but the flowering of Vendor was unaffected. Marketable yield of Vendor was significantly higher at 24°C/08°C than at 24°C/17°C while that of Ohio MR-13 was unaffected. At a constant day air temperature of 24°C, the amount of small fruits decreased as night air temperature was lowered from 14°C to 08°C.

Kleinnendorst and Veen (1983) noted a decline in NAR below a day temperature of 18°C in cucumber.

Khayat *et al.* (1985) opined that the fruit production in the cv., Moneymaker was not reduced by interruption of the optimum night temperature regime (18°C) by short intervals (2 hours) of lower temperature. The same treatment increased the yield on the cv. Cherry by 82 per cent compared with a constant night temperature of 18°c. The yield increase in this cv. was due to a larger number of fruits per plant.

Alberton and Rudich (1986) reported that the development of the root system differ among tomato cv. and the day temperature of 26.5°C and night temperature 16-22°C resulted in the heavier root system.

In an experiment with four cultivars viz. Precodor, Vemone, Marmande and Raf, Noto and Malfa (1986) observed that the shortest number of days from sowing to flowering was noted in plants treated with the lowest temperature and exposed to it for the longest time.

Smeets and Garretsen (1986) and Heuvelink (1989) demonstrated that there are changes in RGR during seedling stage in response to temperature.

De Koning (1988) reported a positive effect of increasing night temperature on final fruit yield and fruit size.

In another experiment by Cholette and Lord (1989) the seeds of the cv. Carmello was sown on 16 January and the plants were grown under night temperatures of 17°C, 12°C or 7°C for 2 months after the 6th leaf had expanded and the first cluster was visible (e.g. 24 February to 15 April). Total and marketable yields were significantly higher on Nutrient Film Technique (NFT) than in soils, but there was no advantage for the early yield. The date on which half of the flowers of the first cluster opened was 2 weeks earlier for the 17°C treatment there for the 7°C treatment indicating that low night temperature reduced the rate of development.

Heuvelink (1989) reported that day temperature was more important than night temperatures in determining the fresh and dry weight, plant length, leaf area and RGR of young tomato plants.

Heuvelink (1989) found that an increased temperature regime reduced plant growth and development, number of leaves and number of trusses. Growth reduction was caused by a lowered leaf area ratio (LAR). The decrease in LAR at an inversed temperature regime was caused mainly by a decrease in specific leaf area (SLA).

Leaf number, the main component of total leaf area is a function of leaf appearance rate. Temperature is a major limitation to leaf appearance rate in crops (Kiniry *et al.* 1991).

Young tomato plants were more affected by low temperature than older plants showing reduced net assimilation rates and reduced leaf growth (Voican and Leibig, 1991). Higher temperature in the early stages of growth of tomato promoted leaf expansion (Cockshull, 1992).

Increase in fruit temperature resulted in immediate cracking in ripe fruits or delayed cracking in green fruits (Peet, 1992). Growth of vegetative organs on aubergines and tomato in greenhouse was negatively influenced by highest temperature among 30.3, 32.1 and 34.0°C. Treatment of higher temperature than day temperature reduced plant height in tomato and cucumber at 21 and 61 days after sowing mainly due to a decrease in internodal length (Abou Habid *et al.* 1992).

Rao *et al.* (1992) studied the rate of net photosynthesis, growth and dry matter (DM) production in tomato cultivars IIHR 224 and Arka Saurabh that had been grown in the chambers at day/night temperatures of 35°C/20°C and 35°C/27°C. Significant cv. differences were observed at both temperatures. Photosynthesis was lower in both cultivars at a night temperature of 27°C. Leaf area and total DM for IIHR 1224 were lower with a night temperature of 27°C. When plants were pre-hardened by exposure to 40°C for 2 hours during the night period at the 3-leaf stage, plants of IIHR 1224 receiving 35°C/27°C treatment had a higher relative growth rate and net assimilation rate than those receiving 35°C/20°C.

Pearce *et al.* (1993) found that average fruit size decreased with temperature, being a consequence of increased truss appearance rate and accelerated fruit development.

Fruit weight in capsicum reduced with temperature whereas it increased in aubergines (La-malfa, 1993). Ercan *et al. (*1994) studied the effect of low temperature on fruit set and yield of the tomato cultivars Dario F_1 and Amfora F_1 and established that low temperatures reduced the pollen count and thus reduced fruit set and yield.

The minimum temperature below which pollen degeneration in the flower began was 5°C for Amphura and 10°C for Dario.

Romano *et al.* (1994) found that vegetative growth of plants was ot affected by low temperature but yield was reduced. Studies conducted by Grimstad (1995) showed that at low temperature pulse at the beginning of the daily light period was most effective for tomato giving higher plant height. Low temperature reduced leaf number and shoot dry weight. Flowering was delayed resulting in a delayed harvest. Tomato fruit set and fruit weight per plant decreased as mean daily temperatures increased from 25 to 29°C (Peet *et al.* 1996).

Rylski and Aloni (1994) reported that the temperature and irradiation condition at early stages of flower development are important factors that determine fruit yield and quality. A low night temperature can induce the tomato seedling to produce a higher flower number (Ho., 1996).

Wang-XiaoXuan (1996) conducted an experiment on 6 tomato cultivars at China and found that germination of seeds and pollen, pollen tube growth, growth of the hypocotyledonary axis and fruit set decreased with decreasing temperatures. Under temperatures of 8°C and12°C, all the above parameters showed a positive correlation with the cold tolerance of the cultivars. Under low temperature in the field, plant growth, flowering, fruiting, pollination and fertilization were inhibited to different degrees and cold tolerant cultivars performing better than cold sensitive ones.

Langton and Cockshull (1997) reported that extension growth in tomato responded to the absolute day and night temperature rather than to difference between day and night temperatures. The optimum temperature for extension growth was rather higher for day temperature than night temperature. At higher air temperature, fruits matured before sufficient growth had occurred (Wada *et al.* 1998)

A study conducted at Vellanikkara condition (Ajithkumar, 1999) showed that the maximum temperature range of 30.6-33.7°C and a minimum temperature range of 22.1-24.3°C was found to be optimum for crop growth of tomato. He also reported that the maximum temperature range of 31.6-32.1°C and minimum temperature range of 24.1-24.3°C were optimum for early flowering whereas minimum temperature range of 22.1-23.3°C during sixth and eighth week after planting are optimum for increased yield.

Mean yield per plant in all the genotypes of tomato tried was more reduced under high temperature in the field and glasshouse condition during summer than during kharif (Muthuvel *et al.* 1999). During summer under polyhouse, number of branches and leaf area index were positively correlated with maximum temperature while RGR was not affected.

Muthuvel *et al.* (1999) observed smaller fruits in tomato plants grown under glasshouse which may be due to competition among the fruits for assimilates. Anbarasan (2002) observed larger fruits in tomato under polyhouse during both summer and kharif than crop in the open field.

High temperature may reduce pollen quality, increase floral anomaly and consequently reduced fruit number (Dorais *et al.* 2001).

2.3.2 Soil temperature

Abdelhafeez (1971) reported that growth of tomato plants in soil temperature below 20°C and air temperature of 17°C.

Saito and Ho (1971) found that exposure of the plants at 9°C for produced fascinated flowers which might be due to the surplus nutrient availability to the young flower buds just on pre or post differential stage. They remarked that at low temperature vegetative growth is restricted which is due to the supply of more nutrients for flower development.

Hisatomi (1972) found that an increase in leaf area and stem thickness was markedly enhanced by the higher soil temperature. Fruit number per unit area and total yield, however, were greater at lower soil temperatures. The adverse of high temperature on the yield of winter crop flowering during February was due to excessive vegetative growth produced.

In a study on tomato cv. Extase grown in containers and soil kept at constant temperatures of 15°C, 20°C, 25°C, 30°C and 35°C, Stanev and Angdb (1978) reported that a reduction of soil temperature from 30°C to 15°C decreased the leaf area by 50 to 70 per cent and an increase in soil temperature to 35°C decreased it by 20 to 40 per cent. Net photosynthetic productivity was the highest at 15°C, the peak at

25-30°C and decreased by 60-70 per cent at 50°C and by 22 to 38 per cent at 35°C.

2.3.3 Relative humidity

Bakker (1988) reported that final yield of tomato was reduced by high humidity at night and had no significant effect by day time humidity. Bakker (1990) observed the effect of humidity on growth and propagation of glasshouse tomatoes, cucumber and sweet pepper. Humidity levels were observed to be 20 to 25 per cent higher as compared to outside conditions. Inside the glass house condition, growth of plants was increased by 30 per cent and it took about 30 days and it took about 30 days lesser for the fruits to mature.

Major long term effect of humidity on greenhouse crops is through its effect on leaf area. Leaf expansion is favored by high humidity. There was a small but significant increase in RGR in response to an increase in daytime humidity in tomato seedling. The effect of humidity on RGR was attributed to the small increase in NAR (Bakker, 1991).

Shoot length and leaf area increased with increase in RH. Higher RH increased the number of flowers produced and reduced the time for flowering (Gislerod and Mortenson, 1991). Percentage of cracked fruits and crack length were decreased by low humidity and increased with high humidity (Ohta *et al.* 1991). High humidity inside greenhouse reduced leaf dry weight (Adams and Holder, 1992).

In greenhouse, high humidity is a major concern in connection with fungal and bacterial (Bailey, 1995). Maroto *et al.* (1995) observed that fruits from plants grown in high humidity had a higher incidence of cracking. High day and night humidity increased blossom end rot from the end of August (Pivot *et al.* 1998).

Ajithkumar (1999) reported that at Vellanikkara condition, relative humidity of 70 to 86 per cent and afternoon relative humidity was negatively correlated with yield.

Significant positive correlations were obtained between morning relative humidity, plant height and LAI. Evening relative humidity also had a significant positive correlation with above characters (Anbarasan, 2002). Improved vegetative growth under low plastic tunnels may largely be attributed to increased air temperature and relative humidity (Kumar and Srivastava, 2002).

Peet *et al.* (2002) reported that fruit weight was most sensitive to high humidity at high temperatures.

2.3.4 Light intensity

Bruggink (1987) stated that, in tomato, cucumber, and sweet pepper seedlings, relative growth rate is not proportional to variation in light integrals. Bruggink and Heuvelink (1987) found that leaf area ratio and total biomass increased with declining light intensity, thus partly compensating for the net assimilating rate.

High light intensity may have a role in increasing cracking. Under high light conditions, fruit soluble solids and fruit growth rates are higher and are sometime associated with increased cracking (Peet, 1992). The area and dry weight of leaves and dry weight of roots and stems were with an irradiance of 14.7 or 8.5 MJm-2day than with lower irradiances. Fruit yield was highest in plants receiving full sun and plants failed to fruit at an irradiance of -3.3MJm^{-1} day^{-1} in greenhouse (Mohd Razi, 1994).

When tomato is grown in glasshouse, the single fruit size and fruit number can be affected by season largely through direct effect of solar radiation on crop photosynthesis and glasshouse air temperature (Cockshull and Ho, 1995).

Shaheen *et al.* (1995) studied different light intensities under polyhouse conditions on tomato. They found that increasing shade level reduced seedling fresh weight and dry weight in both winter and autumn. Highest NAR values were obtained in control treatment. Decreasing the light intensities reduced the values of NAR. A solar radiation flux density of 200 Cal cm^{-1}day^{-1} was considered to be the lowest value for tomato growth (Estefanel *et al.* 1998).

Ajithkumar (1999) reported that bright sunshine of 5.2-10.0 hours required for optimum growth of tomato under Vellanikkara condition. He also found that days to first flowering showed a negative correlation with bright sunshine. The accumulated photosynthetically active radiation and temperature were significantly correlated with flowering and fruit set (Pek and Helyes, 2003).

2.3.5 Ultraviolet radiation

Battaglia and Brenan (2000) studied the effects of relatively short term high intensity exposure to UV-B upon photosynthetic carbon di oxide fixation in cotyledons of cucumber (*Cucumis sativus*) and sunflower (*Helianthus anus*). Treatment with 194 K m^{-2} of UV-B radiation delivered over 16h lead to significantly reduced carbon di oxide fixation rates in cucumber, while sunflower showed no inhibition or slight increase. The concentration of chlorophyll *a* and chlorophyll *b* were unchanged in response to UV-B treatment in cucumber showed statistically significant increase in sunflower. Flavonoids (i.e. methanol extractable UV absorbing compounds) decreased in cucumber and were unchanged in sunflower.

Hao *et al.* (2000) reported that exposure to enhanced UV-B increased leaf chlorophyll and UV-absorbing compounds but decreased leaf area and root/shoot ratio. Also pre-exposure to enhance UV-B mitigated O_3 damage to leaf photosynthesis at elevated CO_2.

Hui *et al.* 2004 studied the effects of enhanced UV-B radiation on hormone changes in vegetative and reproductive tissues of tomato (*Lycopersicon esculentum* Mill.) and their relationships with reproductive characteristics. Two cv., TongHui (TH) and XiaGuang (XG), were grown in the field for one growing season under ambient (Control), ambient plus 2.54 kJ m^{-2} d^{-1} (T_1) or ambient plus 4.25 kJ m^{-2} d^{-1} (T_2) of supplemental UV-B (280–320 nm). The number of open flowers increased significantly in the TH cv. under T2 while it declined in the XG cv. under T1. The pollen germination from both cultivars was inhibited by UV-B treatment, fruit number was enhanced in the TH cv. at both UV-B doses and in the XG cv. at the low dose. On the other hand, seed size (dry weight) was reduced in the XG cv. by both UV-B doses and in the TH cv. at the low UV-B dose. The final germination rates of seeds from control and UV-B treated plants of both cultivars showed no significant differences ($p > 0.05$), while germination was delayed in the TH cv. at both doses of UV-B and in the XG cv. only for T_2.

In a study conducted by Maharaj *et al.* 2010 to examine the effect of hormic doses of ultraviolet radiation in delaying the senescence of tomato, it was found that the development of colour and lycopene content as well as the decline in chlorophyll were significantly retarded in response to the treatment with hormic and hyper doses. Treatment with hyper doses however impaired ripening and caused abnormal browning.

Under controlled conditions when young tomato plants were treated with UV-C radiation for different durations of 10, 30, 60 and 120 minutes, it was found that in 10 and 30 minutes treated plants, leaf colour measured immediately after the irradiation, did not change statistically, whereas the 60 and 120 minutes treatments were characterised by a deep senescence with a general stem and leaf yellowing. The results demonstrate that high UV-C doses determined irreversible damages, both at physiological and morphological levels that lead plants to death, whereas lower irradiations allowed plants to partially recover their normal physiological status (Castronuovo *et al.* 2014).

2.3.6 Carbon dioxide

According to Kimball (1982), crop yields will probably increase by 33 per cent with the doubling of CO_2.

Cure (1986) reported that the net CO_2 exchange rate of crops increased 52per cent on first exposure to a doubled CO_2 concentration, but was only 29per cent higher after the plants had acclimatized to the new concentration. For net assimilation rate, the increases were smaller, but fell with time in a similar way. The C_4 crops responded less than C_3 crops. The responses of biomass accumulation and yield were similar to that for carbon fixation rate. Yield increased on average 41per cent for a doubling of CO_2 concentration. The variation in harvest index was small and erratic except for soybean, where it decreased with a doubling of CO_2 concentration. Conductance and transpiration were both inversely related to CO_2 concentration. Transpiration decreased 23 per cent on average for a doubling of CO_2.

The increasing concentration of CO_2 affects the plants directly, causing changes in their chemical composition, physiological processes, production and fitness (Drake *et al*. 1997).

Prasad *et al.* (2006) percentage decreases in pollen viability, seedset, seed yield and harvest index under elevated temperature and elevated CO_2 when compared with ambient CO_2. Elevated CO_2 increased seed yield (26 per cent) at 32/22°C, but decreased seed yield (10 per cent) at 36/26°C. At high temperatures, elevated CO_2 increased vegetative growth but not seed yield, thus, leading to decreased harvest index.

2.4 PHYSIOLOGICAL PARAMETERS

2.4.1 Leaf Area index

Leaf area index is a major determinant of crop growth rate and temperature is the main determinant of leaf is development (Watson, 1952).

High temperature increased the rate of the leaf initiation and appearance (Milthrope, 1959). De koning and Huevelink (1999) found LAI values as low as 1.5 or 2.0 in summer. De kreji (1995) reported that in tomato, high humidity in winter or early spring caused low leaf area, which negatively influenced production.

In a work reported by Heuvelink (1989) day temperature was more important than night temperature in determining leaf area in tomato.

At leaf are index of 3, an indeterminate tomato crop intercepts theoretically about 90 per cent of incident light. (Cavero *et al.* 1998).

Scholberg *et al.* (2000) reported that polyhouse tomato had higher leaf are index of 5.94 in both summer and kharif season whereas it was only 4026 and 4.31 respectively under open field condition at 60 days after transplanting. For optimum light interception and fruit yields of a field grown tomato crop, the LAI should be around 4 to 5. Lower LAI value would reduce light interception and increase yield loss due to sunburn while higher values may delay the onset of fruit production.

Low LAI resulted in reduction of crop photosynthesis and yield (Heuvelink *et al.* 2005). The strong assimilate demand by the growing fruits at higher temperatures reduced leaf growth in greenhouse (Huevelink and Dorais, 2005). The amount of intercepted light is a predominant factor in tomato crop growth and biomass production and depends mainly on leaf area. This relationship can be described as a negative exponential function of leaf area index. Low light levels observed in late autumn (October and November) and changes in crop light interception as influenced by leaf area development may also reduce growth rate (Huevelink and Dorais, 2005).

2.4.2 Lycopene content

Enríquez *et al.* (2013) reported that the season of production, temperature and lighting conditions in the greenhouse, affected the lycopene biosynthesis process. Lycopene content increased as the photoperiod was expanded and at the 32nd week, and it was higher in fruits collected in greenhouses with double layer of polyethylene

(414 μg g^{-1} freeze-dried fruit) than that in fruits grown under a covered with flat glass coated with $CaCO_3$ (241 μg g^{-1} freeze-dried fruit).

Increased fruit irradiance enhanced ascorbate, lycopene, beta-carotene, rutin, and caffeic acid derivate concentrations and the disappearance of oxidized ascorbate and chlorophylls. Increasing the temperature from 21 to 26°C reduced total carotene content without affecting lycopene content. A further temperature increase from 27 to 32°C reduced ascorbate, lycopene, and its precursor's content, but enhanced rutin, caffeic acid derivates, and glucoside contents (Gautier *et al.* 2008)

Rosales *et al.* (2010) conducted a study to examine how different environmental factors (temperature, solar radiation, and vapour-pressure deficit [VPD]) influenced nutritional quality and flavour of cherry tomato fruits (cv. Naomi) grown in two types of experimental Mediterranean greenhouses: parral (low technology) and multi span (high technology). Values for temperature, solar radiation and VPD peaked in the third sampling in both greenhouses; values were higher in the parral-type greenhouse, triggering abiotic stress. This stress reduced the accumulation of lycopene and essential elements, augmenting the phytonutrient content and the antioxidant capacity of tomatoes.

Helyes *et al.* (2007) conducted a study wherein round type tomato (*Lycopersicon esculentum* Mill.) grown on a supporting trellace system in the field was used to determine the correlation between light exposure and the surface temperature and lycopene content of tomato fruit. The positive correlation between solar radiation and surface temperature was stronger (R^2 = 0.87) on non-shaded (NS) than on shaded (SF) (R^2 = 0.79) tomato fruits. There was strong negative correlation (R^2 = 0.95) between surface temperature and lycopene content of tomato fruits. Increasing solar radiation and temperature explained the lower content of lycopene content and therefore the loss of nutritional quality of the non-shaded tomato fruits was observed.

Kuti and Konuru (2005) reported that Greenhouse-grown cluster and round tomatoes contained more lycopene (30.3 mg kg^{-1}) than field-grown tomatoes (25.2 mg kg^{-1}), whereas cherry tomato types had a higher lycopene content in field-grown (91.9 mg kg^{-1}) than in greenhouse-grown (56.1 mg kg^{-1}) fruits.

2.4.3 Ascorbic acid content

Hamnee *et al.* (1945) reported that very large variations in ascorbic acid content of tomatoes may be associated with growing conditions and indicates that a factor of primary importance in determining the ascorbic acid level may be the light intensity a few days prior to harvest.

Rainfall and fluctuations in shade temperature do not influence the concentration of vitamin C in the tomato fruit whereas illumination does exert an influence, probably due to the nature of the actinic composition of the light reaching the plant (Zilva and Crane, 1949).

According to Harshad *et al.* (1960) Nili crops and summer crops were investigated on sandy clay soil. Applying N slightly decreased the ascorbic-acid content of the fruits in the summer crop but not in the Nili crop. The ascorbic-acid content of fruits which grew and matured at high or low P level was higher than those grown at medium P level. There was no relationship between K supply and ascorbic-acid content.

Gautier *et al.* (2008) reported that fruit temperature and irradiance affected final fruit composition. Increased fruit irradiance enhanced ascorbate, lycopene, beta-carotene, rutin, and caffeic acid derivate concentrations and the disappearance of oxidized ascorbate and chlorophylls. Increasing the temperature from 21 to 26°C reduced total carotene content without affecting lycopene content. A further temperature increase from 27 to 32°C reduced ascorbate, lycopene, and its precursor's content, but enhanced rutin, caffeic acid derivates, and glucoside contents.

2.4.4 Relative water content

In an experiment carried by Keyvan (2010) out at Iran to study the effect of drought stress on yield and relative water content of bread wheat cultivar. It was found that there was a decrease in relative water content when drought stress was induced.

Tahar *et al.* (1990) found a positive relationship between grain yield and relative water content measured during the anthesis and grain filling stage.

2.4.5 Total soluble proteins

Gullen and Erris (2004) studied the effect of high temperature on the activity leaf proteins were studied in strawberry. The total soluble protein content showed a decline when plants were exposed to heat stress.

Camejo *et al.* (2005)reported that when tomato cultivars with different temperature sensitivity to high temperature (Campbell-28 and Amalia) and the wild type Nagcarlang were exposed to 45°C for two hours, 45°C for three hours and 25°C as control and the totala soluble protein content was analysed. A significant increase in protein was found in Amalia and the thermo tolerant type Nagcarlang at 45°C-three hours of exposure while in Campbell-28, the protein content increased with stress but this change was not significant.

Esra *et al.* (2010) reported that two pepper varieties were exposed to 4°C cold stress for three days. Exposure to cold treatment resulted in increased accumulation of apoplastic and total soluble proteins. Drought stress exposure in bread wheat cv. resulted in increased levels of total soluble proteins.

2.4.5 Total chlorophyll content

Chlorophyll accumulation is rapid at high temperatures and different light intensities. At low temperatures and high light intensities (3000-5000 Flux cm^{-2}), the accumulation of chlorophyll content is inhibited in etiolated corn. (William and Naylor, 1967).

Chu *et al.* (1974) studied the effect of heat stress on barley and radish. Barley and raddish were subjected to heat stress (39°C) for one to five days either at high (90-95 per cent) or low (50 per cent) humidity. The results showed that leaf chlorophyll content decreased by high temperatures which was accentuated by water stress.

Tomato cultivars (Amalia and Campbell) and the wild type Nagcalang with different sensitivity to high temperature were exposed to different stress conditions (45°C- two hours exposure, 45°C- three hours exposure) and 25°C as control. Chlorophyll "a" content significantly increased in Campbell and Amalia with the exposure at 45°C for three hours, while this increase was shown in Nagarcalang since two of exposure to stress. Plants exposed to both stress condition increased chlorophyll *b* content in Campbell whereas in Amalia the stress condition decreased chlorophyll *b* while a steady decrease was shown in Nagarcalang. Changes in chlorophyll *a* and b in stressed plants led to a total chlorophyll increase in Campbell. However, the total chlorophyll content decreased in stressed plants by two hours in Amalia (Camejo and Torres, 2001).

Zhang (2008) reported that the chlorophyll content in two varieties of tomato seedlings decreased for three days after exposure to chilling stress and increased on the fourth day. Drought stress resulted in decline of total chlorophyll content in wheat (Keyvan, 2010).

Materials and methods

The current investigation was carried out at the Academy of Climate Change Education and Research during 2014-2015 with the objective to study the effect of growing environment and climate change on the physiology of tomato. The materials and the methods followed are presented below:

3.1 DETAILS OF FIELD EXPERIMENT

3.1.1 Location

The field experiments were conducted during December 2014 to March 2015 under three growing namely, polyhouse, rain shelter and open field at the Central nursery located in the main campus of the Kerala Agricultural University at Vellanikkara, Thrissur district, Kerala. The site is located at 10°31'N and 76°13' E longitude and at an altitude of 22.25 m above MSL.

3.1.2 Climate

The area experiences a typical warm humid climate and receives average annual rainfall of 2663 mm.

3.1.3 Soil

The soil of the experimental site comes under the textural class of sandy clay loam and is acidic in reaction.

3.1.4 Variety

Anagha, the bacterial wilt resistant variety released by Kerala Agricultural University was used for the study.

Table 1. Variety characteristics

Variety	Accession number	Growth habit
Anagha	LE415	Semi determinate

3.2 METHODS

The study was conducted throughout December 2014- March 2015 duration in polyhouse, rain shelter and open field simultaneously in a split plot design with 3 replications. The plot was 16.2 m^{-2} and the crop was raised in grow bags of size 16×16 cm placed at 60×60 cm spacing.

3.2.1 Cultural operations

3.2.1.1 Nursery management

Nursery was raised in pots containing rooting medium of sand, soil and farmyard manure in the ratio 1:1:1 and adequate plant protection measures were also taken. Seedlings were transplanted to the experimental site after 20 days of sowing.

3.2.1.2 Preparation of main field and transplanting

The experimental site, polyhouse, rain shelter and open field were cleared thoroughly in order to avoid weeds during the growing period. The grow bags were filled with the potting material and were kept at a spacing of 60 cm×60 cm. Vermicompost () and pseudomonas (10 gram per grow bag) were incorporated into the grow bags and 20 days old healthy seedling were transplanted. Irrigation was given immediately after transplanting using a rose can.

3.2.1.3 Fertilizers and manure application

Urea, Super phosphate and Muriate of potash were the source material for supplying the nutrients N, P_2O_5 and K_2O respectively. A fertilizer dose of 75:40:25 Kg was applied in split doses as per KAU package of practices.

3.2.1.4 After cultivation

The experimental site was kept free of weeds throughout the crop growth period by hand weeding.

3.2.1.5 Staking and training

Staking and training was practiced using wooden poles and coir.

3.2.1.6 Plant protection

The required plant protection as stated in the KAU package of practices were undertaken as and when required.

3.2.1.7 Harvesting

Fruits were harvested at red ripe stage as indicated by colour change from green to red and fruit parameters were recorded.

3.3 OBSERVATIONS

Three Plants per replication from open field, rain shelter and polyhouse conditions were selected for recording observations. Well-developed fruits were randomly selected from each plant for recording observations.

3.3.1 Phenological characters

3.3.1.1 Days to first flower

The number of days taken from transplanting to opening of first flower was recorded and the mean was worked out.

3.3.1.2 Days to first harvest

The number of days from transplanting to first harvest was recorded for three plants per replication and the mean was used for analysis.

3.3.1.3 Days to last harvest

The number of days from transplanting to last harvest was recorded for three plants per replication and the mean was used for analysis.

3.3.2 Floral characters

3.3.2.1 Length and position of stigma and stamen

The length and relative position of stigma and stamen were recorded in the flowers obtained from each plant per replication and the mean was worked out.

3.3.3 Yield and yield attributes

3.3.3.1 Percentage of fruit set

The numbers of fruits formed from the total number of flowers produced from the three plants per replication were recorded and the mean was worked out.

3.3.3.2 Average fruit weight (g)

Total weight of five fruits per replication was observed at each harvest and the mean was calculated.

3.3.3.3 Fruit yield per plant and total yield

Fruit yield per plant was calculated for all the selected plants by adding the yield of individual harvest and expressed in kilograms. The per plant fruit yield was extrapolated to yield obtained in a hectare of land to calculate total yield expressed in tons per hectare.

3.3.3.4 Number of harvests

Total number of harvests from 3 plants per replication was recorded and the mean was worked out.

3.3.4 Physiological parameters

3.3.4.1 Total soluble proteins (mg g^{-1})

Total soluble protein content in each plant per replication was recorded at 30 days, 45 days, 60 days, and 90 days interval using Lowry’s method.

3.3.4.2 Leaf relative water content (percentage)

The leaf relative water content of the selected plants was recorded on a weekly basis and computed in percentage.

$$\mathbf{RWC} = \frac{\mathbf{(Weight\ of\ the\ sample\ after\ saturation - initial\ weight)}}{\mathbf{saturation\ sample\ weight}} * \mathbf{100}$$

3.3.4.2 Lycopene content (mg g^{-1} sample)

The fruit from selected plants from replication were taken. The carotenoids in the sample were extracted in acetone and then taken up the in petroleum ether. Lycopene has an absorption maximum at 473mm and 503 nm one mole of lycopene when dissolved in one litre light petroleum ether (40-60 degree) and measured in a spectrophotometer at 503 nm in 1cm light path given an absorbance of $172*10^4$. There for a cone of 3.1206µg lycopene per ml give until absorbance.

Absorbance 1(unit) = 3.1206 µg lycopene /ml

$$\mathbf{Mg\ of\ lycopene\ in\ 100\ gram\ sample} = \frac{\mathbf{(3.106 * absorbance)}}{\mathbf{weight\ of\ the\ sample}}$$

3.3.4.3 SPAD index

The SPAD index values were computed at weekly intervals using the SPAD502 instrument.

3.3.4.4 Leaf area index

The leaf area index was recorded at weekly intervals using CI 110/120- digital plant canopy imager.

3.3.4.5 Fruit ascorbic acid content (mg g^{-1} sample)

The fruit ascorbic acid content was computed by volumetric titration using the 2,6, dichlorophenol indophenol dye against the ascorbic acid.

3.3.5 Weather observations

The weather parameters were recorded using automatic weather station installed inside each growing environment. The UV radiations were recorded using the UV biometer.

Table 2. Weather parameters used in the experiment

S .No.	Weather parameter	Unit
1	Maximum temperature	°C
2	Minimum temperature	°C
3	Rainfall	mm
4	Relative humidity	Per cent (%)
5	Solar radiation	(W m^{-2})
6	UV radiation	(W m^{-2})
7	PAR	(W m^{-2})
8	Soil temperatures	°C
	Minimum soil temperature	°C
	Maximum soil temperature	°C
9	Soil moisture	Percentage (%)
10	Canopy temperature	°C
11	Canopy air temperature difference	
12	Carbon dioxide	ppm

3.3.6 STATISTICAL ANALYSIS

The data recorded from the field experiment was analysed statistically using Analysis of variance technique. Split plot design was used in the analysis of weather and crop data.

Correlation and regression analysis were done between the growth, yield and physiological characters with the weekly mean values of maximum temperature, minimum temperature, relative humidity, solar radiation, UV radiation, photosynthetically active radiation (PAR), canopy temperature, canopy air temperature difference to determine the effect of weather elements on the growth, yield and physiological characters of rice. Regression equations were worked out from these observations. The different statistical software like Microsoft – excel and SPSS were used in the study for various statistical analyses.

3.4 CLIMATE CHANGE SCENARIOS

Impacts of climate change will depend not only on the response of the Earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter.

The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively).

Climate change data projected by GCM's on daily basis is used for the present study.

Table 3. Descriptions of Representative Concentration Pathway (RCP) Scenarios

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Results

The results of the experiment entitled “The effect of growing environment and climate change on the physiology of tomato, *Lycopersicon esculentum* Mill.” are presented in this chapter. The effect of different growing environment namely, open field, rain shelter and polyhouse and different time of transplanting on the different physiological parameters and the yield of tomato cultivar Anagha were studied.

4.1 PHENOLOGICAL CHARACTERS

4.1.1 Days to first flower

As it is apparent from the Table. 4, the date of transplanting and growing environment had a substantial effect on the number of days taken for appearance of the first flower. The days to first flower was found to be highest (23 days) in the plants transplanted inside the polyhouse on 1 December 2014. The crops planted in the open field on 20 January 2015 took the lowest number of days to flower. The number of days to first flower progressively decreased throughout the season for all the four different treatments.

Table 4. Number of days to first flower

Date of transplanting	Growing environment	Days to first flower
01-Dec-14	Polyhouse	23.0[a]
	Rain shelter	20.0[bc]
	Open field	19.0[c]
10-Dec-14	Polyhouse	22.0[ab]
	Rain shelter	21.0[b]
	Open field	19.0[c]
10-Jan-15	Polyhouse	20.0[bc]
	Rain shelter	18.0[cd]
	Open field	17.0[d]
20-Jan-15	Polyhouse	20.0[bc]
	Rain shelter	19.0[c]
	Open field	17.0[d]
	CD 5%	1.967

4.1.2 Days to first harvest

The different dates of transplanting and growing environment had a significant effect on the days to first harvest (Table. 5). Among all the different dates of transplanting, crops inside the polyhouse condition took more number of days to first harvest. The crops transplanted inside the polyhouse and rain shelter on 1 December 2014 took an extreme 70 days for the first harvest while the open field crop took just 60 days. For the second crop transplanted on 10 December 2014, the number of days taken for first harvest was 65, 61 and 61 days respectively for the polyhouse, rain shelter and open field condition. All the crops transplanted inside the polyhouse, rain shelter and in the open field on 10 January 2015 took the same 50 days each while it was 47 days for crops inside the polyhouse and rain shelter crops and 45 days for the open field crop transplanted on 20 January 2015. Irrespective of the growing environment the days taken to first harvest showed a declining trend in the crops transplanted on 1 December 2014 to 20 January 2015.

Table 5. Number of days to first harvest

Date of Transplanting	Growing environment	Days to first harvest
01-Dec-14	Polyhouse	70.0^{a}
	Rain shelter	70.0^{a}
	Open field	60.0^{c}
10-Dec-14	Polyhouse	65.0^{b}
	Rain shelter	61.0^{c}
	Open field	61.0^{c}
10-Jan-15	Polyhouse	50.0^{d}
	Rain shelter	50.0^{d}
	Open field	50.0^{d}
20-Jan-15	Polyhouse	46.0^{e}
	Rain shelter	46.0^{e}
	Open field	46.0^{e}
	CD 5%	1.499

4.1.3 Days to last harvest

The dates of transplanting and the growing environment had a significant effect on the number of days taken for last harvest (Table 6). The crops transplanted inside the polyhouse on 1 December 2014 took the maximum days for the last harvest (114 days) while the crop transplanted on 20 January 2015 in the open field took the least number of days for attaining the last harvest (56 days). A gradual decrease in the number of days to last harvest was evident from the crops transplanted on 1 December 2014 to the crops transplanted on 20 January 2015, irrespective of the growing environment.

Table 6. Days to last harvest

Date of transplanting	Growing condition	Days to last harvest
01-Dec-14	Polyhouse	114.0^{a}
	Rain shelter	112.0^{a}
	Open field	88.0^{e}
10-Dec-14	Polyhouse	107.0^{b}
	Rain shelter	101.0^{c}
	Open field	95.0^{d}
10-Jan-15	Polyhouse	81.0^{f}
	Rain shelter	81.7^{f}
	Open field	65.0^{h}
20-Jan-15	Polyhouse	76.0^{g}
	Rain shelter	76.7^{g}
	Open field	56.0^{i}
	CD 5%	2.188

4.2 FLORAL CHARACTERS

4.2.1 Mean style length (mm)

The mean style length is presented in table 7. The greatest mean style length was observed when plants were transplanted on 1 December 2014 inside the rain shelter and polyhouse (8.10 mm and 8.07 mm). Among the crops grown under different growing condition the mean style length of the polyhouse and rain shelter planted crops were statistically similar except for the crops transplanted on 20 January 2015, where the plants inside the polyhouse recorded a significant length than crops inside the rain shelter. Among all the dates of planting mean style length reduced with delay in transplanting from 1 December 2014 to 20 January 2015 in all the crops regardless of the growing environment.

Table 7. Mean style length (mm)

Date of transplanting	Growing environment	Mean style length
01-Dec-14	Polyhouse	8.07[a]
	Rain shelter	8.10[a]
	Open field	6.80[c]
10-Dec-14	Polyhouse	7.03[b]
	Rain shelter	6.60[d]
	Open field	6.03[e]
10-Jan-15	Polyhouse	6.10[e]
	Rain shelter	5.87[g]
	Open field	5.87[g]
20-Jan-15	Polyhouse	5.97[f]
	Rain shelter	5.20[h]
	Open field	5.07[i]
	CD 5%	0.043

4.2.2 Mean stamen length

As is apparent from the Table 8, the date of transplanting and the growing environment had a significant effect on the mean stamen length. The greatest mean stamen lengths were recorded for the crops transplanted on 1 December 2014 inside the polyhouse and rain shelter (8.30 mm and 8.27 mm respectively). Among the crops transplanted under different growing environments, the stamen length were statistically similar in the crops transplanted in the open field on 10 December 2014 and inside the polyhouse on 10 January 2015, whereas the stamen length of the crops transplanted inside the rain shelter and in open field on 10 January 2015 were statistically similar The least mean stamen length was recorded in crops transplanted inside the rain shelter and in open field on 20 January 2015 (5.03 mm 4.87 mm respectively). A progressive decrease in the mean stamen length with passage of each date of transplanting from 1 December 2014 to 20 January 2015 was recorded among all the crops regardless of the growing environment.

Table 8. Mean stamen length (mm)

Date of transplanting	Growing environment	Mean stamen length
01-Dec-14	Polyhouse	8.30^{a}
	Rain shelter	8.27^{a}
	Open field	6.90^{c}
10-Dec-14	Polyhouse	6.97^{b}
	Rain shelter	6.83^{d}
	Open field	6.07^{f}
10-Jan-15	Polyhouse	6.07^{f}
	Rain shelter	5.73^{g}
	Open field	6.10^{f}
20-Jan-15	Polyhouse	6.17^{e}
	Rain shelter	5.03^{h}
	Open field	4.87^{i}
	CD 5%	0.05

4.3 PHYSIOLOGICAL PARAMETERS

4.3.1 Leaf relative water content (%)

The different dates of planting and the growing environment did not have a significant effect on the leaf relative water content of the tomato plants up to the third week from the date of transplanting. The effect of the growing environment and transplanting date was evident from the fourth week and continued up to week 9 (Table 9). The highest leaf relative water content was observed in the first week following transplanting in the plants under polyhouse condition transplanted on 10 December 2014 (94.5%) followed by plants transplanted in open field on 1 December 2014 . The highest and the lowest leaf relative water content for all the treatments were obtained during the first week after transplanting and last week prior to the final uprooting of the crops respectively. The leaf relative content showed a decreasing trend from the 1 week of transplanting to the final uprooting irrespective of the growing condition. For all the different dates of transplanting the plants within the polyhouse condition reported the highest values of leaf relative water content while the open field crops sustained the lowest value throughout the growing period.

Table 9. Weekly Relative Water Content

Growing environment	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9
01-Dec-14									
Polyhouse	93.3^{ab}	91.3^{a}	89.6^{b}	88.7^{a}	88.3^{a}	86.4^{a}	84.8^{a}	83.5^{a}	81.3^{a}
Rain shelter	92.5^{bc}	90.6^{ab}	87.6^{bc}	86.2^{b}	83.6^{c}	82.0^{c}	79.6^{c}	76.9^{d}	75.8^{b}
Open field	93.4^{ab}	89.4^{b}	85.4^{d}	83.8^{c}	81.2^{d}	78.8^{e}	75.5^{ef}	72.7^{i}	71.2^{bc}
10-Dec-14									
Polyhouse	94.5^{a}	92.1^{a}	92.6^{a}	89.4^{a}	87.0^{b}	84.6^{b}	83.2^{b}	82.5^{b}	82.6^{a}
Rain shelter	93.2^{ab}	90.3^{ab}	89.1^{b}	85.8^{b}	82.9^{c}	82.1^{c}	80.5^{c}	79.4^{c}	75.5^{b}
Open field	92.8^{b}	89.3^{b}	87.6^{bc}	86.3^{b}	82.5^{cd}	80.5^{d}	78.4^{d}	75.7^{f}	73.8^{b}
10-Jan-15									
Polyhouse	92.8^{b}	90.4^{a}	88.6^{b}	87.1^{b}	85.8^{b}	83.2^{c}	79.6^{c}	75.4^{g}	75.2^{b}
Rain shelter	92.8^{ab}	90.2^{ab}	86.9^{c}	85.0^{bc}	82.9^{c}	81.4^{cd}	80.2^{c}	76.6^{e}	75.4^{b}
Open field	92.1^{bc}	88.3^{bc}	84.6^{ed}	81.1^{d}	78.9^{e}	74.7^{f}	72.6^{g}	70.4^{k}	68.4^{cd}
20-Jan-15									
Polyhouse	91.0^{c}	89.2^{b}	86.4^{cd}	84.0^{c}	81.4^{d}	78.9^{e}	76.5^{e}	72.7^{j}	70.6^{c}
Rain shelter	91.6^{bc}	88.3^{bc}	85.6^{cd}	84.3^{c}	79.2^{e}	77.9^{e}	74.9^{f}	73.2^{h}	71.0^{bc}
Open field	91.9^{bc}	86.2^{c}	83.2^{e}	79.6^{e}	75.7^{f}	73.4^{g}	70.2^{h}	69.2^{l}	67.0^{e}
CD 5%	1.7	1.5	1.5	1.5	1.5	1.3	1.1	1.8	2.1

4.3.2 Total soluble proteins (mg g^{-1} sample)

The total soluble protein content (TSP) at different intervals are represented in Table 10. The total soluble protein contained within the crops were measured and recorded at 30 and 45 days interval. The dates of transplanting and the growing environment had a substantial effect on the total soluble proteins of the crop. The TSP values were consistently higher in crops transplanted inside the rain shelter on 20 January 2015 (0.065 mg g^{-1} at 30 DAT and 0.131 mg g^{-1} at 45 DAT). The lowest values of TSP (0.001 mg g^{-1}) at 30 DAT were recorded in the plants transplanted inside the polyhouse on 20 January 2015 whereas the plants in the open field transplanted on 10 January 2015 recorded the least TSP values (0.021 mg g^{-1}) at 45 DAT.

Table 10. Total soluble proteins (TSP)

Date of transplanting	Growing environment	TSP at 30 DAT	TSP at 45 DAT
01-Dec-14	Polyhouse	0.009[f]	0.026[h]
	Rain shelter	0.006[g]	0.033[g]
	Open field	0.016[d]	0.032[g]
10-Dec-14	Polyhouse	0.017[c]	0.087[e]
	Rain shelter	0.006[g]	0.127[b]
	Open field	0.004[h]	0.093[d]
10-Jan-15	Polyhouse	0.003[i]	0.029[g]
	Rain shelter	0.015[e]	0.023[hi]
	Open field	0.002[j]	0.021[i]
20-Jan-15	Polyhouse	0.001[k]	0.057[f]
	Rain shelter	0.065[a]	0.131[a]
	Open field	0.038[b]	0.123[c]
	CD 5%	0.0001	0.003

4.3.3 Fruit ascorbic acid content (mg^{-1} g sample)

As is apparent from the Table 11 the dates of transplanting and the growing environment had a substantial effect on the ascorbic acid content of the fruit. Crops inside the rain shelter recorded the highest amount of ascorbic acid in all the different dates of transplanting. The amount of ascorbic acid in fruits obtained from the rain shelter was statistically similar for all the date of sowing except for the crop transplanted on 20 January 2015. The highest and the lowest value of ascorbic acid were recorded in the fruits obtained from the crops transplanted inside the rain shelter and in open field on 10 December 2014 (2.6 and 0.83 mg per g sample).

4.3.4 Fruit lycopene content (mg g^{-1} sample)

Table. 12 represents the fruit lycopene content. The dates of transplanting and growing environment had significant effect on the fruit lycopene content. The highest amount of lycopene was recorded in the fruits obtained from the crops transplanted inside on 1 and 10 December 2014. The lycopene content, irrespective of the date of transplanting and growing condition was found to be the highest (1.52 mg per g of the sample) and lowest (0.91 mg per g sample) in the fruits obtained from the crops inside the polyhouse transplanted on 1 and 10 December 2014 and open field crop transplanted on 20 January 2015 respectively.

Table 11. Fruit ascorbic acid content

Date of transplanting	Growing environment	Ascorbic acid
	Polyhouse	1.33[bc]
01-Dec-14	Rain shelter	2.04[a]
	Open field	1.19[c]
	Polyhouse	0.89[cd]
10-Dec-14	Rain shelter	2.06[a]
	Open field	0.83[d]
	Polyhouse	1.13[cd]
10-Jan-15	Rains helter	1.85[a]
	Open field	1.63[b]
	Polyhouse	1.16[c]
20-Jan-15	Rain shelter	1.53[b]
	Open field	1.17[c]
	CD 5%	0.316

Table 12. Fruit lycopene content (mg g^{-1} sample)

Date of transplanting	Growing environment	Lycopene
01-Dec-14	Polyhouse	1.47[b]
	Rain shelter	1.34[e]
	Open field	1.17[g]
10-Dec-14	Polyhouse	1.44[c]
	Rain shelter	1.26[f]
	Open field	1.02[h]
10-Jan-15	Polyhouse	1.52[a]
	Rain shelter	1.46[bc]
	Open field	1.04[h]
20-Jan-15	Polyhouse	1.52[a]
	Rain shelter	1.38[d]
	Open field	0.91[i]
	CD 5%	0.027

4.3.5 SPAD index value

The weekly and stage wise SPAD index value are presented in the Table. 13 and 14. The SPAD index value was highest in the open field crops regardless of the dates of transplanting. The highest SPAD index value (51.3) was recorded in the crops transplanted in the open field on 10 January 2015 and the least value (21.4) in the crops transplanted inside the rain shelter on 10 December 2014.

Table 13. Weekly SPAD index value

Growing environment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
01-Dec-14									
Polyhouse	41.7^{a}	43.5^{a}	31.2^{f}	38.1^{ab}	36.9^{cd}	36.9^{c}	35.1^{bc}	37.0^{c}	34.3^{bc}
Rain shelter	36.7^{ab}	39.4^{a}	38.6^{d}	43.3^{a}	35.4^{d}	35.7^{c}	35.2^{bc}	39.1^{bc}	41.1^{ab}
Open field	45.1^{a}	39.9^{a}	43.6^{b}	48.2^{a}	43.6^{b}	46.1^{ab}	43.8^{a}	42.5^{bc}	44.9^{a}
10-Dec-14									
Polyhouse	32.3^{bc}	26.9^{c}	29.8^{f}	41.9^{ab}	34.9^{d}	34.4^{c}	34.7^{bc}	38.8^{bc}	37.7^{b}
Rain shelter	21.4^{d}	31.8^{bc}	35.4^{e}	43.4^{a}	45.9^{b}	48.3^{a}	40.4^{ab}	47.3^{ab}	48.5^{a}
Open field	31.1^{bc}	35.4^{ab}	35.9^{f}	47.1^{a}	39.3^{c}	43.3^{ab}	43.3^{a}	50.7^{a}	47.7^{a}
10-Jan-15									
Polyhouse	26.4^{cd}	29.4^{bc}	34.0^{e}	35.5^{b}	34.0^{d}	36.5^{c}	36.5^{b}	43.5^{b}	35.6^{b}
Rain shelter	32.2^{bc}	36.3^{ab}	39.8^{cd}	39.7^{ab}	42.9^{b}	43.2^{ab}	42.7^{a}	38.6^{bc}	35.4^{bc}
Open field	39.0^{ab}	44.8^{a}	42.8^{bc}	48.7^{a}	50.5^{a}	51.3^{a}	43.2^{a}	29.4^{d}	25.8^{c}
20-Jan-15									
Polyhouse	27.7^{c}	29.9^{bc}	35.5^{e}	39.0^{ab}	34.3^{d}	38.7^{c}	38.7^{ab}	34.3^{cd}	27.4^{c}
Rain shelter	31.7^{bc}	33.4^{b}	41.1^{c}	41.0^{ab}	29.4^{e}	42.9^{b}	31.6^{c}	31.3^{cd}	34.4^{bc}
Open field	35.4^{b}	44.5^{a}	50.5^{a}	36.7^{ab}	36.2^{cd}	48.7^{a}	34.6^{bc}	30.5^{d}	29.3^{c}
CD 5%	5.190	5.925	2.304	7.751	3.085	5.419	4.066	6.200	6.220

4.3.6 Leaf area index

The different date of transplanting and the growing environment had a significant effect on the leaf area index of the crops (Table. 14 and 15). The maximum values of LAI were obtained during the flowering and fruiting stage. The maximum LAI value of 3.8 was observed among the crops transplanted in the open field on 1 December 2014 and in the crops transplanted inside the rain shelter and polyhouse on 20 January 2015. Regardless of the growing environment and date of transplanting LAI increased exponentially up to the fourth week following transplantation. A higher value of LAI (2.5) was maintained for a prolonged period of 14 weeks among the crops inside the polyhouse. Within the rain shelter higher values of LAI were sustained for a moderate period of 13 weeks, whereas it was even more diminutive (11 weeks) in case of the crops in the open field. The least values of maximum LAI (3.2) was documented in the crops in the open field transplanted on 20 January 2015.

Table 14. Weekly LAI

Growing environment	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9
				01-Dec-14					
Polyhouse	0.91^{ab}	1.66^{a}	2.67^{a}	3.17^{a}	3.14^{ab}	3.31^{a}	3.24^{ab}	2.18^{ab}	3.25^{a}
Rain shelter	0.83^{bc}	1.48^{ab}	1.91^{b}	2.56^{b}	2.93^{bc}	2.47^{b}	2.29^{bc}	3.16^{a}	2.45^{ab}
Open field	0.88^{b}	1.45^{ab}	1.54^{bc}	1.34^{d}	1.48^{e}	1.61^{bc}	1.37^{cd}	1.71^{ab}	1.50^{bc}
				10-Dec-14					
Polyhouse	0.84^{bc}	1.75^{a}	2.18^{ab}	3.08^{a}	3.35^{a}	3.62^{a}	3.57^{a}	2.72^{a}	3.58^{a}
Rain shelter	0.87^{b}	1.99^{a}	1.42^{bc}	1.19^{d}	1.46^{e}	1.83^{bc}	2.20^{a}	2.51^{a}	2.15^{b}
Open field	0.75^{c}	1.29^{ab}	1.24^{c}	1.38^{d}	1.45^{e}	1.52^{c}	1.71^{c}	2.43^{a}	1.42^{c}
				10-Jan-15					
Polyhouse	0.77^{bc}	1.13^{b}	2.58^{a}	3.09^{a}	3.44^{a}	3.53^{a}	3.60^{a}	2.97^{a}	3.52^{a}
Rain shelter	0.81^{bc}	1.24^{ab}	1.65^{bc}	2.35^{bc}	2.65^{c}	2.41^{b}	2.88^{b}	2.65^{a}	1.78^{bc}
Open field	0.79^{bc}	1.58^{a}	1.58^{bc}	1.38^{d}	1.56^{e}	2.07^{b}	1.97^{c}	1.50^{ab}	0.69^{d}
				20-Jan-15					
Polyhouse	1.00^{a}	1.42^{ab}	2.40^{ab}	3.35^{a}	3.35^{a}	3.20^{a}	3.50^{a}	3.05^{a}	3.67^{a}
Rain shelter	1.02^{a}	1.31^{ab}	2.23^{ab}	1.97^{c}	2.20^{d}	3.18^{a}	3.62^{a}	3.17^{a}	3.03^{a}
Open field	0.91^{ab}	1.52^{ab}	2.24^{ab}	1.22^{d}	1.70^{e}	1.41^{c}	1.19^{d}	1.40^{ab}	0.03^{d}
CD	0.11	0.43	0.54	0.36	0.36	0.47	0.62	2.26	0.66

Table 15. Maximum LAI

Date of transplanting	Growing environment	Maximum LAI
01-Dec-14	Polyhouse	3.6^{c}
	Rain shelter	3.5^{c}
	Open field	3.8^{a}
10-Dec-14	Polyhouse	3.7^{ab}
	Rain shelter	3.6^{c}
	Open field	3.6^{c}
10-Jan-15	Polyhouse	3.6^{c}
	Rain shelter	3.7^{ab}
	Open field	3.6^{c}
20-Jan-15	Polyhouse	3.8^{a}
	Rain shelter	3.8^{a}
	Open field	3.2^{d}
	CD 5%	0.159

4.4. YIELD AND YIELD ATTRIBUTES

4.4.1 Total yield

The total yield in tons per hectare was found significantly influenced by the date of transplanting and the growing environment (Table 16). The maximum yield of 111.5 tons/hectare and 111.2 tons per hectare were obtained from the crops transplanted inside the polyhouse on 1 and 10 December 2014 respectively. The yields from the crops transplanted inside the polyhouse on 1 and 10 December 2014 and the yield from the crops transplanted inside the rain shelter on 1 December 2014 were statistically similar. Regardless of the dates of transplanting the yields from the crops inside the polyhouse were consistently highest followed by the crops inside the rain shelter and open field. The lowest yields were obtained from the crops in the open field transplanted on 20 January 2015.

Table 16. Total yield (tons ha^{-1})

Date of transplanting	Growing environment	Total yield
01-Dec-14	Polyhouse	111.5^{a}
	Rain shelter	92.4^{a}
	Open field	73.2^{ab}
10-Dec-14	Polyhouse	111.2^{a}
	Rain shelter	71.2^{b}
	Open field	57.5^{bc}
10-Jan-15	Polyhouse	82^{ab}
	Rain shelter	68.5^{b}
	Open field	38.4^{c}
20-Jan-15	Polyhouse	73^{ab}
	Rain shelter	66.7^{b}
	Open field	7.5^{d}
	CD 5%	19.831

4.4.2 Percentage fruit set (%)

The percentage fruit set values are given in Table 18. The highest percentage of fruit set (61.7 and 50.1 per cent respectively) was observed in the plants transplanted inside the polyhouse on 1 and 10 December 2014. Whereas, the lowest fruit set percentage was observed in crops planted in the open field on 10 and 20 January 2015. Irrespective of the dates of transplanting the highest and lowest fruit set consistently occurred within the polyhouse and in the plants in the open field respectively.

4.4.3 Fruit yield per plant (kg)

The different dates of transplanting and growing environment had a significant effect on the fruit yield obtained from a single plant (Table 17). The highest fruit yield per plant were recorded from the crops planted inside the polyhouse on 1 and 10 December 2014 (4.5 kg per plant). The per plant yield obtained from the crops transplanted on 1 and 10 December 2014 inside the polyhouse and rain shelter were statistically similar. As the cropping seasons proceeded the fruit yield per plant decreased. The least values were recorded in the crops transplanted in the open field on 20 January 2015 (0.3 kg per plant).

Table 17. Percentage fruit set and Fruit yield per plant

Date of transplanting	Growing environment	Percentage fruit set	Fruit yield per plant
01-Dec-14	Polyhouse	61.7^{a}	4.5^{a}
	Rain shelter	43.0^{c}	3.8^{b}
	Open field	26.9^{e}	2.9^{bc}
10-Dec-14	Polyhouse	50.1^{b}	4.5^{a}
	Rain shelter	34.6^{d}	2.7^{bc}
	Open field	24.0^{ef}	2.3^{c}
10-Jan-15	Polyhouse	25.4^{ef}	3.3^{b}
	Rain shelter	23.7^{ef}	2.9^{bc}
	Open field	20.1^{ef}	1.5^{d}
20-Jan-15	Polyhouse	26.1^{e}	2.9^{bc}
	Rain shelter	26.0^{e}	2.7^{bc}
	Open field	20.0^{f}	0.3^{e}
	CD 5%	5.378	0.794

4.3.4 Average fruit weight (g)

The highest average fruit weight was recorded in the crop inside rain shelter transplanted on 20 January 2015 (59.0 g), 10 January 2015 (56.0 g) and 10 December 2014 (53.0 g) followed by fruit obtained from the crop transplanted on 10 December 2014, 10 January 2015 and 20 January 2015 inside polyhouse. The lowest fruit weight was consistently obtained in the open field except for the first season (Table 18).

4.3.5 Number of harvests

The total numbers of harvests for the different treatments are represented in the Table 18. The greatest number of harvests (12 and 11) were obtained from the crops grown inside the polyhouse and rain shelter transplanted on 1 December 2014 while the least was obtained among the crops transplanted in the open field on 10 and 20 January 2015 (3 each).

Table 18. Average fruit weight and Number of harvest

Date of planting	Growing environment	Average fruit weight	No. of harvest
Dec-01	Polyhouse	36^{c}	12^{a}
	Rain shelter	48^{ab}	11^{b}
	Open field	50^{ab}	8^{e}
Dec-10	Polyhouse	39^{bc}	10^{c}
	Rain shelter	52^{a}	9^{d}
	Open field	35^{c}	7^{f}
Jan-10	Polyhouse	46^{ab}	6^{g}
	Rain shelter	58^{a}	6^{g}
	Open field	13^{d}	3^{h}
Jan-20	Polyhouse	44^{b}	6^{g}
	Rain shelter	56^{a}	6^{g}
	Open field	13^{d}	3^{h}
	CD 5%	6.1	0.288

4.5. WEATHER INSIDE THE DIFFERENT GROWING

4.5.1. Weekly solar radiation (Wm^{-2})

4.5.1.1. Open field

The highest values of weekly solar radiation for the different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 were 705.0, 716.6, 712.9 Wm^{-2} respectively. While the lowest solar radiations received for the same dates of transplanting were 568.4, 584.8 and 600.1 Wm^{-2} respectively. The solar radiation showed a declining trend in the first three dates of sowing but tended to follow an increasing trend in the last date of sowing (Fig. 1).

4.5.1.2. Rain shelter and polyhouse

The highest values of solar radiations for the different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 were 667.7, 507.6 and 414.3 Wm^{-2} were respectively, while the lowest solar radiations for the same dates of transplanting were 203.0, 201.2 and 243.4 Wm^{-2} respectively (Fig. 1).

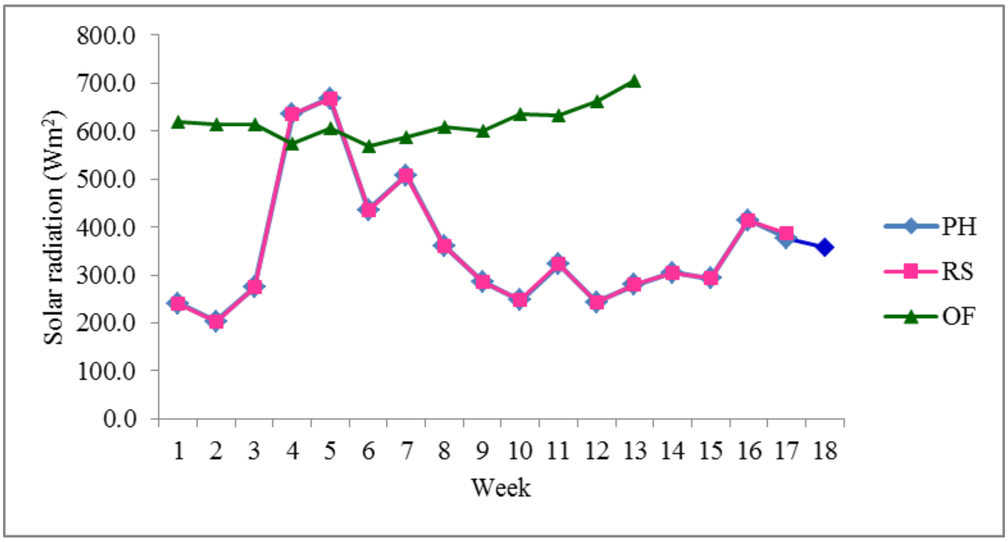


Fig 1. Weekly variation in solar radiation

4.5.2 Weekly minimum temperature (°C)

4.5.2.1. Open field

The highest values of minimum temperatures for the different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 were 26.6, 27.2, 27.5 and 28.2°C respectively. While the lowest values of minimum temperatures for the same dates of transplanting were 26.6, 27.2, 27.5 and 28.5°C respectively. The weekly minimum temperatures showed a consistent increasing trend all throughout the four dates of transplanting (Fig. 2).

4.5.2.2. Rain shelter

The peak values of minimum temperature for the different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 were 28°C, 27.4°C, 29.8°C and 29.8°C respectively. While the lowest values for the same dates of transplanting were 21.8, 22.2, 25.2 and 24.8°C respectively. An increasing trend in the weekly minimum temperature was documented in all four dates of transplanting (Fig. 2).

4.5.2.3. Polyhouse

The highest values of weekly minimum temperature for the different dates of transplanting namely 1 and 10 December 2014 was 29°C, for 10 and 20 January 2015 it was 30.6°C, respectively. While the lowest of minimum temperature for the first, second, third dates of transplanting was 22°C and 25.6°C for fourth date of transplanting (Fig. 2).

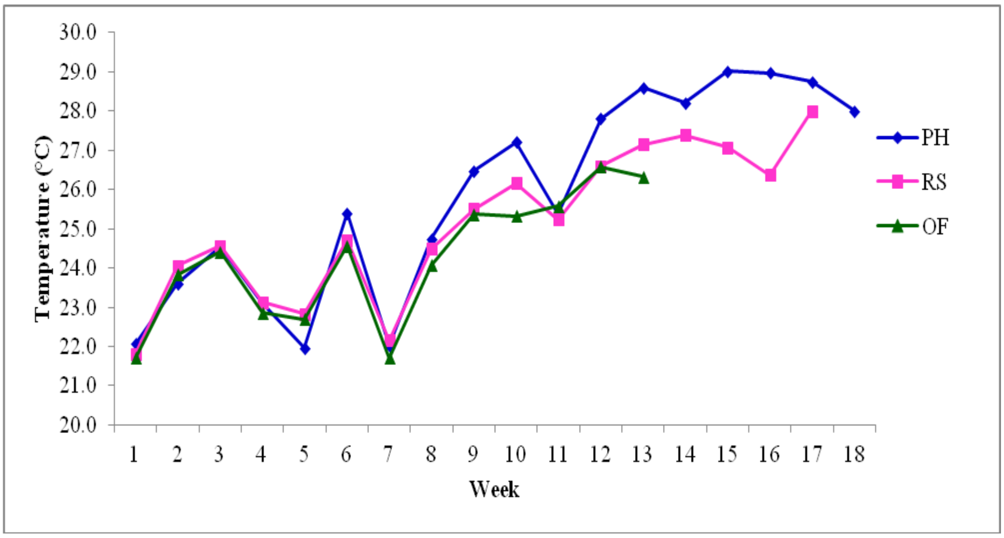


Fig 2. Weekly variation in minimum temperature

4.5.3 Weekly maximum temperature (°C)

4.5.3.1. Open field

The highest values of maximum temperatures for the different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 were 38.9°C, 36.7°C, 38.6°C and 39.7°C respectively. While the lowest values were 33.7°C, 33.6° C, 34.5°C and 35.7°C respectively (Fig. 3).

4.5.3.2. Rain shelter

The lowest values of maximum temperatures recorded inside the rain shelter for the crops transplanted on 1 and 10 December 2014 was 34.7°C while it was 36.5 and 36.2°C each for the crops transplanted on 10 and 20 January 2015. The peak maximum temperatures were 41.0, 40.7, 41.8 and 41°C correspondingly for the different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 (Fig. 3).

4.5.3.3. Polyhouse

Within the polyhouse the lowest maximum temperature recorded for the four different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and

20 January 2015 were 33.7, 33.7, 34.5 and 35.7°C, while the peak maximum temperatures were 38.9, 37.6, 38.6 and 39.7°C (Fig. 3).

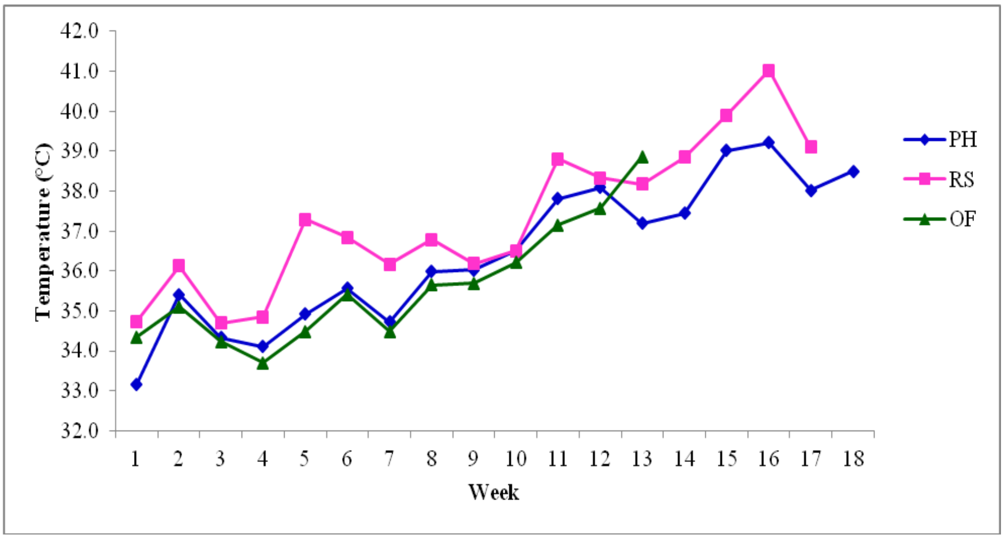


Fig 3. Weekly variation in maximum temperature

4.5.4 Minimum relative humidity

4.5.4.1. Open field

The lowest minimum relative humidity documented for the first crop transplanted on 1 December 2014 was 23.7 per cent and 29.7 per cent for the crops transplanted on 10 December 2014, 10 and 20 January 2015 following three seasons. The peak values of minimum relative humidity were 54.3, 59, 49 and 49 per cent each for the four consecutive dates of transplanting (Fig. 4).

4.5.4.2. Rain shelter

The lowest minimum relative humidity inside the rain shelter was 28.1 per cent for all the four different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015seasons whereas, the highest minimum relative humidity was 54.3, 55.8, 46.3 and 48 per respectively for the first, second, third and fourth dates of transplanting (Fig. 4).

4.5.4.3 Polyhouse

The lowest minimum relative humidity inside the polyhouse was 25.1 per cent for all the four different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015seasons whereas, the highest minimum relative humidity was 44.7, 45.6, 46.7 and 46.7 per respectively (Fig. 4).

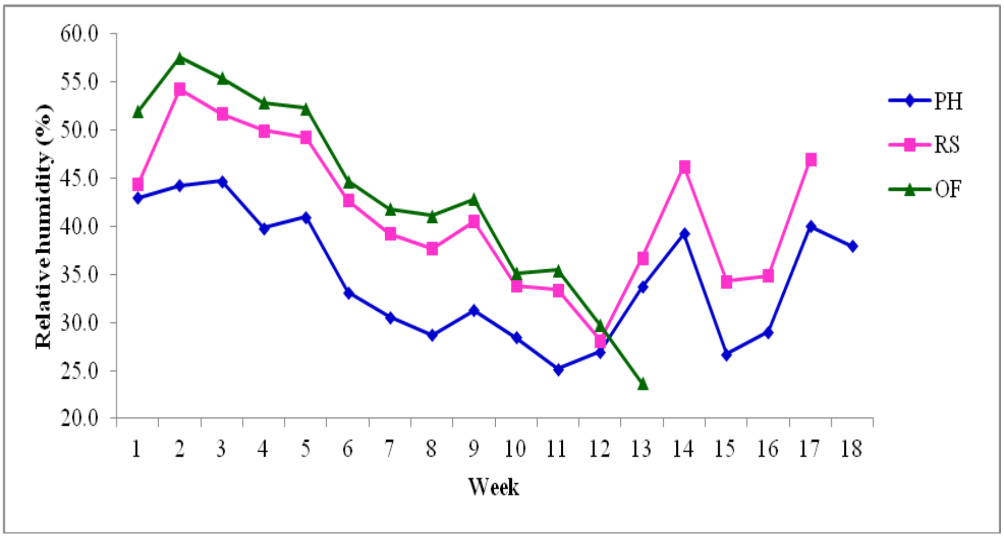


Fig 4. Weekly variation in minimum relative humidity

4.5.5 Maximum relative humidity (percentage)

4.5.5.1 Open field

The lowest maximum relative humidity in the open field condition was 49.3 per cent for the first date of transplanting on 1 December 2014 and 63.7 per cent for rest of the three dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 whereas, the highest maximum relative humidity was 99 per cent for the first two dates of transplanting and 87.1 and 83.4 per cent respectively for the third and fourth dates of transplanting (Fig. 5).

4.5.5.2 Rain shelter

The lowest maximum relative humidity recorded inside the rainshelter was 64.4 per cent for all the four different dates of transplanting namely 1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015 seasons whereas, the highest maximum relative humidity was 89 per cent for the first and second dates of transplanting and 81.6 and 79.1 per cent respectively for the third and fourth dates of transplanting (Fig. 5).

4.5.5.3. Polyhouse

The lowest maximum relative humidity documented inside the polyhouse was 63.6 per cent for all the four different dates of transplanting namely 1 December 2014, 10 December 2014, 10 and 20 January 2015 seasons whereas, the highest maximum relative humidity was 93.6 per cent for the first and second dates of transplanting crop season and 83 per cent each for the third and fourth dates of transplanting (Fig. 5).

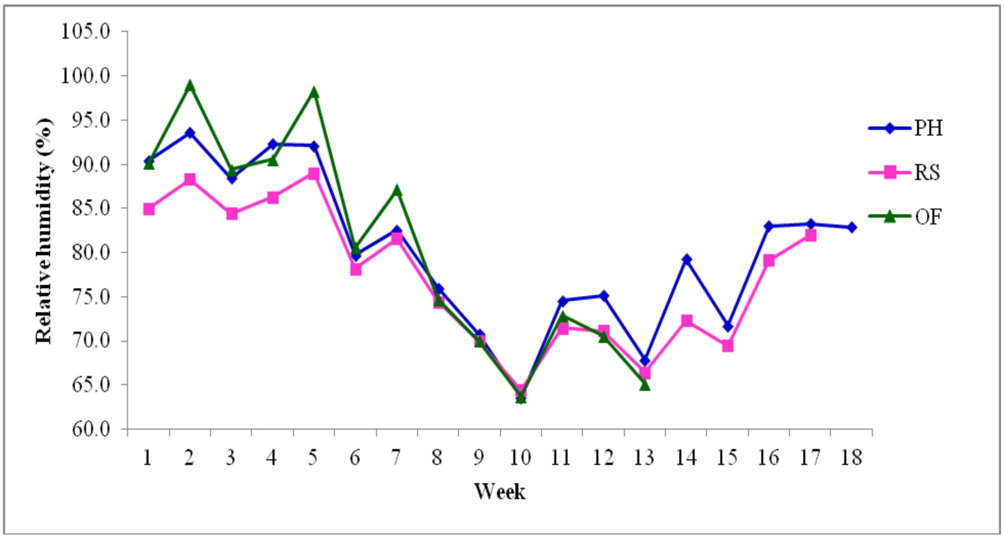


Fig 5. Weekly variation in maximum relative humidity

4.5.6 Minimum soil temperature (°C)

4.5.6.1 Open field

The lowest minimum temperature recorded in the open field during the first three dates of transplanting namely 1 December 2014, 10 December 2014 and 10 January 2015 was 21.8°C and 23.5°C during the last date of transplanting. While, the peak value of minimum soil temperature recorded was 28.5°C for all the four dates of transplanting (Fig. 6).

4.5.6.2 Rain shelter

The lowest minimum temperature recorded inside the rain shelter during the first three dates of transplanting namely 1 December 2014, 10 December 2014 and 10 January 2015 was 21.3°C and 22.5°C during the last date of transplanting. The peak value of minimum soil temperature obtained was 26.8°C for the first date of transplanting, 27°C each during the second and third dates of transplanting and 23.5°C during the fourth date of transplanting (Fig. 6).

4.5.6.3 Polyhouse

The lowest minimum temperature recorded inside the polyhouse during the first three dates of transplanting namely 1 December 2014, 10 December 2014 and 10

January 2015 was 22.3°C and 22.6°C during the last date of transplanting on 20 January 2015. While, the peak value of minimum soil temperature obtained was 26.4°C for the crops transplanted on 1 December 2014 and 26.6°C during the second date of transplanting on 10 December 2014 and 27.7°C during the third and fourth dates of transplanting (Fig. 6).

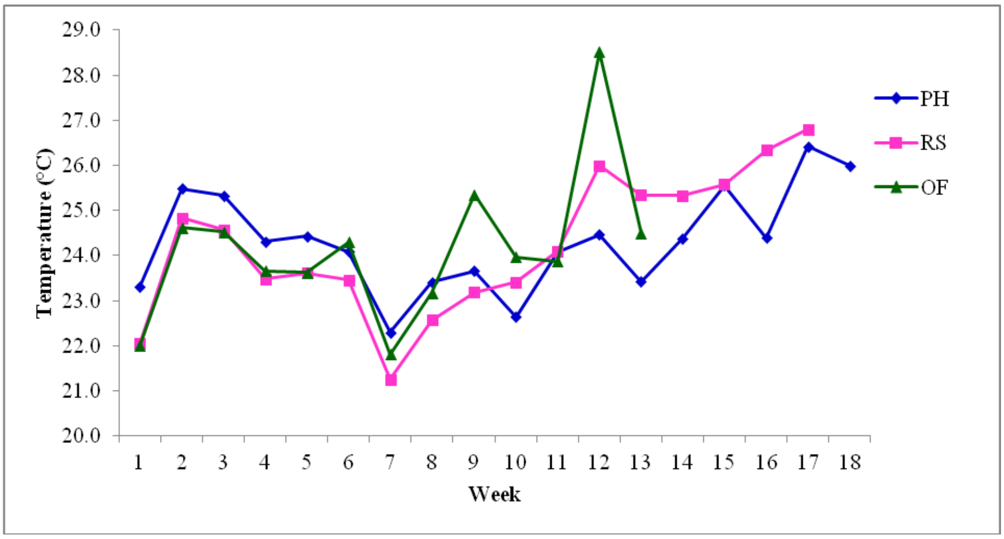


Fig 6. Weekly variation in minimum soil temperature

4.5.7 Maximum soil temperature (°C)

4.5.7.1 Open field

The lowest maximum soil temperature for the first and second dates of transplanting (1 December 2014 and 10 December 2014) was 35.2°C while it was 38.3°C during the third and fourth dates of transplanting (10 January 2015 and 20 January 2015). The peak values of maximum soil temperature was 56.1, 55.7, 62.6 and 62.7°C correspondingly for first, second, third and fourth dates of transplanting (Fig. 7).

4.5.7.2 Rain shelter

The lowest maximum soil temperature during the first and second dates of transplanting (1 and 10 December 2014) crop season was 32.7°C and during the third and fourth dates of transplanting (10 and 20 January 2015) was 36 and 36.4°C. The peak values of maximum soil temperature was 42.7°C in the first and second dates of transplanting and 41.9°C during the third and fourth dates of transplanting (Fig. 7).

4.5.7.3 Polyhouse

The lowest maximum soil temperature during the first, second, third and fourth dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) was 28.7°C. The peak values of maximum soil temperature was 33.2 and 33.9°C in the first and second dates of transplanting 34.1°C during the third and fourth dates of transplanting cropping season (Fig. 7).

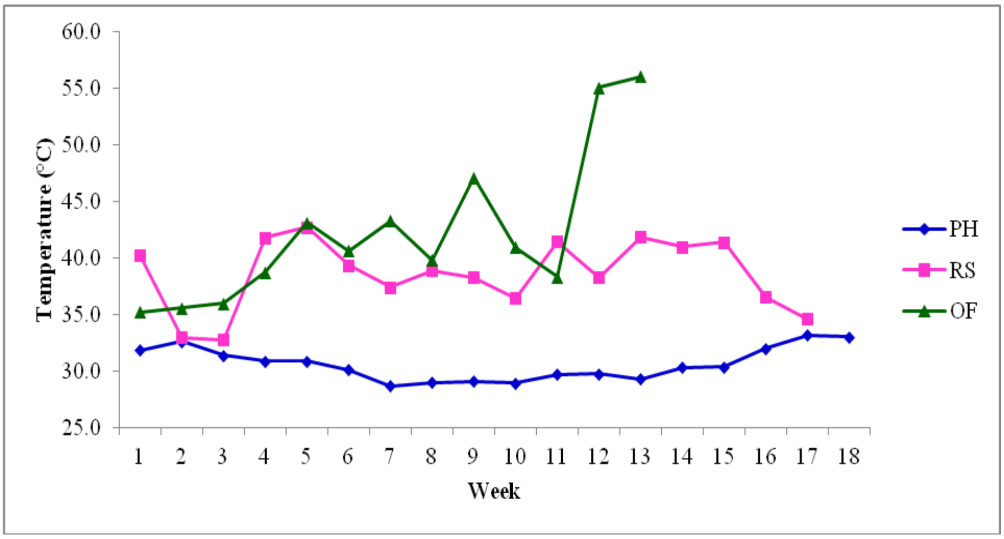


Fig 7. Weekly variation in maximum soil temperature

4.5.8 Soil moisture (%)

5.8.1 Open field

All throughout the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) crop season the lowest average soil moisture retained a single value of 28.1 per cent while the peak average soil moisture was 40.4 per cent for the first and second date of transplanting and 33.4 per cent for the third and fourth dates of transplanting (Fig. 8).

4.5.8.2 Rain shelter

All throughout the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) the lowest average soil moisture retained a single value of 19.4 per cent while the peak average soil moisture was 40.5 per cent for the first and second crop season and 30.6 per cent for the third and fourth crop season (Fig. 8).

4.5.8.3 Polyhouse

The lowest value of average soil moisture inside the Polyhouse during the first and second dates of transplanting (1 and 10 December 2015) was 27.7 per cent whereas, during the third and fourth dates of transplanting (10 and 20 January 2015) it was 23.2 per cent. The peak values recorded for the same was 40.8 per cent for the initial two dates of transplanting and 34.6 for the penultimate and ultimate dates of transplanting (Fig. 8).

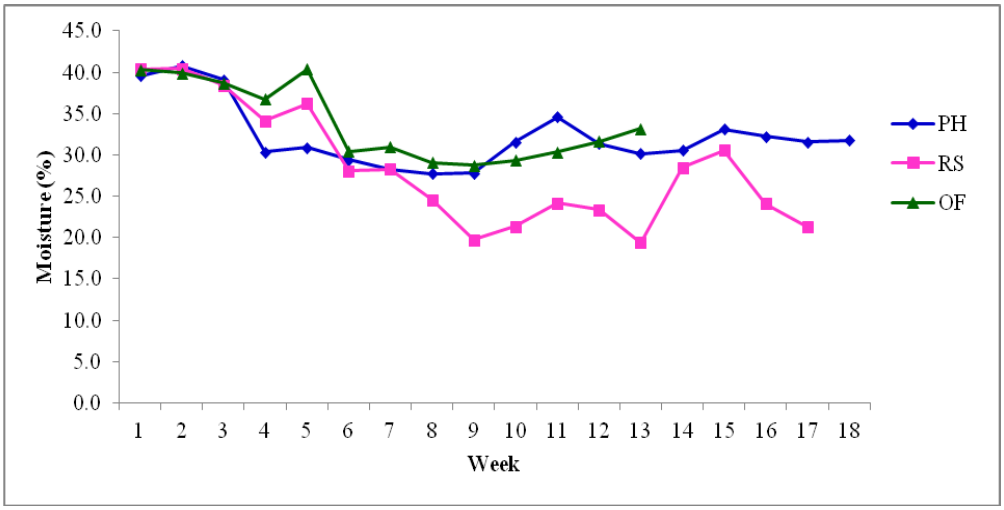


Fig 8. Weekly variation in soil moisture

4.5.9 Ultra violet radiations (Wm^{-2})

4.5.9.1 Open field

The lowest values of UV radiation during the first, second, third and fourth dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were 14.3, 13.5, 12.5, 63.3 W m^{-2} respectively whereas the peak values were 71.6, 77.2, 77 and 81.3 W m^{-2} (Fig. 9).

4.5.9.2 Rain shelter

The lowest values of UV during the first, second, third and fourth dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were 1.7, 3.4, 12.5, 10.6 W m^{-2} respectively whereas the peak values were 14.8, 30.9, 22.9 and 14.3 W m^{-2} (Fig. 9).

4.5.9.3 Polyhouse

The lowest values of UV during the first, second, third and fourth dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were 0.7, 0.9, 1.8 and 1.7 W m^{-2} respectively whereas the peak values were 4.1W m^{-2} for the entire four seasons (Fig. 9).

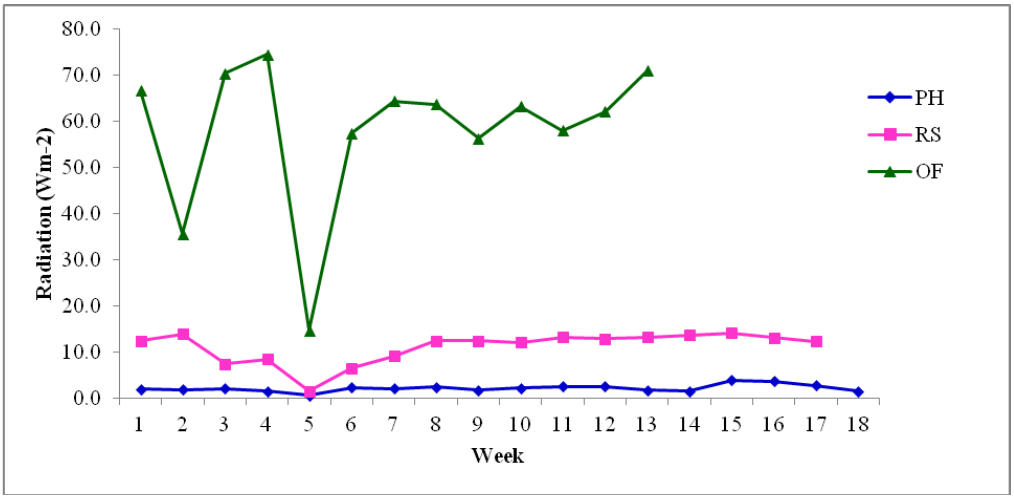


Fig 9. Weekly variation in UV radiation

4.5.10 Canopy temperature (°C)

4.5.10.1 Open field

The lowest values of canopy temperatures during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were 22.2, 28.8, 30.1, and 28.8°C respectively whereas, the peak values were 37.3, 38.7, 34.9 and 37.6°C (Fig. 10).

4.5.10.2 Rain shelter

The lowest values of canopy temperatures during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were 29.7, 28.8, 29.2, and 30.4°C respectively whereas, the peak values were 40.5, 41.4, 37.7 and 37.7°C (Fig. 10).

4.5.10.3 Polyhouse

The lowest values of canopy temperatures during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were 22.2, 28.8, 30.1, and 28.8°C respectively whereas, the peak values were 37.3, 38.7, 34.9 and 37.6°C (Fig. 10).

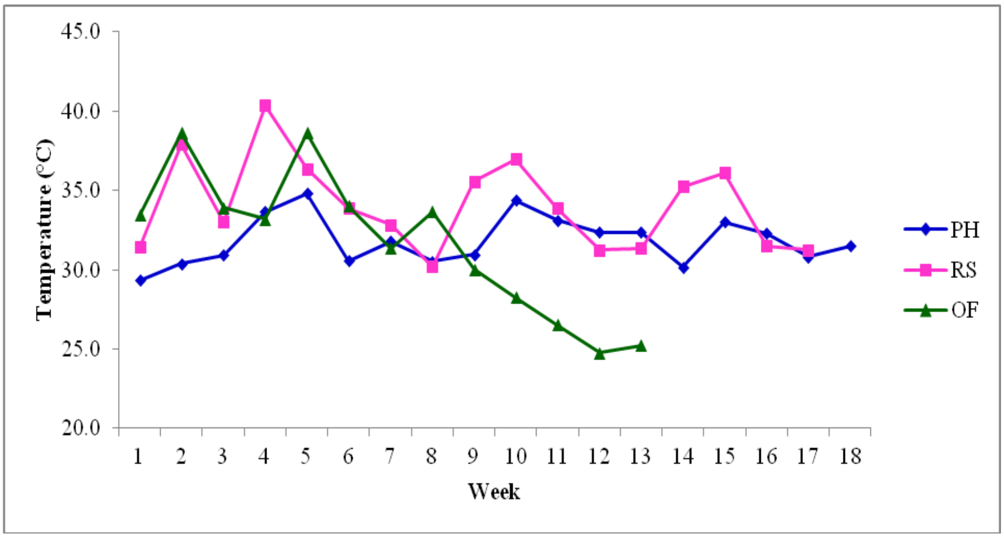


Fig 10. Weekly variation in canopy temperature

4.5.11 Canopy air temperature difference (°C)

4.5.11.1 Open field

The lowest values of canopy air temperature difference in the open field during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were -3.8, -3.5, 0.2, and -2.1° respectively whereas, the peak values were 2.4, 4.2, 0.9 and 1.5° (Fig. 11).

4.5.11.2 Rain shelter

The lowest values of canopy air temperature difference inside the rain shelter during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were -4, -3.6, -2.9, and -3.4°C respectively whereas, the peak values were 2.4, 4.2, 0.9 and 1.5°C (Fig. 11).

4.5.11.3 Polyhouse

The lowest values of canopy air temperature difference within the polyhouse during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) were -5.3, -4.5, -5.1, and -4.3°C respectively whereas, the peak values were 0.1, 0.9, -1.8 and 0°C (Fig. 11).

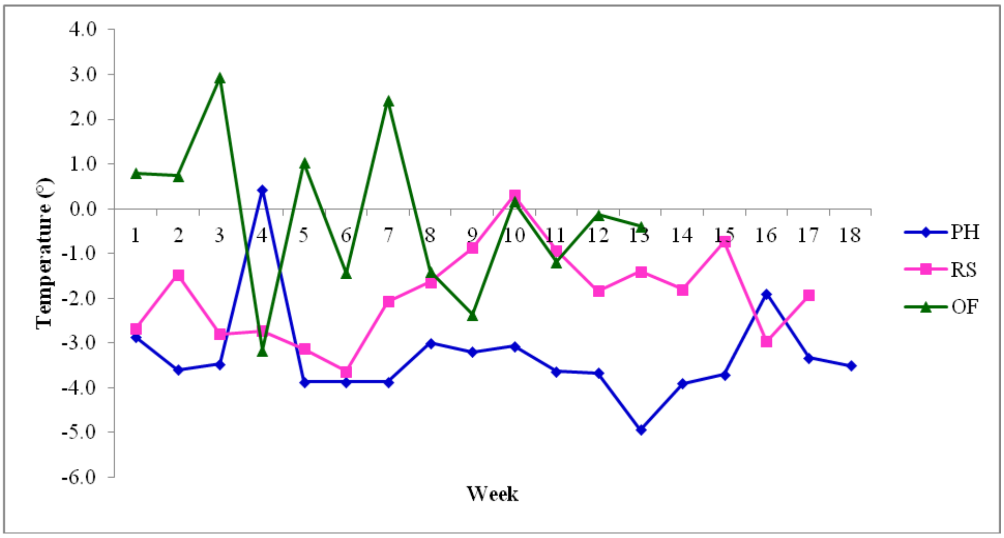


Fig 11. Weekly variation in canopy air temperature difference

4.5.12 Photosynthetically active radiation (Wm^{-2})

4.5.12.1 Open field

The lowest values of PAR in the open field during the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) was 313.8 Wm^{-2} whereas, the peak value was 1321.0 Wm^{-2} during the first date of transplanting and 1300.0Wm^{-2} in the following second, third and fourth dates of transplanting (Fig. 12).

4.5.12.2 Rain shelter

During the first and second crop dates of transplanting (1 and 10 December 2014) the lowest value of PAR was 122.5 Wm^{-2} and for the third and fourth dates of transplanting (10 and 20 January 2015) it was 103.9 Wm^{-2} within the rain shelter whereas, peak value was 712.7 Wm^{-2} for all the dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) (Fig. 12).

4.5.12.3 Polyhouse

The lowest and the highest value of PAR remained 103.9 Wm^{-2} and 996.3 Wm^{-2} all throughout the four dates of transplanting (1 and 10 December 2014, 10 and 20 January 2015) crop season inside the polyhouse (Fig. 12).

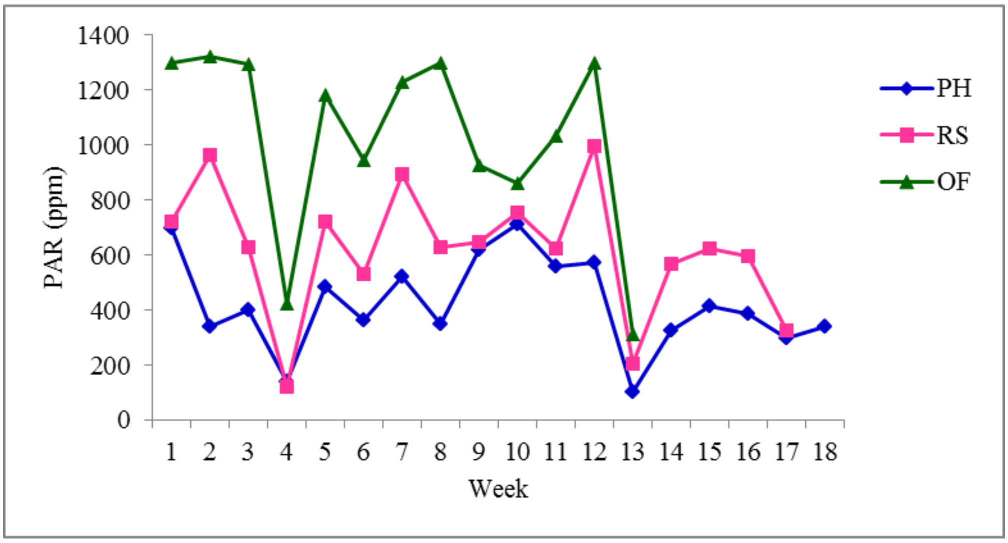


Fig 12. Weekly variation in photosynthetically active radiation

4.6. DIURNAL VARIATION IN WEATHER PARAMETERS

4.6.1 Temperature (°C)

The highest value of air temperature inside the polyhouse, rain shelter and open field were 35.3, 35 and 35.5 respectively whereas the lowest values were 22.4, 22.6 and 22.5 respectively. The peak temperature inside the polyhouse occurred around 17:00 hours correspondingly two hours after the peak in the rain shelter and open field. The rise in temperature during the initial hours were also delayed by almost an hour in the polyhouse (Fig. 13)

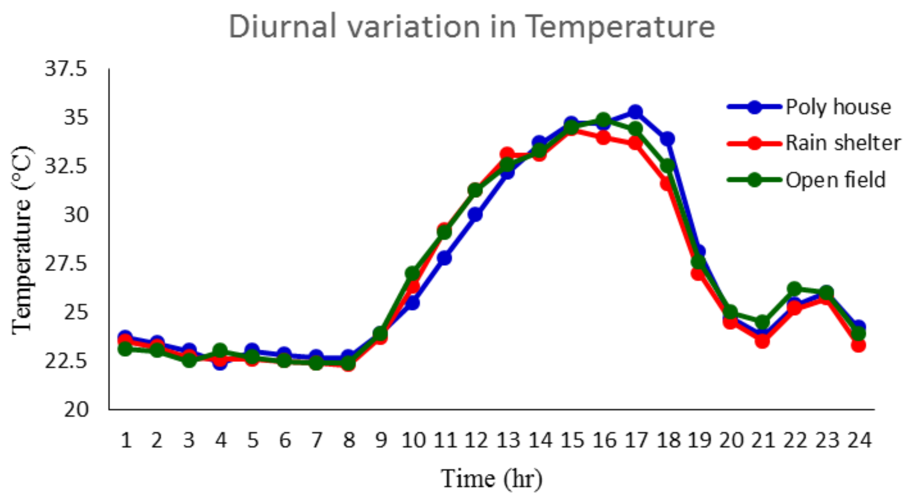


Fig 13. Diurnal variation in temperature

4.6.2 Relative humidity (%)

The highest value of relative humidity in each of the growing environment were 94, 89 and 100 percent and it occurred in the early morning hours (around 2:00 am), whereas the least values were 32 and 48 and 48.4 percent correspondingly in the polyhouse, rain shelter and open field and occurred around 16:00 hours in the evening (fig. 14).

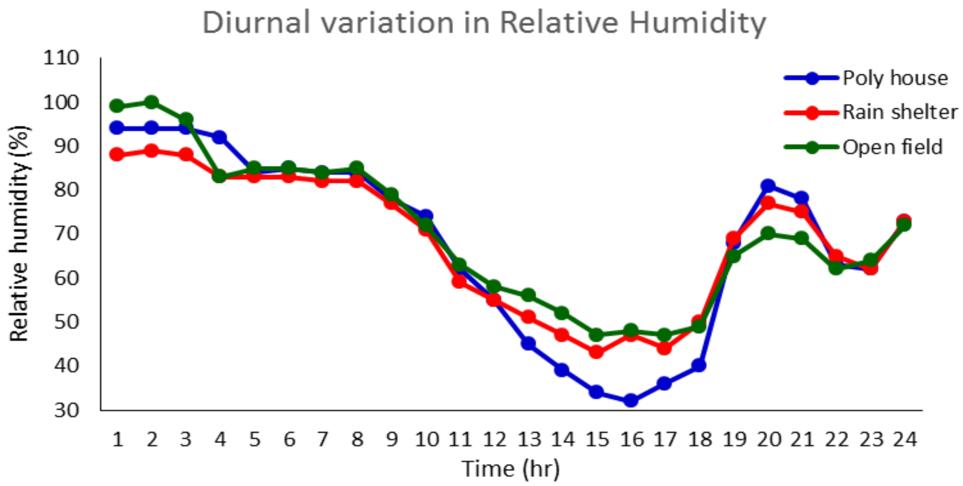


Fig 14. Diurnal variation in relative humidity

4.6.3 Solar radiation (Wm^{-2})

The intensity of solar radiation showed a rapid increase from around 09.00 hours inside all the three growing environments. The peak value recorded open field and protected environments were drastically different. In open field condition the radiation reached up 1048Wm^{-2}. Whereas, inside polyhouse and rain shelter it was consistently below 400 Wm^{-2} without much fluctuation (Fig. 15).

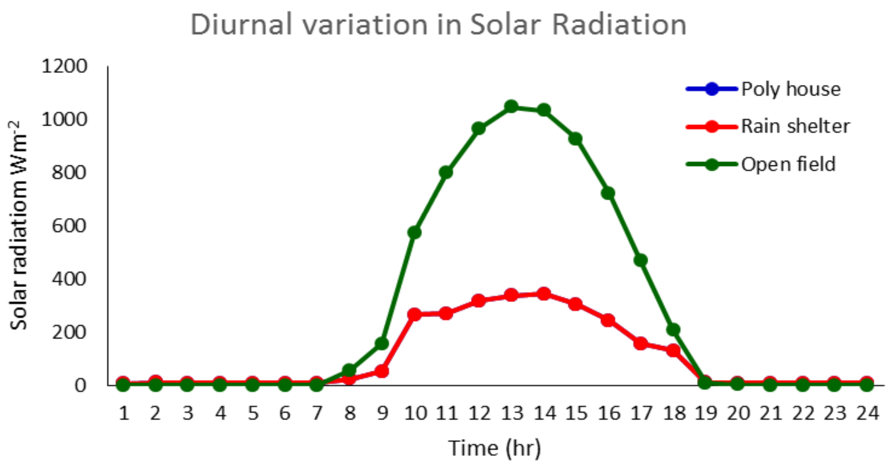


Fig. 15. Diurnal variation in solar radiation

4.6.3 Soil temperature (°C)

The highest value of soil temperature inside the open field, rain shelter and polyhouse were 38.3°C, 32.6°C and 32.2°C and occurred around 17:00 hours. The polyhouse, rain shelter and open field having extreme difference in their highest value. The least values of soil temperatures recorded inside the polyhouse, rain shelter and open field were 23.7 °C, 23.0°C and 22.6 °C respectively (Fig. 16).

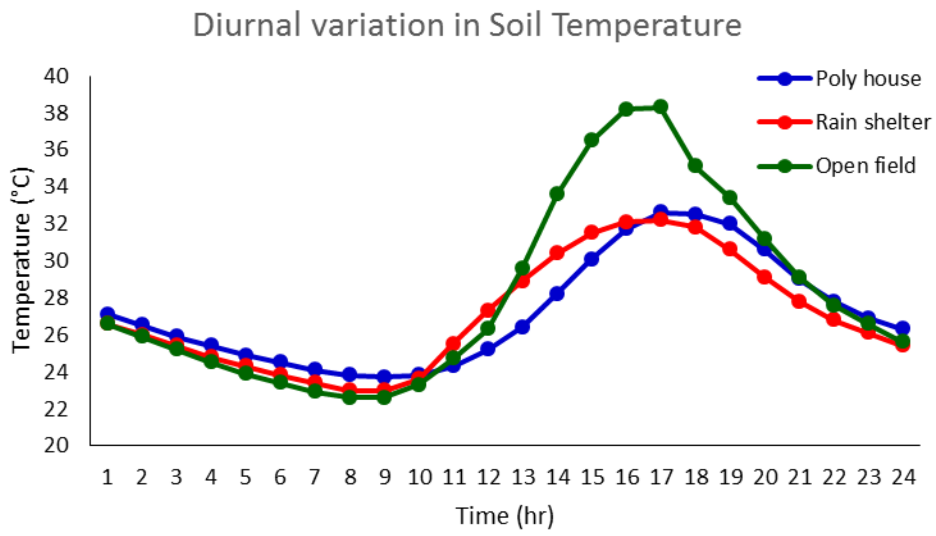


Fig 16. Diurnal variation in soil temperature

4.6.4 Soil moisture (Percentage)

Least soil moisture was recorded during the early morning hours in all the growing environment and it peaked by early evening hours. The maximum soil moisture inside the polyhouse was 41.1% whereas it was 40.7% in rain shelter and open field. The minimum soil moisture inside polyhouse was 40.4% and it was 40.1% in rain shelter and polyhouse (Fig. 17).

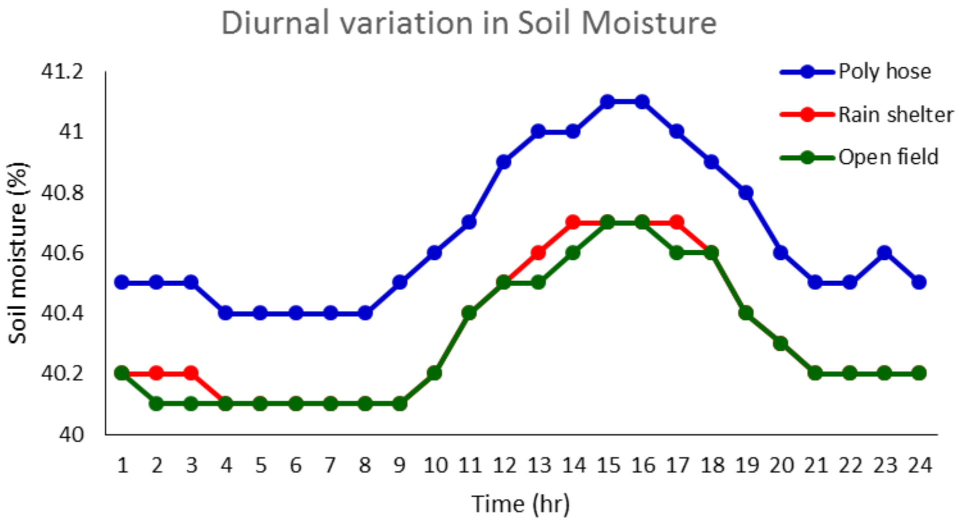


Fig 17. Diurnal variation in soil moisture

4.6.5 Ultraviolet radiation (Wm^{-2})

The highest UV radiation was recorded in the open field followed by rain shelter and polyhouse. The peak values of UV radiations in the open field condition was 129 Wm^{-2} and it was attained around 12:00 hours. Inside the rain shelter the maximum UV radiations recorded was 17.75 Wm^{-2} (14:00 hours). The least UV radiations were recorded in the polyhouse 13.35 Wm^{-2} (14:00 hours) (Fig.18).

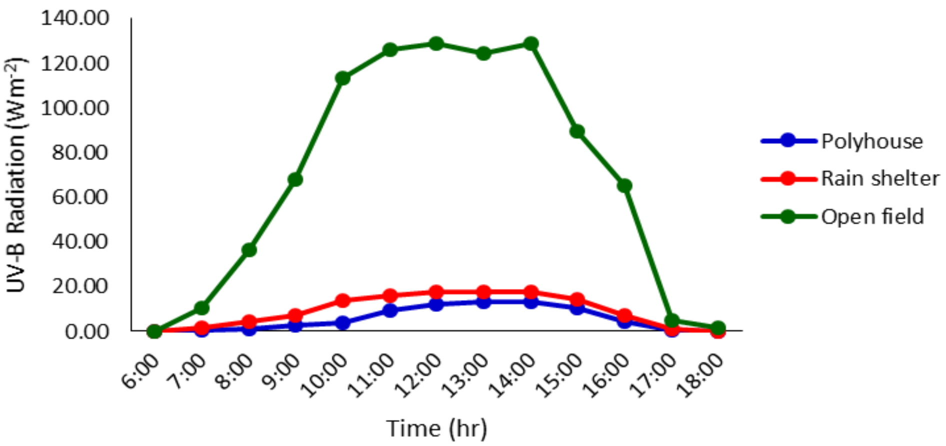


Fig 18. Diurnal variation in UV radiation

4.6.6 Carbon dioxide (ppm)

The highest values of CO_2 (486 and 410 ppm) inside the polyhouse and in the open field were recorded in the morning hours at 6:00 am whereas the lowestt values of CO_2 (310 and 306 ppm) inside the polyhouse and in open field was recorded around 15:00 and 14:00 hours respectively (fig. 19).

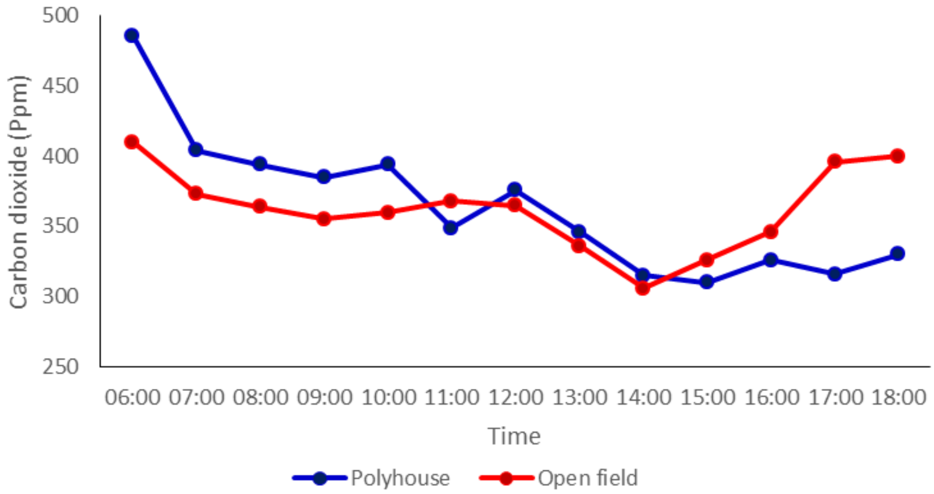


Fig 19. Diurnal variation in CO_2 concentration

4.7. CROP WEATHER RELATIONSHIPS

4.7.1 Phenology of tomato

Depending on the various phenological events, the duration of the various biotic events were classified into the vegetative stage, the flowering stage, fruiting stage and the harvesting stage.

4.7.1.1 Days to first flower

Days to first flowering varied significantly for all the four dates of transplanting and the growing environment. The number of days to first flowering had positive correlation with maximum relative humidity during week one, two, three, four, five, vegetative and flowering stage (0.544, 0.555, 0.646, 0.587, 0.513, 0.619 and 0.593) respectively. The minimum relative humidity had significant positive correlation during week three and week five (0.360 and 0.382) respectively. Whereas, soil moisture had significant positive correlation during first, second, third week and vegetative stage (0.629, 0.617, 0.494 and 0.537). Minimum soil temperature showed positive correlation during second, third and vegetative stage (0.406, 0.525, 0.501) respectively.

Days to first flowering had negative correlation with maximum temperature (-0.558, -0.646), minimum temperature (-0.515, -0.454), UV radiation (-0.489, -

0.489), CATD (-0.479, -0.401) and PAR (-0.488, -0.680) during vegetative and flowering stage. Solar radiation exhibited negative correlation during the first week, second week and vegetative stage (-0.646, -0.536 and-0.350) (Table 19).

Table 19. Correlation between days to first flowering and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Vegetative stage	Flowering stage
SR	-0.646	-0.536	NS	0.415	NS	-0.350	NS
T_{min}	-0.467	NS	-0.402	-0.633	-0.563	-0.558	-0.646
T_{max}	-0.571	NS	-0.570	-0.454	-0.466	-0.515	-0.454
RH-I	0.544	0.555	0.646	0.587	0.513	0.619	0.593
RH-II	NS	NS	0.360	NS	0.382	NS	NS
ST_{min}	NS	0.406	0.525	NS	-0.501	0.542	NS
ST_{max}	-0.366	-0.542	NS	NS	-0.488	-0.428	NS
SM	0.629	0.617	0.494	NS	NS	0.537	NS
UV	-0.429	-0.454	-0.497	-0.476	-0.538	-0.489	-0.489
CT	-0.370	NS	NS	NS	NS	NS	NS
CATD	-0.483	NS	-0.413	NS	-0.419	-0.479	-0.401
PAR	NS	-0.488	-0.365	-0.712	-0.577	-0.488	-0.680

4.7.1.2 Days to first harvest

Days to first harvest had a positive correlation with solar radiation (0.675 and 0.547) during week four and five, maximum relative humidity (0.796, 0.778, 0.875, 0.844, 0.757, 0.806, 0.573 and 0.626) throughout week one, two, three, four, five, six, seven and eight, minimum relative humidity (0.616, 0.655, 0.739, 0.685 and 0.757) respectively during week one, two, three, four and five, minimum soil temperature (0.623 and 0.782) respectively during week two and three, average soil moisture (0.889, 0.864, 0.757, 0.467 and 0.409) respectively during week one, two, three, four and five and canopy temperature (0.538 and 0.362) respectively during week four and five.

Similarly significant negative correlations for days to first harvest were observed with solar radiation (-0.468, -0.350 and -0.446) during week one, two and nine, minimum temperature (-0.774, -0.636, -0.856, -0.859, -0.677, -0.899, -0.819 and -0.617) and maximum temperature (-0.773, -0.-862, -0.738, -0.627, -0.706, -0.782, -0.777 and -0.798), during week one, three, four, five, six, seven, eight and nine, minimum soil temperature (-0.476, -0.489, -0.779, -0.697 and -0.763) during week five, six, seven, eight and nine, maximum soil temperature (-0.398, -0.415 and -0.358) respectively during week two, seven and eight, average soil moisture (-0.539, -0.691

and -0.358) during week seven, eight and nine and canopy air temperature difference (-0.538) during week six.

Days to first harvest had a positive correlation with maximum relative humidity (, 0.879, 0.896 and 0.670) all through the vegetative, flowering and fruiting stage, minimum relative humidity (0.678 and 0.686) and soil moisture (0.821 and 0.505) during vegetative and flowering stages, canopy temperature (0.587 and 0.567) during flowering and harvesting stage, minimum soil temperature (0.644) during vegetative stage and solar radiation (0.636) during flowering stage.

Days to first harvest exhibited a strong negative correlation with minimum temperature (-0.839, -0.912, -0.858, -0.474), maximum temperature (-0.7410, -0.667, -0.758, -0.379) throughout vegetative, flowering, fruiting and harvesting stage, minimum soil temperature (-0.761, -0.731) and canopy air temperature difference (-0.353, -0.409) during fruiting and harvesting stage, minimum relative humidity (-0.427) and maximum relative humidity (-0.453) during harvesting stage and PAR (-0.514) during flowering stage (Table 20 and 21).

Table 20. Correlation between days to first harvest and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.468	-0.350	NS	0.675	0.547	NS	NS	NS	-0.446
T_{min}	-0.774	NS	-0.636	-0.856	-0.859	-0.677	-0.899	-0.819	-0.617
T_{max}	-0.773	NS	-0.862	-0.738	-0.627	-0.706	-0.782	-0.777	-0.798
RH-I	0.796	0.778	0.875	0.844	0.757	0.806	0.573	0.626	-0.795
RH-II	0.616	0.655	0.739	0.685	0.757	NS	-0.364	NS	NS
ST_{min}	NS	0.623	0.782	NS	-0.476	-0.489	-0.779	-0.697	-0.763
ST_{max}	NS	-0.398	NS	NS	NS	NS	-0.415	-0.358	NS
SM	0.889	0.864	0.757	0.467	0.409	NA	-0.539	-0.691	-0.358
UV	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT	NS	NS	NS	0.538	0.362	NS	NS	NS	NS
CATD	NS	NS	NS	NS	NS	-0.538	NS	NS	NS

Table 21. Correlation between days to first harvest and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	NS	0.636	NS	NS
T_{min}	-0.839	-0.912	-0.858	-0.474
T_{max}	-0.740	-0.667	-0.758	-0.379
RH-I	0.879	0.896	0.670	-0.453
RH-II	0.678	0.686	NS	-0.427
ST_{min}	0.644	NS	-0.761	-0.731
ST_{max}	NS	NS	NS	NS
SM	0.821	0.505	NS	NS
UV	NS	NS	NS	NS
CT	NS	0.587	NS	0.567
CATD	NS	NS	-0.353	-0.409
PAR	NS	-0.514	NS	NS

4.7.1.3 Days to last harvest

Days to last harvest had significant positive correlations with solar radiation (0.413) during week four, minimum relative humidity (0.496, 0.473, 0.556, 0.486 and 0.582) during week one to five, maximum relative humidity (0.762, 0.612, 0.779, 0.781, 0.679, 0.738, 0.527 and 0.600) during week one to eight, minimum soil temperature (0.531 and 0.633) during week two and three, average soil moisture (0.755, 0.697, 0.589 and 0.356) during week one to four and canopy temperature (0.518) during week four.

Likewise, days to last harvest had significant negative correlations with solar radiation (-0.686, -0.587, -0.469 and -0.702) during week one, two, eight and nine, minimum temperature (-0.630, -0.486, -0.795, -0.687, -0.613, -0.750, -0.674 and -0.566) and maximum temperature (-0.586, -0.729, -0.527, -0.449, -0.584, -0.606, -0.617 and -0.645) during week one to nine except for week two, minimum soil temperature (-0.549, -0.481, -0.848, -0.753 and -0.880) during week five to nine, maximum soil temperature (-0.352, -0.641, -0.421, -0.372, -0.678, -0.590 and -0.586) during week one, two, five, six, seven, eight and nine, average soil moisture (-0.729, -0.735 and -0.466) during week seve to nine, UV radiation (-0.390, -0.495, -0.640, -0.482, -0.471, -0.557, -0.560, -0.521 and -0.570) during week one to nine, canopy air temperature difference (-0.462, -0.378, -0.400, -0.661, -0.428 and -0.444) during week one, three, five, six, seven, eight and nine and PAR (-0.510, -0.398, -0.808 and -0.479).

Days to last harvest was worked out for each treatment and its correlation with the various weather parameters are provided in the Table (22 and 23). The days to last harvest showed significant negative correlations with UV radiation (-0.526, -0.456, -0.547, -0.409), canopy air temperature difference (-0.428, -0.433, -0.565, -0.642) throughout vegetative, flowering, fruiting and harvesting stage, minimum temperature (-0.632, -0.796, -0.697) and maximum temperature (-0.547, -0.468, -0.572) during vegetative, flowering, fruiting stage, maximum soil temperature (-0.422, -0.575, -0.595) during vegetative, flowering and fruiting stage, PAR during vegetative (-0.510) and flowering stage (-0.677), minimum soil temperature fruiting (-0.848) and harvesting stage (-0.872), solar radiation (-0.586) and minimum relative humidity (-0.560) during harvesting stage.

Days to last harvest exhibited a significant positive correlation with maximum relative humidity (0.777, 0.805, and 0.612) throughout vegetative flowering and fruiting stage, minimum relative humidity during vegetative (0.507) and flowering stage (0.484), canopy air temperature during flowering (0.565) and harvesting stage (0.615), Minimum soil temperature (0.589) and soil moisture (0.653) during vegetative stage.

Table 22. Correlation between days to last harvest and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.686	-0.587	NS	0.413	NS	NS	NS	-0.469	-0.702
T_{min}	-0.630	NS	-0.486	-0.795	-0.687	-0.613	-0.750	-0.674	-0.566
T_{max}	-0.586	NS	-0.729	-0.527	-0.449	-0.584	-0.606	-0.617	-0.645
RH-I	0.762	0.612	0.779	0.781	0.679	0.738	0.527	0.600	-0.727
RH-II	0.496	0.473	0.556	0.486	0.582	NS	-0.372	NS	-0.388
ST_{min}	NS	0.531	0.633	NS	-0.549	-0.481	-0.848	-0.753	-0.880
ST_{max}	-0.352	-0.641	NS	NS	-0.421	-0.372	-0.678	-0.590	-0.586
SM	0.755	0.697	0.589	0.356	NS	NS	-0.729	-0.735	-0.466
UV	-0.390	-0.495	-0.640	-0.482	-0.471	-0.557	-0.560	-0.521	-0.570
CT	NS	NS	NS	0.518	NS	NS	NS	NS	NS
CATD	-0.462	NS	-0.378	NS	-0.400	-0.661	-0.428	-0.444	NS
PAR	NS	-0.510	-0.398	-0.808	-0.479	NS	NS	NS	NS

Table 23. Correlation between days to last harvest and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	NS	NS	NS	-0.586
T_{min}	-0.632	-0.796	-0.697	NS
T_{max}	-0.547	-0.468	-0.572	NS
RH-I	0.777	0.805	0.612	NS
RH-II	0.507	0.484	NS	-0.560
ST_{min}	0.589	NS	-0.848	-0.872
ST_{max}	-0.422	NS	-0.575	-0.595
SM	0.653	NS	NS	NS
UV	-0.526	-0.456	-0.547	-0.409
CT	NS	0.565	NS	0.615
CATD	-0.428	-0.433	-0.565	-0.642
PAR	-0.511	-0.678	NS	NS

4.7.2 Floral characters

4.7.2.1 Mean stamen length (mm)

From the Table 24, it is observed that the mean stamen length varied significantly for all the four dates of transplanting and the growing environment. The mean stamen length had significant positive correlation with solar radiation (0.468, 0.435) during week four and five, minimum relative humidity (0.399, 0.546, 0.458 and 0.645) during week two to five, maximum relative humidity (0.537, 0.706, 0.694, 0.611 and 0.694) during week one to five, maximum soil temperature (0.734, 0.786, 0.728 and 0.422) during week one, two, three and five, average soil moisture (0.726, 0.755, 0.732, 0.360,0.477) during week one to five and canopy temperature (0.496) during week four.

Similarly, it had significant negative correlation with solar radiation (-0.514, -0.453) during week one and two, minimum temperature (-0.682, -0.363, -0.628 and -0.771) and maximum temperature (-0.743, -0.637, -0.655 and -0.510) during week one to five except for week two, minimum soil temperature (-0.530 and -0.382) during week two and three, UV radiation (-0.394, -0.374, -0.371 and -0.542) during week two to five, canopy temperature (-0.353, -0.397) during week one and three and canopy air temperature difference (-0.446) during week five.

The mean stamen length had high negative correlation with the minimum temperature (-0.663, -0.728), maximum temperature (-0.609, -0.605), UV radiation during vegetative and flowering stage. CATD (-0.384) and PAR (-0.672) during harvesting stage and minimum soil temperature during vegetative stage (-0.354).

Mean stamen length showed a positive correlation with minimum relative humidity (0.432, 0.502), maximum relative humidity (0.678, 0.686), maximum soil temperature (0.750, 0.412), soil moisture (0.704, 0.484) during vegetative and flowering stage. Whereas solar radiation (0.468) and canopy temperature (0.513) had positive correlation during harvesting stage.

Table 24. Correlation between mean length of stamen and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Vegetative stage	Flowering stage
SR	-0.514	-0.453	NS	0.468	0.435	NS	0.468
T_{min}	-0.682	NS	-0.363	-0.628	-0.771	-0.663	-0.728
T_{max}	-0.743	NS	-0.637	-0.655	-0.510	-0.609	-0.605
RH-I	0.537	0.706	0.694	0.611	0.694	0.678	0.686
RH-II	NS	0.399	0.546	0.458	0.645	0.432	0.502
ST_{min}	NS	-0.530	-0.382	NS	NS	-0.354	NS
ST_{max}	0.734	0.786	0.728	NS	0.422	0.750	0.412
SM	0.727	0.755	0.732	0.360	0.478	0.704	0.484
UV	NS	-0.394	-0.374	-0.371	-0.542	-0.383	-0.395
CT	-0.353	NS	-0.397	0.496	NS	NS	0.513
CATD	NS	NS	NS	NS	-0.446	NS	-0.384
PAR	NS	NS	NS	-0.819	-0.519	NS	-0.672

4.7.2.2 Mean style length (mm)

Mean length of style length showed a significant positive correlation with solar radiation (0.466, 0.423) during week four and five, minimum relative humidity (0.406, 0.533, 0.449 and 0.628) during week two to five, maximum relative humidity (0.599, 0.689, 0.698, 0.623 and 0.704) during week one to five, minimum soil temperature (0.461 and 0.704) during week two and three, average soil moisture

(0.725, 0.742, 0.702 and 0.460) during week one to five except for week four, canopy temperature (0.484) during week four.

Similarly, it had significant negative correlation with solar radiation (-0.533, and 0.472) during week one and two, minimum temperature (-0.700, -0.366, -0.644 and -0.768) and maximum temperature (-0.700, -0.366, -0.644, -0.652 and -0.501) during week one to five except for week two, minimum soil temperature (-0.550) during week five, maximum soil temperature (-0.524 and -0.400) during week two and three, UV radiation (-0.419, -0.385, -0.387 and -0.522) during week two to five, canopy temperature (-0.402) during week one, canopy air temperature difference (-0.448) during week five.

Mean style length showed a significant positive correlation with minimum relative humidity (0.431, 0.492), maximum relative humidity (0685, 0.709), soil moisture (0.686, 0.451) throughout vegetative and flowering stage. Solar radiation (0.461) and canopy temperature (0.486) had positive correlation during flowering stage and minimum soil temperature also exhibited a positive correlation during vegetative stage (0.471).

It had significant negative correlation with minimum temperature (-0.671, -0.738), maximum temperature (-0.603, -0.592), UV radiation (-0.0.402, -0.397) throughout vegetative and flowering stage. CATD (-0.392) and PAR (0.693) had negative correlation during flowering stage. Maximum soil temperature showed negative correlation during vegetative stage (-0.363) (Table 25).

Table 25. Correlation between mean length of style and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Vegetative stage	Flowering stage
SR	-0.533	-0.472	NS	0.466	0.423	NS	0.461
T_{min}	-0.700	NS	-0.366	-0.644	-0.768	-0.671	-0.738
T_{max}	-0.732	NS	-0.644	-0.652	-0.501	-0.603	-0.592
RH-I	NS	0.406	0.533	0.449	0.628	0.431	0.492
RH-II	0.559	0.689	0.698	0.623	0.704	0.685	0.709
ST_{min}	NS	0.461	0.704	NS	-0.550	0.471	NS
ST_{max}	NS	-0.524	-0.400	NS	NS	-0.363	NS
SM	0.725	0.742	0.702	NS	0.461	0.686	0.451
UV	NS	-0.419	-0.385	-0.387	-0.522	-0.402	-0.397
CT	-0.402	NS	NS	0.484	NS	NS	0.486
CATD	NS	NS	NS	NS	-0.448	NS	-0.392
PAR	NS	NS	NS	-0.835	-0.515	NS	-0.693

4.7.3 Physiological parameters

4.7.3.1 Leaf area index (LAI)

The leaf area index showed a significant negative correlation with solar radiation (-0.478, -0.511, -0.474, -0.467, -0.641, -0.665, -0.677, -0.660 and -0.459) and UV radiation (-0.575, -0.567, -0.699, -0.612, -0.535, -0.620, -0.590 and -0.611) during week one to nine, minimum relative humidity (-0.376, -0.355, -0.373, -0.429 and -0.442) during week two, four, six, eight and nine, minimum soil temperature (-0.402) during week three, the maximum soil temperature (-0.418, -0.514, -0.412, -0.691, -0.429, -0.546, -0.589 and -0.530) during week one to nine except for week four, canopy air temperature difference (-0.481, -0.508, -0.462, -0.367, -0.410 and -0.451) during week one to seven except week six, canopy temperature (-0.405 and -0.408) during week six and eight and PAR (-0.423 and -0.403) during week one and five (table 26).

Table 26. Correlation between LAI and different weather parameters during weeks after planting

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.478	-0.511	-0.474	-0.467	-0.641	-0.665	-0.677	-0.660	-0.459
T_{min}	NS	NS	NS	NS	NS	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	NS	-0.376	NS	-0.355	NS	-0.373	NS	-0.429	-0.442
RH-II	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST_{min}	NS	NS	-0.402	NS	NS	NS	NS	NS	NS
ST_{max}	-0.418	-0.514	-0.412	NS	-0.691	-0.429	-0.546	-0.589	-0.530
SM	NS	NS	NS	NS	NS	-0.402	-0.423	NS	NS
UV	-0.575	-0.567	-0.699	-0.612	-0.535	-0.643	-0.620	-0.593	-0.611
CT	NS	NS	NS	NS	NS	-0.405	NS	0.408	NS
CATD	-0.481	-0.508	-0.462	-0.367	-0.410	NS	-0.451	NS	NS
PAR	-0.423	NS	NS	NS	-0.403	NS	NS	NS	NS

The leaf area index showed a negative correlation with the solar radiation (-0.621, -0.561, -0.697, -0.552), UV radiation (-0.639, -0.651, -0.642, -0.401), the CATD (-0.583, -0.465, -0.362, -0.461) during vegetative, flowering, fruiting and harvesting stage. Whereas, maximum soil temperature (-0.473, -0.606, -0.539) showed a significant negative correlation during vegetative, fruiting and harvesting stage and early morning relative humidity showed negative correlation during flowering (-0.401) and fruiting stages (-0.458). The Soil moisture during fruiting stage (-0.434) also had a negative correlation with LAI (Table 27).

Table 27. Correlation between LAI and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.621	-0.561	-0.697	-0.552
T_{min}	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS
RH-I	NS	-0.401	-0.458	NS
RH-II	NS	NS	NS	NS
ST_{min}	NS	NS	NS	NS
ST_{max}	-0.473	NS	-0.606	-0.539
SM	NS	NS	-0.434	NS
UV	-0.639	-0.651	-0.642	-0.401
CT	NS	NS	NS	NS
CATD	-0.583	-0.465	-0.362	-0.461
PAR	NS	NS	NS	NS

4.7.3.2 Fruit lycopene content (mg g^{-1} sample)

Fruit lycopene content had significant negative correlation solar radiation (-0.681, -0.734, -0.707, -0.543, -0.644, -0.871, -0.870, -0.913 and -0.897), maximum soil temperature (-0.673, -0.773, -0.802, -0.641, -0.840, -0.716, -0.845, -0.866 and -0.853) and the canopy air temperature difference (-0.809, -0.512, -0.665, -0.618, -0.852, -0.676, -0.795, -0.547 and -0.689) during week one to nine, UV radiation (-0.978, -0.783, -0.938, -0.803, -0.934, -0.936, -0.937 and -0.946) during week two to nine, minimum relative humidity (-0.466, -0.502, -0.430, -0.502, -0.589, -0.355, -0.730 and -0.535) during week one to nine except for week five, the minimum soil temperature (-0.439 and -0.457) during week eight and nine, the canopy air temperature (-0.402, -0.414, -0.732 and -0.438) during week one, five, six and nine.

The Lycopene content showed a significant negative correlation with the solar radiation (-0.897, -0.618, -0.919, -0.881), the minimum relative humidity (-0.491, -0.472, -0.553, -0.61), maximum soil temperature (-0.821, -0.631, -0.859, -0.929), UV radiation (-0.957, -0.899, -0.954, -0.854), CATD (-0.781, -0.862, -0.872, -0.812) throughout vegetative, flowering, fruiting and harvesting stage respectively. Minimum soil temperature had negative correlation during fruiting (-0.408), harvesting stage (-0.579). Also canopy temperature showed negative correlation during fruiting stage (-0.431). It had a positive correlation with minimum temperature (0.552) and maximum relative humidity (0.476) during harvesting stage (table 28 and 29).

Table 28. Correlation between Lycopene and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.681	-0.734	-0.707	-0.543	-0.644	-0.871	-0.870	-0.913	-0.821
T_{min}	NS	NS	0.377	NS	NS	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	-0.466	-0.502	-0.430	-0.502	NS	-0.589	-0.355	-0.730	-0.535
ST_{min}	NS	NS	NS	NS	NS	NS	NS	-0.439	-0.457
ST_{max}	-0.673	-0.773	-0.802	-0.641	-0.840	-0.716	-0.845	-0.866	-0.853
SM	NS	NS	NS	NS	NS	NS	NS	NS	NS
UV	NS	-0.978	-0.783	-0.938	-0.803	-0.934	-0.936	-0.937	-0.946
CT	-0.402	NS	NS	NS	-0.414	-0.732	NS	NS	-0.438
CATD	-0.809	-0.512	-0.665	-0.618	-0.852	-0.676	-0.795	-0.547	-0.689
PAR	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 29. Correlation between Lycopene and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.897	-0.618	-0.919	-0.881
T_{min}	NS	NS	NS	0.552
T_{max}	NS	NS	NS	NS
RH-I	NS	NS	NS	0.476
RH-II	-0.491	-0.472	-0.553	-0.610
ST_{min}	NS	NS	-0.408	-0.579
ST_{max}	-0.821	-0.631	-0.859	-0.929
SM	NS	NS	NS	NS
UV	-0.957	-0.899	-0.954	-0.854
CT	NS	NS	-0.431	NS
CATD	-0.781	-0.862	-0.872	-0.812
PAR	NS	NS	NS	NS

4.7.3.3 Fruit ascorbic acid (mg g^{-1} sample)

The correlation between ascorbic acid and different weather parameters was found out and is presented in the Table (31) for all the four dates of transplanting. Fruit ascorbic content had significant negative correlation solar radiation (-0.401 and -0.441) during the week one and two, average soil moisture (-0.446, -0.438, -0.479 and -0.734) during week six to nine. It had significant positive correlation with maximum temperature (0.420 and 0.448) during week five and six, canopy temperature (0.390 and 0.510) during week two and eight (table 30).

The fruit ascorbic acid showed significant negative correlation with soil moisture during fruiting (-0.675) and harvesting stage (-0.653).

It had a positive correlation with maximum temperature throughout vegetative stage (0.402), flowering (0.428) and harvesting stage (0.502), maximum soil temperature during flowering stage (0.519) and canopy temperature had significant positive during flowering (0.357) and fruiting (0.461) respectively (Table 31).

Table 30. Correlation between Ascorbic acid and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.401	-0.441	NS	NS	NS	NS	NS	NS	NS
T_{min}	NS	NS	NS	NS	NS	NS	NS	NS	NS
T_{max}	NS	0.404	NS	NS	0.420	0.448	NS	NS	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST_{min}	-0.384	NS	NS	NS	NS	NS	NS	NS	NS
ST_{max}	0.371	NS	NS	0.505	NS	NS	NS	NS	NS
SM	NS	NS	NS	NS	NS	-0.446	-0.438	-0.479	-0.734
UV	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT	NS	0.390	NS	NS	NS	NS	NS	0.510	NS
CATD	NS	NS	NS	NS	NS	NS	NS	NS	NS
PAR	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 31. Correlation between Ascorbic acid and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	NS	NS	NS	NS
T_{min}	NS	NS	NS	NS
T_{max}	0.402	0.428	NS	0.502
RH-I	NS	NS	NS	NS
RH-II	NS	NS	NS	NS
ST_{min}	NS	NS	NS	NS
ST_{max}	NS	0.519	NS	NS
SM	NS	NS	-0.675	-0.653
UV	NS	NS	NS	NS
CT	NS	0.357	0.461	NS
CATD	NS	NS	NS	NS
PAR	NS	NS	NS	NS

4.7.3.4 SPAD index

The SPAD index showed a significant positive correlation with solar radiation (0.516, 0.625, 0.712, 0.509, 0.486, 0.752, 0.665, 0.712 and 0.644) during week one to nine, minimum relative humidity (0.541, 0.494, 0.492, 0.574, 0.442, 0.731 and 0.460) during week one, two, three, four, six, eight and nine, maximum soil temperature

(0.492, 0.551, 0.765, 0.664, 0.507, 0.518, 0.637, 0.566 and 0.702) and UV radiation (0.781, 0.839, 0.513, 0.773, 0.527, 0.744, 0.777, 0.798 and 0.767) during week one to nine, canopy temperature (0.529, 0.409, 0.566, 0.396 and 0.384) during week one, five, six, seven and nine,, canopy air temperature difference (0.698, 0.619, 0.519, 0.834, 0.487, 0.630, 0.619 and 0.597) during week one to nine except week two, PAR (0.683, 0.739, 0.581, 0.584, 0.774 and 0.722) during week one to nine except week two and eight.

It had negative correlation with the minimum temperature (-0.564 and -0.444) during week three and six, maximum temperature (-0.567, -0.350, -0.364 and -0.354) during week two, five, six, seven and eight (table 32).

Table 32. Correlation between SPAD index and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	0.516	0.625	0.712	0.509	0.486	0.752	0.665	0.712	0.644
T_{min}	NS	NS	-0.564	NS	NS	-0.44	NS	NS	NS
T_{max}	NS	-0.567	NS	NS	-0.350	-0.364	NS	-0.354	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	-0.355	-0.412
RH-II	0.541	0.494	0.492	0.574	NS	0.442	NS	0.731	0.460
ST_{min}	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST_{max}	0.492	0.551	0.765	0.664	0.507	0.518	0.637	0.566	0.702
SM	NS	NS	NS	0.372	NS	NS	NS	NS	NS
UV	0.781	0.839	0.513	0.773	0.527	0.744	0.777	0.798	0.767
CT	0.529	NS	NS	NS	0.409	0.566	0.396	NS	0.384
CATD	0.698	NS	0.619	0.519	0.834	0.487	0.630	0.619	0.597
PAR	0.683	NS	0.739	0.581	0.584	0.774	0.654	NS	0.722

SPAD index value showed a significant positive correlation with solar radiation (0.728, 0.509, 0.727, 0720), minimum relative humidity (0.522, 0.469, 0.370, 0.659), maximum soil temperature (0.683, 0.596, 0.582, 0.759), UV radiation (0.774, 0.683, 0.755, 0.817), CATD (0.635, 0.806, 0.768. 0.636), PAR (0.627, 0.69, 0.824, 0.552). The SPAD index value had significant positive correlation with minimum soil temperature during harvesting stage and canopy temperature during fruiting stage (0.425).

It had negative correlation with minimum temperature during vegetative (-0.437), fruiting (-0.563) and harvesting stage (-0.563). Maximum relative humidity during harvesting stage (-0.499) had positive correlation (Table 33).

Table 33. Correlation between SPAD index and different weather parameters

	Vegetative state	flowering stage	fruiting stage	harvesting stage
SR	0.728	0.509	0.727	0.720
T_{min}	-0.437	NS	-0.354	-0.563
T_{max}	NS	NS	NS	NS
RH-I	NS	NS	NS	-0.499
RH-II	0.522	0.469	0.370	0.659
ST_{min}	NS	NS	NS	0.425
ST_{max}	0.683	0.596	0.582	0.759
SM	NS	NS	NS	NS
UV	0.774	0.683	0.755	0.817
CT	NS	NS	0.425	NS
CATD	0.635	0.806	0.768	0.636
PAR	0.627	0.690	0.824	0.552

4.7.3.5 Total soluble proteins (mg g^{-1})

4.7.3.5.1 Total soluble proteins at day 30 (mg g^{-1})

The total soluble protein content in the leaves showed significant positive correlation with the UV radiation (0.723, 0.714), CATD (0.682, 0.636), PAR (0.749, 0.764) during vegetative and flowering stage, solar radiation (0.593) and maximum soil temperature (0.444) had during vegetative stage.

While, it had negative correlations with the maximum relative humidity (-0.41) and minimum soil temperature (-0.403) in the third week following transplanting and vegetative stage (-0.388) Table (34).

Table 34. Correlation between TSP day 30 and different weather parameters

	Week1	Week2	Week3	Week4	Vegetati ve stage	Floweri ng stage
SR	0.745	0.649	NS	NS	0.593	NS
T_{min}	NS	NS	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS	NS	NS
RH-I	NS	NS	-0.410	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	NS
ST_{min}	NS	NS	-0.403	NS	-0.388	NS
ST_{max}	0.36	0.564	0.412	NS	0.444	NS
SM	NS	NS	NS	NS	NS	NS
UV	0.698	0.658	0.667	0.728	0.723	0.714
CT	0.514	NS	NS	NS	NS	NS
CATD	0.734	NS	0.655	0.409	0.682	0.636
PAR	0.615	0.508	0.747	0.674	0.749	0.764

4.7.3.5.2 Total soluble proteins at day 45 (mg g^{-1})

The total soluble protein content in the leaves showed significant positive correlation with the maximum temperature (0.596, 0.678 and 0.606), maximum soil temperature (0.48, 0.437 and 0.594) during the vegetative flowering and fruiting stage, minimum temperature during vegetative (0.547) and fruiting stage (0.395). PAR (0.368) and Minimum soil temperature (0.676) showed positive correlation during flowering and fruiting stage. It had negative correlations with maximum relative humidity during the vegetative (-0.592), flowering (-0.373) and fruiting stage (-0.4) and soil moisture during the vegetative (-0.528) and fruiting stage (-0.624) (Table 35).

Table 35. Correlation between TSP day 45 and different weather parameters

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Vegetative stage	flowering stage	fruiting stage
SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
T_{min}	NS	0.569	0.515	0.384	0.389	0.504	0.547	NS	0.395
T_{max}	0.61	0.578	0.57	0.649	0.665	0.502	0.596	0.678	0.606
RH-I	-0.35	-0.68	-0.67	-0.45	NS	-0.65	-0.59	-0.37	-0.4
RH-II	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST_{min}	NS	NS	NS	NS	0.714	0.41	NS	NS	0.676
ST_{max}	0.378	0.549	0.426	0.367	0.547	0.608	0.48	0.44	0.594
SM	-0.53	-0.58	-0.46	NS	NS	-0.46	-0.528	NS	-0.624
UV	NS	NS	NS	NS	0.44	NS	NS	NS	NS
CT	NS	NS	NS	NS	NS	0.491	NS	NS	0.354
CATD	NS	NS	NS	NS	NS	0.562	NS	NS	0.389
PAR	NS	NS	NS	0.398	0.519	NS	NS	0.368	NS

4.7.3.6 Relative water content (%)

The average leaf relative water content had significant positive correlation minimum soil temperature (0.417 and 0.342) during week one and three.

Average leaf relative water content had significant negative correlation with the solar radiation (-0.682, -0.617, -0.386, -0.519, -0.655 and -0.738) during week one, two, six, seven, eight and nine, minimum relative humidity (-0.677, -0.600, -0.682 and -0.602) during week six and nine, minimum soil temperature (-0.382 and -0.563) during week eight and nine, maximum soil temperature (-0.557, -0.567, -0.650, -0.670, -0.749, -0.774, -0.753, -0.739 and -0.782) and UV radiation (-0.746, -0.736, -0.645, -0.747, -0.569, -0.740, -0.736, -0.744 and -0.733) during week one to nine, canopy temperature (-0.520, -0.445 and -0.602) during week one, five and six, the

CATD (-0.739, -0.721, -0.687, -0.633, -0.815 and -0.560) during week one, three, four, five, six, seven and nine, average soil moisture (-0.380) during week seven (table 36).

Table 36. Correlation between relative water content and different weather parameters

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
SR	-0.682	-0.617	NS	NS	NS	-0.386	-0.519	-0.655	-0.738
T_{min}	NS	NS	NS	NS	NS	NS	NS	NS	NS
T_{max}	0.236	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	-0.677	-0.6	-0.682	-0.602
ST_{min}	0.417	0.206	0.342	NS	NS	NS	-0.254	-0.382	-0.563
ST_{max}	-0.557	-0.567	-0.65	-0.67	-0.749	-0.774	-0.753	-0.739	-0.782
SM	NS	NS	NS	NS	NS	NS	-0.38	NS	NS
UV	-0.746	-0.736	-0.645	-0.747	-0.569	-0.74	-0.736	-0.744	-0.733
CT	-0.52	NS	NS	NS	-0.445	-0.602	NS	NS	NS
CATD	-0.739	NS	-0.721	-0.32	-0.687	-0.633	-0.815	NS	-0.56
PAR	-0.655	-0.556	-0.742	-0.504	-0.796	-0.436	-0.503	-0.486	-0.526

The average leaf relative water content had negative correlation with maximum soil temperature (-0.673, -0.673, -0.786, -0.799), UV radiation (-0.757, -0.723, -0.748, -0.737), CATD (-0.666, -0.639, -0.733, -0.725), PAR (-0.720, -0.730, -0.679, -0.684) throughout vegetative, flowering fruiting and harvesting stage. Solar radiation had negative correlation during vegetative (-0.596), fruiting (-0.573) and the harvesting stage (-0.695). Canopy temperature showed negative correlation during vegetative (-0.452) and fruiting (-0.382) stage and minimum soil temperature during fruiting (-0.392) and harvesting stage (-0.58). Also, minimum relative humidity showed negative correlation during harvesting stage (-0.665).

Average leaf relative water content had positive correlation with minimum temperature (0.481) and maximum relative humidity (0.468) during harvesting stage and minimum relative humidity showed positive correlation (0.75) during fruiting stage and minimum soil temperature during vegetative stage (0.464) (Table 37).

Table 37. Correlation between relative water content and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.596	NS	-0.573	-0.695
T_{min}	NS	NS	NS	0.481
T_{max}	NS	NS	NS	NS
RH-I	NS	NS	NS	0.468
RH-II	NS	NS	0.75	-0.665
ST_{min}	0.464	NS	-0.392	-0.58
ST_{max}	-0.673	-0.673	-0.786	-0.799
SM	NS	NS	NS	NS
UV	-0.757	-0.723	-0.748	-0.737
CT	-0.452	NS	-0.382	NS
CATD	-0.666	-0.639	-0.733	-0.725
PAR	-0.720	-0.730	-0.679	-0.684

4.7.4 Yield and yield attributes

4.7.4.1 Total yield and fruit yield per plant

The total yield had significant negative correlation with (-0.604, -0.576, -0.387, -0.438, -0.449, -0.614 and -0.704) during week one, two, six, seven, eight and nine, minimum temperature (-0.358, -0.475, -0.380 and -0.434) during week one, four, five and seven, maximum temperature (-0.407, -0.440, -0.390, -0.351 and -0.373) during week one, three, four, six and seven, minimum relative humidity (-0.489, -0.408 and -0.438) during week seven to nine, maximum relative humidity (-0.402) during week nine, minimum soil temperature (-0.553, -0.633, -0.677 and -0.738) during week five, seven, eight and nine, maximum soil temperature (-0.524, -0.752, -0.704, -0.492, -0.724, -0.615, -0.835, -0.814 and -0.725) and UV radiation (-0.582, -0.759, -0.698, -0.659, -0.677, -0.709, -0.709, -0.678 and -0.721) during week one to nine, average soil moisture (-0.470) during week seven, canopy air temperature (-0.561) during week six, canopy air temperature difference (-0.553,-0.446, -0.476, -0.609, -0.707, -0.533, -0.413 and -0.500) during week one and week three to nine, PAR (-0.503, -0.416, -0.518, -0.785 and -0.684) during week one to five.

Similarly, it had positive correlation with maximum relative humidity (0.462, 0.432, 0.519, 0.469, 0.469, 0.467, 0.495 and 0.463) during week one to eight, minimum soil temperature (0.443) during week three, average soil moisture (0.398 and 0.369) during week one and two.

The correlation between total yield and different weather parameters was found out and is presented in the Table (40) for all the four dates of transplanting. It showed strong significant negative correlation with maximum temperature (-0.708, -0.477, -0.806, 0.776), UV radiation (-0.711, -0.638, -0.721, -0.551), CATD (-0.507, -0.623, -0.714, -0.684), PAR (-0.582, -0.765, -0.423, -0.426) throughout vegetative, flowering, fruiting and harvesting stage respectively. Whereas solar radiation showed a significant negative correlation during vegetative (-0.499), fruiting (-0.363) and harvesting stage (-0.648). Maximum temperature showed negative correlation during vegetative (-0.363), flowering (-0.363), and fruiting stage (-0.367). Minimum soil temperature had negative correlation during fruiting (-0.706) and harvesting stage (-0.852). Also minimum relative humidity showed negative correlation during harvesting stage (-0.675).

It had a positive correlation with maximum relative humidity throughout vegetative (0.498), flowering (0.480) and fruiting (0.497) and canopy temperature showed significant positive correlation during harvesting stage (0.494) (Table 38 and 39).

Table 38. Correlation between total yield / fruit yield per plant and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.604	-0.576	-0.387	NS	NS	-0.438	-0.449	-0.614	-0.704
T_{min}	-0.358	NS	NS	-0.475	-0.380	NS	-0.434	NS	NS
T_{max}	-0.407	NS	-0.440	-0.390	NA	-0.351	-0.373	NS	-0.396
RH-I	0.462	0.432	0.519	0.469	0.469	0.467	0.495	0.463	-0.402
RH-II	NS	NS	NS	NS	NS	NS	-0.489	-0.408	-0.438
ST_{min}	NS	NS	0.443	NS	-0.553	NS	-0.633	-0.677	-0.738
ST_{max}	-0.524	-0.752	-0.704	-0.492	-0.724	-0.615	-0.835	-0.814	-0.725
SM	0.398	0.369	NS	NS	NS	NS	-0.470	NS	NS
UV	-0.582	-0.759	-0.698	-0.659	-0.677	-0.709	-0.709	-0.678	-0.721
CT	NS	NS	NS	NS	NS	-0.561	NS	NS	NS
CATD	-0.553	NS	-0.446	-0.476	-0.609	-0.707	-0.533	-0.413	-0.500

Table 39. Correlation between total yield / fruit yield per plant and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.499	NS	-0.515	-0.648
T_{min}	NS	-0.435	NS	0.083
T_{max}	-0.363	-0.363	-0.367	NS
RH-I	0.498	0.480	0.497	NS
RH-II	NS	NS	NS	-0.675
ST_{min}	NS	NS	-0.706	-0.852
ST_{max}	-0.708	-0.477	-0.806	-0.776
SM	NS	NS	NS	NS
UV	-0.711	-0.638	-0.721	-0.551
CT	NS	NS	NS	0.494
CATD	-0.507	-0.623	-0.714	-0.684
PAR	-0.582	-0.765	-0.423	-0.426

4.7.4.2 Average fruit weight (g)

Average fruit weight had negative correlation with solar radiation (-0.484, -0.524, -0.492, -0.457, -0.602, -0.721, -0.737, -0.736, -0.613), UV radiation (-0.497, -0.652, -0.582, -0.565, -0.511, -0.617, -0.641, -0.626 and -0.684) during week one to nine, minimum temperature (-0.370) and minimum relative humidity (-0.352) during week nine, minimum soil temperature (-0.511, -0.542 and -0.418) during week four, six, seven and eight, maximum soil temperature during (-0.455, -0.574, -0.388, -0.545, -0.489 and -0.572) during week one, two, five, seven, average soil moisture (-0.544, -0.586, -0.395 and -0.621) during week six to nine, canopy air temperature difference (-0.451, -0.413, -0.658, -0.502, -0.480 and -0.351) during week one, two, four, six, eight and nine, PAR (-0.470, -0.353 and -0.503) during week one, three and four. It had significant positive correlation with canopy temperature (0.394) during week eight.

Average fruit weight showed a significant negatively correlation with solar radiation (-0.726, -0.537, -0.743, -0.65), UV radiation (-0.608, -0.478, -0.622, -0.454), CATD (-0.446, -0.510, -0.502, -0.485) throughout vegetative, flowering, fruiting and harvesting stage respectively. Maximum soil temperature during vegetative (-0.418), fruiting (-0.421) and harvesting stage (-0.616) also had negatively significance with average fruit weight. Minimum soil temperature (-0.396, -0.566) and soil moisture (-0.592, -0.692) showed negative correlation during fruiting and harvesting stage.

Minimum relative humidity also had negative correlation during harvesting stage (-0.372). The only parameter that influenced the average fruit weight positively was the canopy temperature throughout vegetative and harvesting stage (0.524 and 0.365 respectively) (Table 40 and 41).

Table 40. Correlation between average fruit weight and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.484	-0.524	-0.492	-0.457	-0.602	-0.721	-0.737	-0.736	-0.613
T_{min}	NS	NS	NS	NS	NS	NS	NS	NS	-0.370
T_{max}	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	NS	NS	NS	-0.352
ST_{min}	NS	NS	NS	-0.511	NS	0.063	-0.542	-0.418	NS
ST_{max}	-0.455	-0.574	NS	NS	-0.388	NS	-0.545	-0.489	-0.572
SM	NS	NS	NS	NS	NS	-0.544	-0.586	-0.395	-0.621
UV	-0.497	-0.652	-0.582	-0.565	-0.511	-0.617	-0.641	-0.626	-0.684
CT	NS	0.517	0.461	NS	NS	NS	NS	0.394	NS
CATD	-0.451	-0.413	NS	-0.658	NS	-0.502	NS	-0.480	-0.351
PAR	-0.470	NS	-0.353	-0.503	NS	NS	NS	NS	NS

Table 41. Correlation between average fruit weight and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.726	-0.537	-0.743	-0.650
T_{min}	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS
RH-I	NS	NS	NS	NS
RH-II	NS	NS	NS	-0.372
ST_{min}	NS	NS	-0.396	-0.566
ST_{max}	-0.418	NS	-0.421	-0.616
SM	NS	NS	-0.592	-0.692
UV	-0.608	-0.479	-0.622	-0.454
CT	0.524	NS	NS	0.365
CATD	-0.446	-0.510	-0.502	-0.485
PAR	-0.398	-0.383	NS	NS

4.7.4.3 Percentage fruit set

The percent of fruit set occurred had significant negative correlation (-0.718, -0.651, -0.418 and -0.672) during week one, two, eight and nine, minimum temperature (-0.577, -0.614, -0.602, -0.607 and -0.481), maximum temperature (-0.631, -0.536, -0.462, -0.407, -0.463, -0.553, -0.465 and -0.491) during week one, three, four, five, six, seven, eight and nine, minimum relative humidity (-0.460, -0.407 and -0.491), maximum relative humidity (-0.473) during week nine, minimum soil temperature (-0.325, -0.477, -0.441, -0.423, -0.435, -0.545, -0.618, -0.575 and -0.587) during week one to nine, average soil moisture (-0.512 and -0.481), UV radiation (-0.514, -0.545, -0.493, -0.544, -0.464, -0.563, -0.560, -0.553 and -0.562) during week one to nine, canopy air temperature (-0.540) during week one, canopy air temperature difference (-0.559, -0.564, -0.562, -0.609, -0.564, -0.368 and -0.474) during week one, PAR (-0.500, -0.557, -0.807 and -0.636) during week two to five.

Similarly, it had significant positive correlation with solar radiation (0.432) during week one, maximum relative humidity (0.548, 0.471, 0.582, 0.574, 0.569, 0.469, 0.473, and 0.622) during week one to eight, minimum soil temperature (0.587 and 0.733) during week two and three, average soil temperature (0.594, 0.586 and 0.474) during week one to three.

The percent of fruit set occurred had significant negative correlation with the minimum temperature (-0.535, -0.7, -0.471), maximum temperature (-0.509, -0.425, -0.468), maximum soil temperature (-0.450, -0.390, -0.581), UV radiation (-0.554, -0.517, -0.563), CATD (-0.567, -0.476, -0.638), PAR (-0.577, -0.820, -0.356) throughout vegetative, flowering, fruiting stages respectively. Whereas solar radiation (-0.484) and canopy temperature (-0.371) had a significant negative correlation during vegetative stage. Minimum soil temperature had negatively significance during fruiting stage (-0.592). Minimum relative humidity showed negatively significance during seventh week (-0.46) and eighth week (-0.407).

It had a significant positive correlation with maximum relative humidity throughout vegetative (-0.572), flowering (-0.647) and fruiting stage (-0.448). Minimum soil temperature (0.676) and soil moisture (0.48) had positively significance during vegetative stage. Solar radiation also had negatively significance during flowering stage (0.372) (Table 42 and 43).

Table 42. Correlation between percentage fruit set and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8
SR	-0.718	-0.651	NS	0.432	NS	NS	NS	-0.418
T_{min}	-0.577	NS	NS	-0.614	-0.602	NS	-0.607	-0.481
T_{max}	-0.631	NS	-0.536	-0.462	-0.407	-0.463	-0.553	-0.465
RH-I	0.548	0.471	0.582	0.574	0.569	0.469	0.473	0.622
RH-II	NS	NS	NS	NS	NS	NS	-0.460	-0.407
ST_{min}	NS	0.587	0.733	NS	NS	NS	-0.598	-0.551
ST_{max}	NS	-0.477	-0.441	-0.423	-0.435	-0.545	-0.618	-0.575
SM	0.594	0.586	0.474	NS	NS	NS	-0.512	-0.481
UV	-0.514	-0.545	-0.493	-0.544	-0.464	-0.563	-0.560	-0.553
CT	-0.540	NS	NS	NS	NS	NS	NS	NS
CATD	-0.559	NS	-0.564	NS	-0.562	-0.609	-0.564	-0.368
PAR	NS	-0.500	-0.557	-0.807	-0.636	NS	NS	NS

Table 43. Correlation between percentage fruit set and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage
SR	-0.484	0.372	NS
T_{min}	-0.535	-0.700	-0.471
T_{max}	-0.509	-0.425	-0.468
RH-I	0.572	0.647	0.448
RH-II	NS	NS	NS
ST_{min}	0.676	NS	-0.592
ST_{max}	-0.450	-0.390	-0.581
SM	0.480	NS	NS
UV	-0.554	-0.517	-0.563
CT	-0.371	NS	NS
CATD	-0.567	-0.476	-0.638
PAR	-0.577	-0.820	-0.356

4.8. PHYSIOLOGICAL PARAMETERS AND YIELD

4.8.1 Relative water content (%)

The total yield attained had significant positive correlation with the relative water content during the vegetative, flowering, fruiting and harvesting stage (0.814, 0.855, 0.843 and 0.707 respectively) (Table 44 and 45).

4.8.2 Leaf area index (LAI).

The total yield obtained had a significant correlation with the LAI during the fruiting and harvesting stage (0.584 and 0.615 respectively) (Table 44 and 45).

4.8.3 SPAD index value (μg ml^{-1})

The SPAD index value during the week three and six and the vegetative stage had a significant negative correlation with the yield obtained (-0.753, -0.727 and -0.377 respectively) (Table 44 and 45).

Table 44. Correlation between yield and physiological parameters

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
SPAD index	NS	NS	-0.75	NS	NS	-0.73	NS	NS	NS
RWC	0.411	0.838	0.767	0.834	0.835	0.820	0.812	0.780	0.823
LAI	NS	NS	NS	0.636	0.635	0.636	0.537	0.754	0.737

4.8.4 Total soluble proteins

The total soluble proteins at 30 and 45 days after transplanting had a significant negative correlation with the total yield (-0.674 and -0.563 respectively) (Table 46).

Table 45. Correlation between yield and physiological parameters

	Vegetative stage	Flowering stage	Fruiting stage	harvesting stage
SPAD index	-0.378	NS	NS	NS
RWC	0.814	0.855	0.843	0.707
LAI	0.467	0.723	0.716	NS

Table 46. Correlation between yield and total soluble protein

	TSP at 30 DAT	TSP at 45 DAT
Yield	-0.674	-0.563

4.8.5 Net canopy photosynthesis rate

The net canopy photosynthesis of the crops within the polyhouse and in open filed is depicted in the figure (20). The peak net photosynthesis rate in the open field condition was recorded around 8:00 hours while within the polyhouse the same was attained around 10:00 hours. The CO_2 concentration corresponding to the peak photosynthesis rate was 364 ppm and 394 ppm respectively for the open field condition and polyhouse crops. Fig (21) shows the net canopy photosynthesis rate at different CO_2 levels. The maximum photosynthesis rate (19.42) was recorded at 600 ppm and the lowest values (7.46) were recorded at 800 ppm.

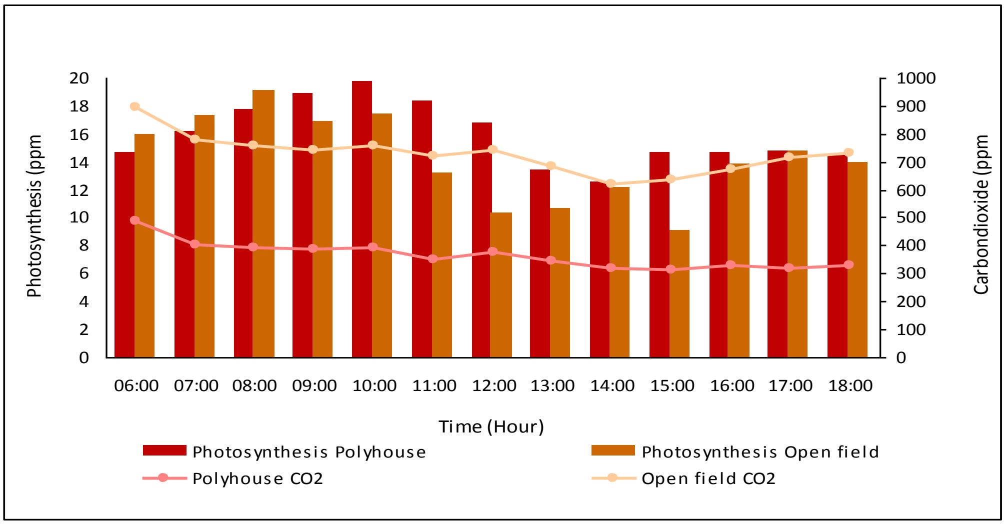


Fig. 20 Diurnal variation in net photosynthesis and carbon dioxide

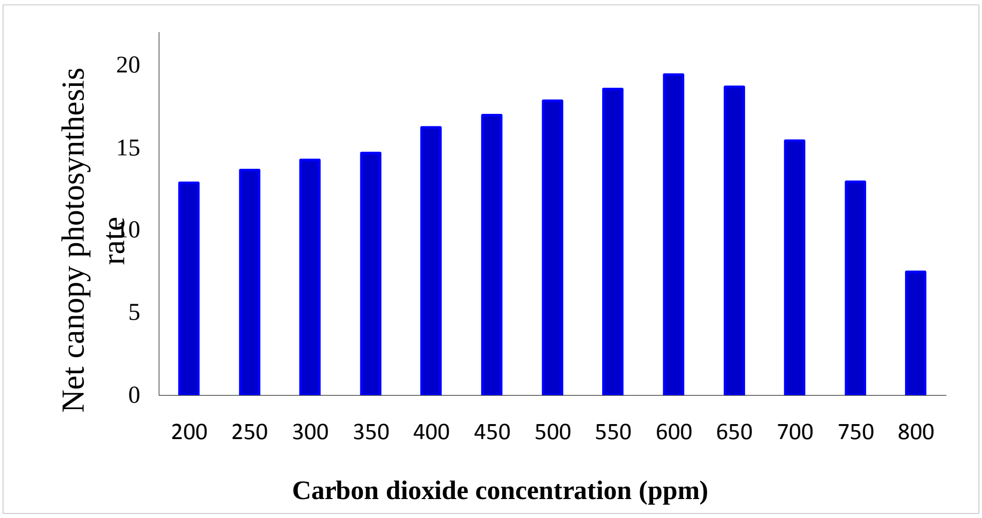


Fig 21. Net canopy photosynthesis rate at different CO_2 concentrations

4.8.6 Length of style

The length of the style and its relative position significantly affected the yield. Under the polyhouse condition for the crops transplanted on 1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015, it was found that when the difference between the style and stamen was positive i.e. the style was positioned lower to the stamen the yield was higher. The yield reduced consistently as the difference grew smaller and turned negative. When the difference was 0.25 mm, 0.15 mm, 0.13 mm and -0.075 mm the yield was 111.5 t ha^{-1}, 111.2 t ha^{-1}, 82 t ha^{-1} and 73 t ha^{-1}.

Under the polyhouse condition for the crops transplanted on 1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015, it was found that when the difference between the style and stamen was positive i.e. the style was positioned lower to the stamen the yield was higher. The yield reduced consistently as the difference grew smaller and turned negative. When the difference was 0.213 mm, 0.027 mm, 0 mm and -0.120 mm the yield was 92.4 t ha^{-1}, 71.2 t ha^{-1} and 68.1 t ha^{-1} and 66.7 t ha^{-1}.

Under the polyhouse condition for the crops transplanted on 1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015, it was found that when the difference between the style and stamen was positive i.e. the style was positioned lower to the stamen the yield was higher. The yield reduced consistently as the difference grew smaller and turned negative. When the difference was 0.240 mm, 0.2 mm, -0.1260 mm and -0.18 mm the yield was 73.2 tons ha^{-1}, 57.5 tons ha^{-1}, 38.4 tons ha^{-1} and 7.5 tons ha^{-1} (Figure 22, 23 and 24).

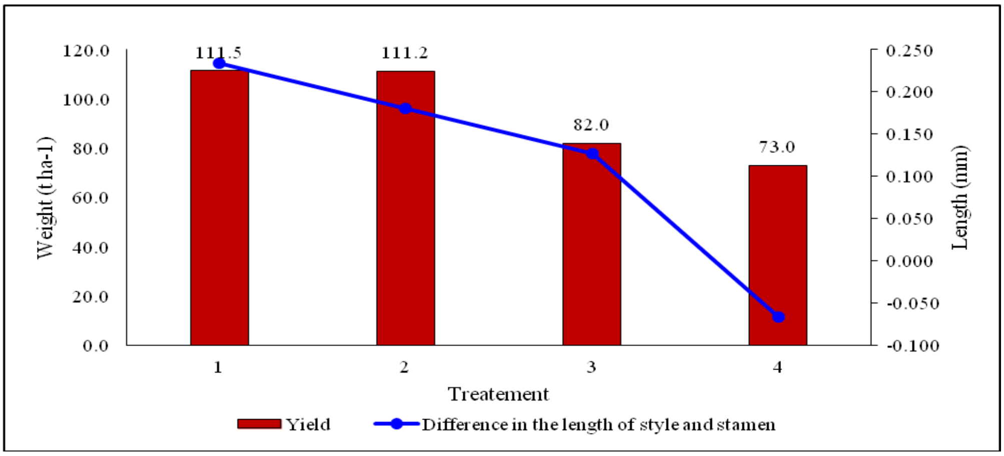


Fig 22. Relative position of stigma and stamen and the variation in yield in the polyhouse crops

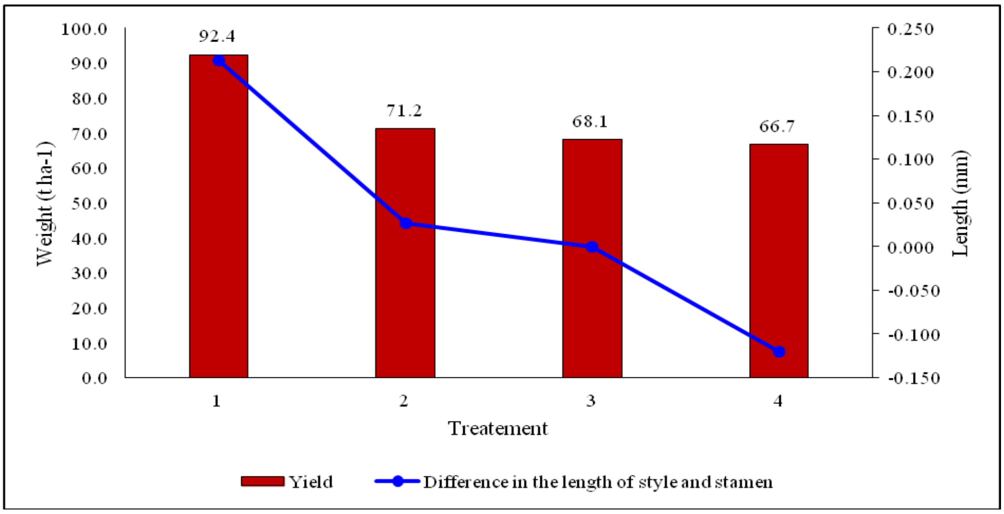


Fig 23. Relative position of stigma and stamen and the variation in yield in the Rain shelter crops

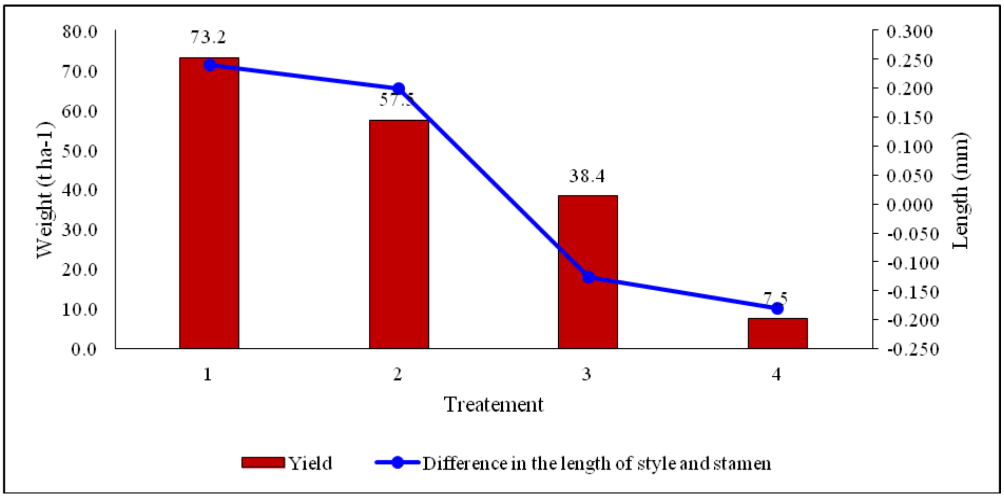


Fig 24. Relative position of stigma and stamen and the variation in yield in the open field crops

4.9. MULTIPLE REGRESSION MODELS DEVELOPED

4.9.1 Physiological parameters

4.9.1.1 Maximum Leaf area index (LAI)

$MLAI = 6.79 – 0.002\ UV_2 - 0.082\ STN_3 - 0.011\ SM_5 + 0.011\ SM_6$ $\quad R^2 = 0.725$

Where, SM_5 = Soil moisture from fifth week (%)

SM_6 = Soil moisture from sixth week (%)

ST_{min3} = Minimum soil temperature from third week (°C)

UV_2 = UV radiation from second week (Wm^{-2})

4.9.1.2 Average SPAD index value

$SPAD\ index = 97.721 + 0.746\ CATD_5 - 2.299\ T_{min2} + 0.275\ ST_{max(veg)}$ $\quad R^2=0.848$

Where, T_{min2}= Maximum temperature from second week (°C)

$CATD_5$= Canopy air temperature from fifth week (°)

$ST_{max\ (veg)}$ = Maximum soil temperature from vegetative stage (°C)

4.9.1.3 Average Relative water content

RWC= 93.761 - 0.268 ST_{max5} - 0.006 $PAR_{(flw)}$ + 0.508 $CATD_5$ R^2=0.879

Where, $CATD_5$ = Canopy air temperature difference from fifth week (°)

$PAR_{(flw)}$ = photosynthetically active radiation from vegetative stage (Wm^{-2})

ST_{max5} = Maximum soil temperature from fifth week (°C)

4.9.1.4 Total soluble protein at 30 days after transplanting

TSS = 0.189 – 0.001 RH I_3 + 0.001 UV_1 -0.002 $ST_{max\ (veg)}$ $R^2_=$ 0.893

Where, RH I_3 = Maximum relative humidity from third week (%)

$ST_{max\ (veg)}$ = Maximum soil temperature from vegetative stage (°C)

UV_1 = UV radiation from first week (Wm^{-2})

4.9.1.5 Total soluble protein at 45 days after transplanting

TSS = -0.983 + 0.1CT_6 + 0.18 ST_{min1} + 0.008 T_{max4} R^2 = 0.626

Where, T_{max4} = Maximum temperature (°C)

CT_6 = Canopy temperature from sixth week (°C)

ST_{min1} = Minimum soil temperature (°C)

4.9.1.6 Lycopene

Lycopene = 14.83 – 0.073 $UV_{(frt)}$ R^2 = 0.908

Where, $UV_{(frt)}$ = UV radiation from fruiting stage

4.9.1.7 Ascorbic acid

Ascorbic acid = 12.166 -0.910 SM_9 + 0.98 T_{max6} R^2 = 0.702

Where, T_{max6} = Maximum temperature from sixth week

SM_9 = Soil moisture from ninth week

4.9.2 FLORAL CHARACTERS

4.9.2.1 Mean style length

Mean style length = 1.13-0.002 $UV_{(flw)}$ - 0.038 T_{min5} + 0.13 SM_5 R2= 0.886

Where, T_{min5} = Minimum air temperature from fifth week (°C)

SM_5 = Soil moisture from fifth week (°C)

UV $_{(flw)}$ = UV radiation from flowering stage

4.9.2.2 Mean stamen length

Mean stamen length = 0.876 + 0.013 SM_2 - 0.002 UV_5 - 0.007 RH II_3 R2= 0.826

Where, RH I_3 = Maximum relative humidity from third week (%)

SM_2= Soil moisture from second week (°C)

UV_5= UV radiation from second week (Wm^{-2})

4.9.3 PHENOLOGICAL CHARACTERS

4.9.3.1 Days to first flowering

Days to first flowering = 3.435 + 1.426 $ST_{min(veg)}$ -0.323 CT_3 - 0.195CT_1 (R2= 0.701)

Where, CT_1= Canopy temperature from first week (°C)

CT_3= Canopy temperature from third week (°C)

$ST_{min\ (veg)}$ = Minimum soil temperature from vegetative stage (°C)

4.9.3.1 Days to first harvest

Days to first harvest = 204.361- 6.015 $T_{min\ (flw)}$ R^2= 0.825

Where, $T_{min\ (flw)}$ = Minimum air temperature from flowering stage (°C)

4.9.3.2 Days to last harvest

Days to last harvest = 659.196 - 8.3 ST_{min9} - 11.73ATN_8 - 1.40 RH I $_{(flw)}$ R^2=0.987

Where, T_{min8} = Minimum air temperature from eighth week (°C)

RH II $_{(flw)}$ = Minimum Relative humidity from flowering stage (%)

ST_{min9} = Minimum soil temperature from ninth week (°C)

4.9.4 YIELD AND YIELD ATTRIBUTES

4.9.4.1 Number of harvest

Number of harvest = 71.61-1.18 $ST_{min\ (harv)}$ -0.72 $T_{min\ (flw)}$ R^2=0.901

Where, $T_{min(flw)}$ = Minimum air temperature from harvesting stage (°C)

$ST_{min\ (harv)}$ = Minimum soil temperature from harvesting stage (°C)

4.9.4.2 Total yield

Total yield = 634.937 - 22.495 $ST_{min(harv)}$ -0.701UV $_{(flw)}$ + 0.081 SR $_{(harv)}$ R^2 = 0.801

Where, $ST_{min(harv)}$ = Minimum soil temperature from harvesting stage (°C)

$SR_{(harv)}$ = Solar radiation from harvesting stage (Wm^{-2})

$UV_{(flw)}$ = UV radiation from flowering stage (Wm^{-2})

4.10 CLIMATE CHANGE AND PHYSIOLOGY OF TOMATO

The future climatic projections have taken from Ensemble of 17 General Circulation Models. The future carbon dioxide concentrations and climate data has been incorporated into crop simulation model-DSSAT and predicted the future physiological parameters for the years 2030, 2050 and 2080. The climate data for the years 2030, 2050 and 2080 under different RCPs has been presented in the figures (25-36).

Fig 25. Climate of Vellanikkara in 2030s under RCP 2.6

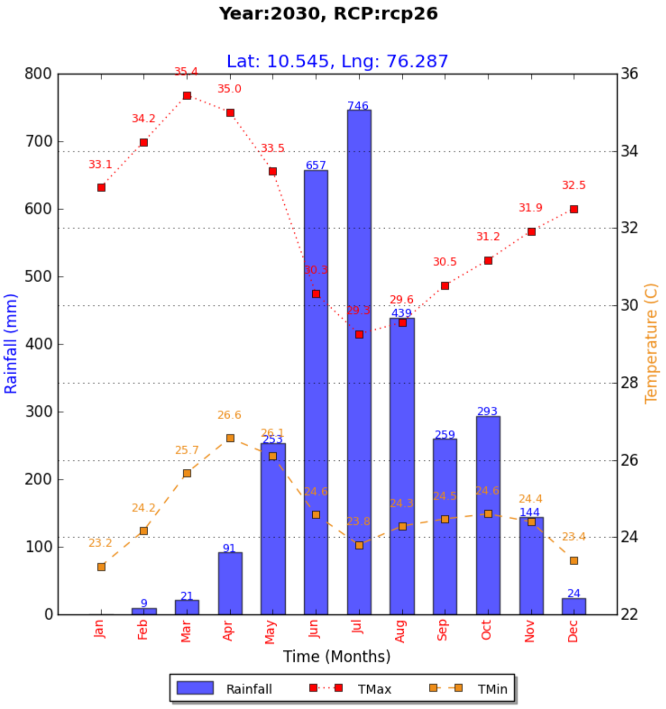


Fig 26. Climate of Vellanikkara in 2030s under RCP 4.5

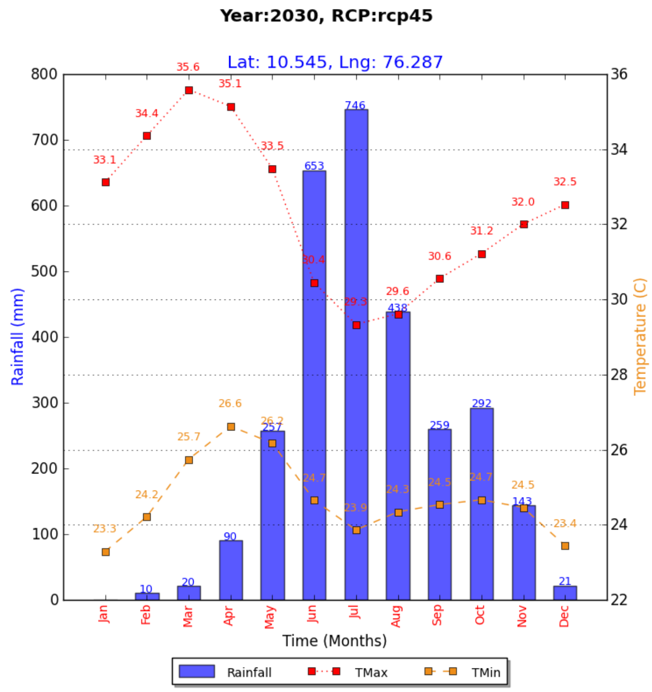


Fig 27. Climate of Vellanikkara in 2030s under RCP 6.0

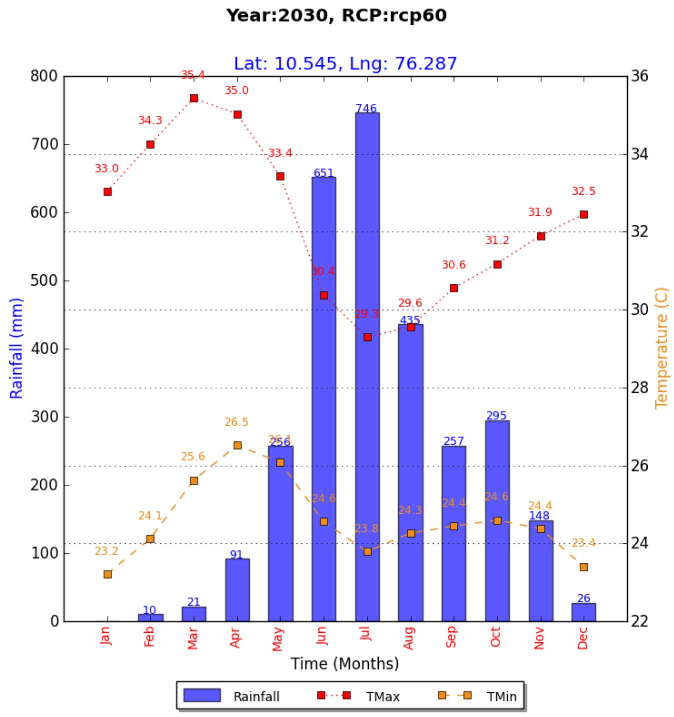


Fig 28. Climate of Vellanikkara in 2030s under RCP 8.5

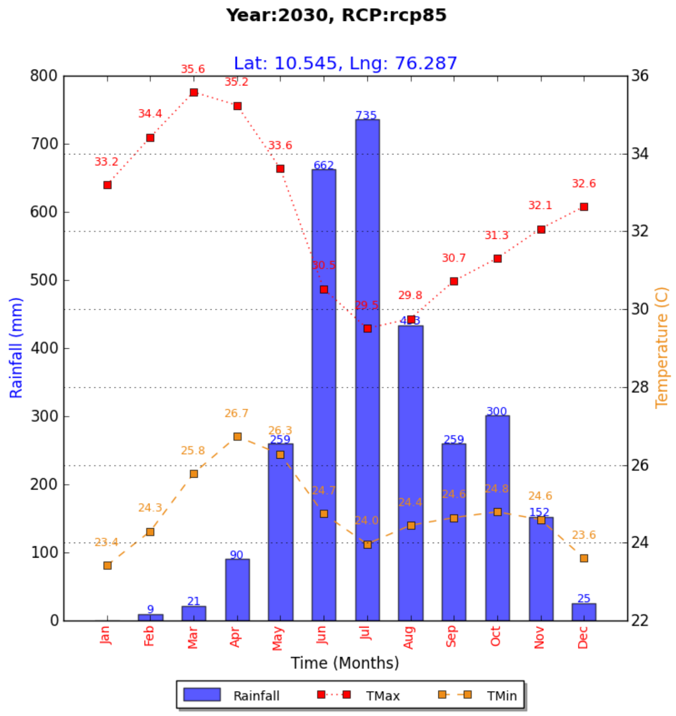


Fig 29. Climate of Vellanikkara in 2050s under RCP 2.6

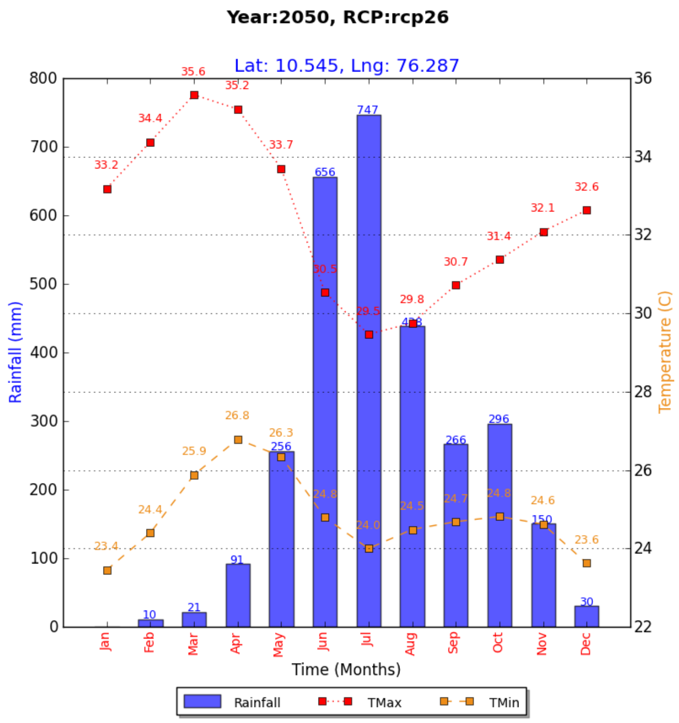


Fig 30. Climate of Vellanikkara in 2050s under RCP 4.5

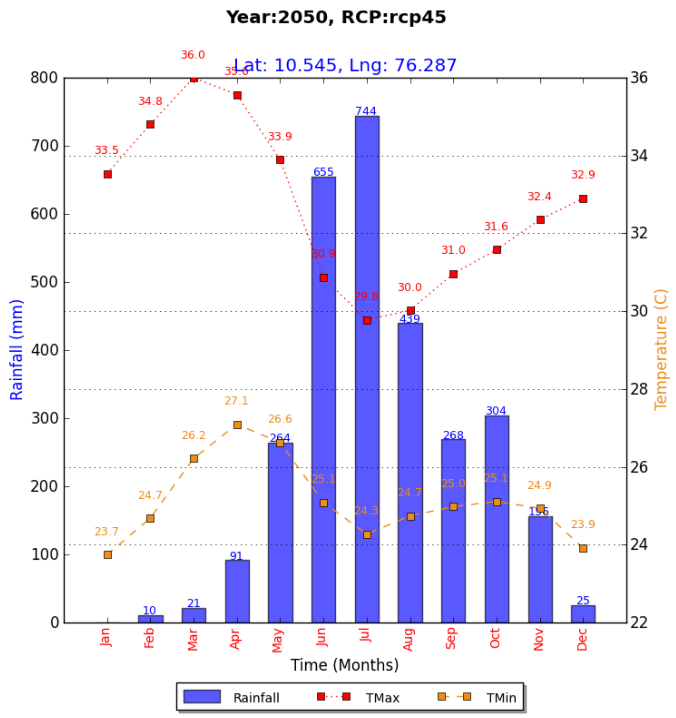


Fig 31. Climate of Vellanikkara in 2050s under RCP 6.0

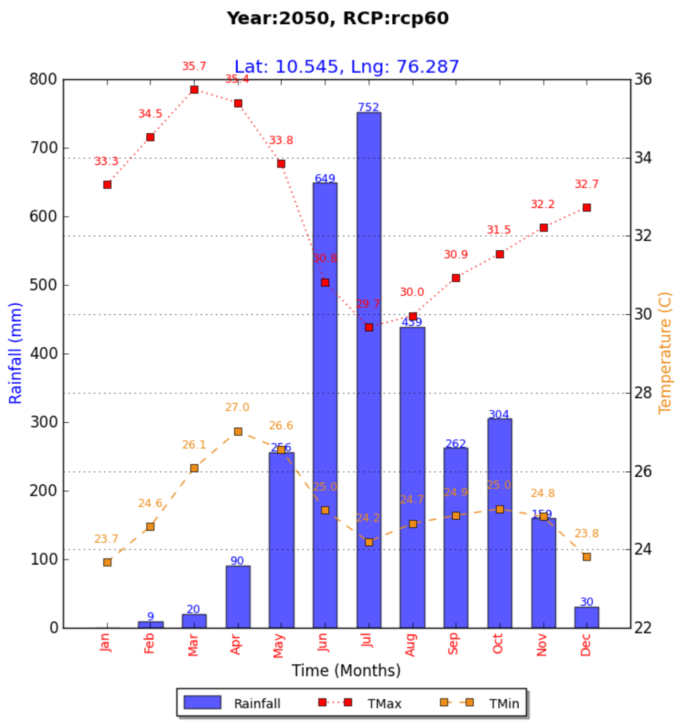


Fig 32. Climate of Vellanikkara in 2050s under RCP 8.5

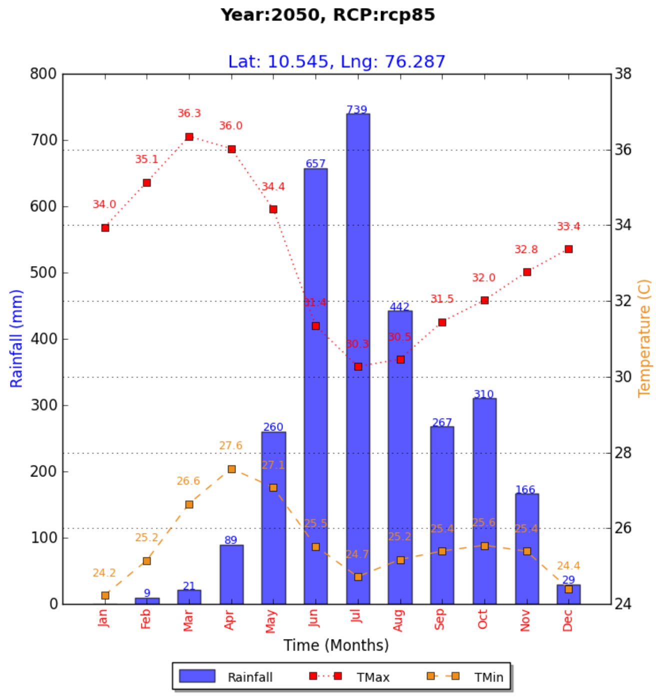


Fig 33. Climate of Vellanikkara in 2080s under RCP 2.6

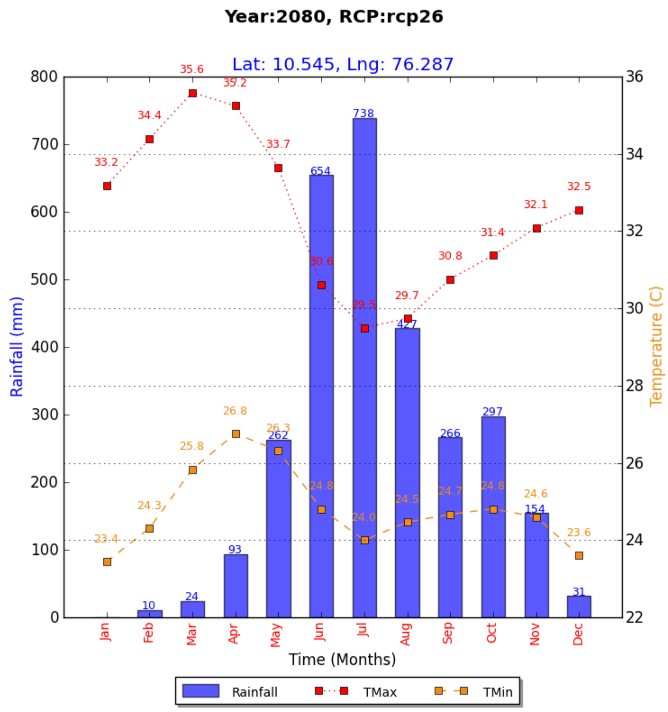


Fig 34. Climate of Vellanikkara in 2080s under RCP 4.5

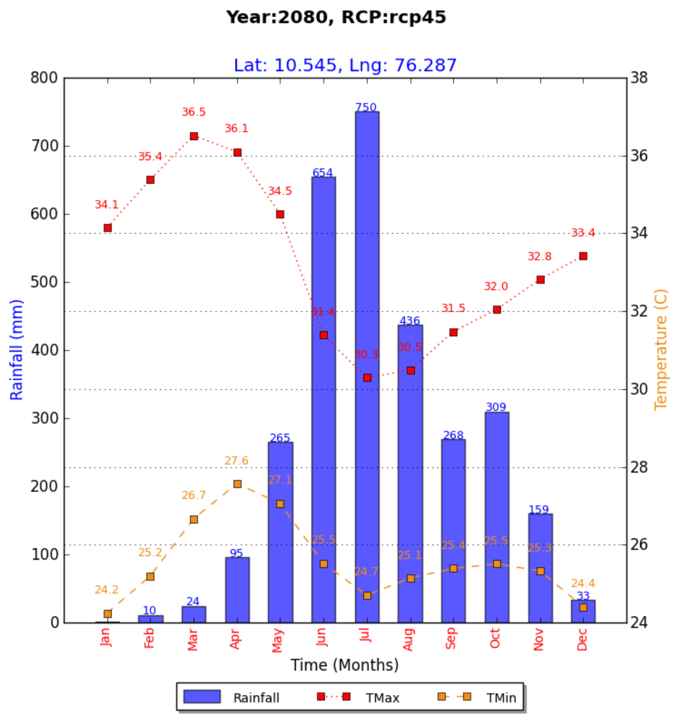


Fig 35. Climate of Vellanikkara in 2080s under RCP 6.0

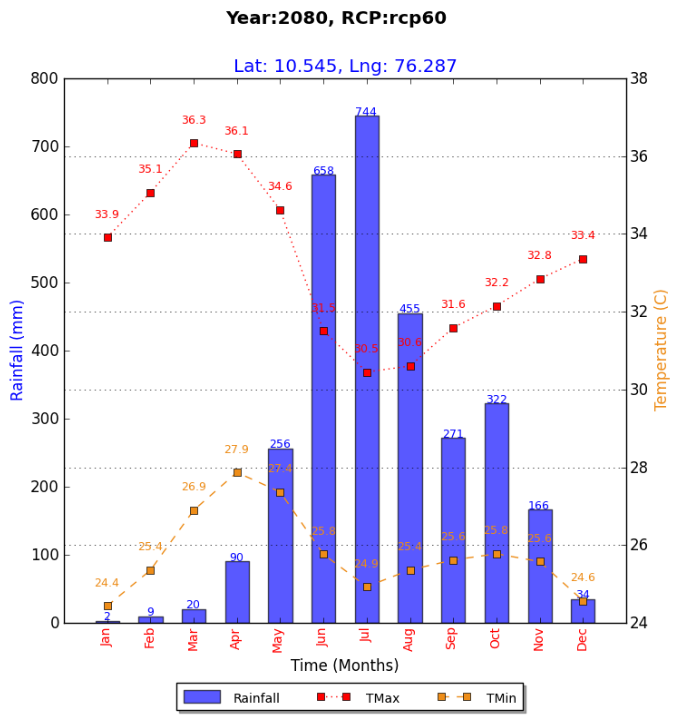
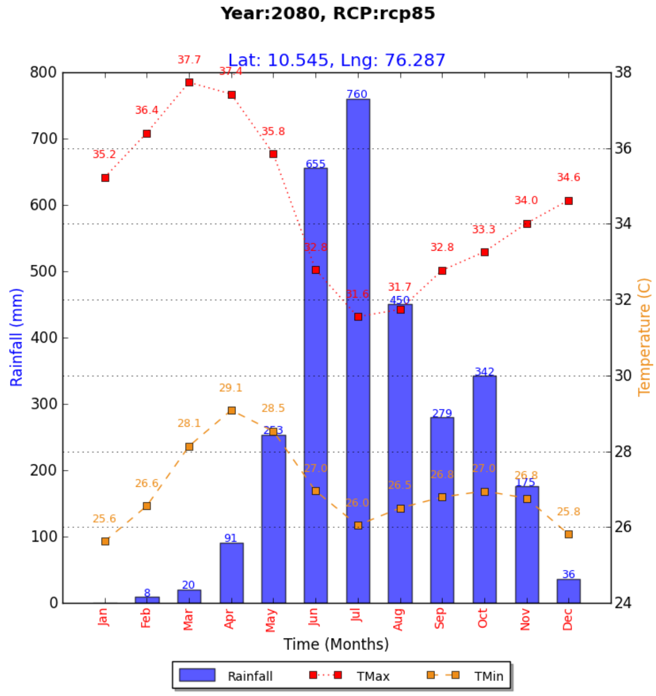


Fig 36. Climate of Vellanikkara in 2080s under RCP 8.5



4.10.1 Phenology of tomato

4.10.1.1 Duration of the crop

The duration to last harvest in the years 2030, 2050 and 2080 varied significantly under the different RCP scenarios (2.6, 4.5, 6.0 and 8.5). Under the RCP 2.6 scenario the duration to last harvest in the years 2030, 2050 and 2080 are predicted to be 114, 112 and 109 days respectively. Under the RCP 4.5 scenario the duration to last harvest in the years 2030, 2050 and 2080 are predicted to be 114, 105 and 94 days respectively. Under the RCP 6.0 scenario the duration to last harvest in the years 2030, 2050 and 2080 are predicted to be 109, 108 and 94 days respectively whereas for the RCP scenario 8.5 the days to last harvest in the years 2030, 2050 and 2080 are 112, 96 and 72 days respectively (figure 37).

4.10.2 Physiological parameters

4.10.2.1 Fruit ascorbic acid content

Under the RCP 2.6 scenario, the fruit ascorbic acid content for the crop transplanted in the year 2030, 2050 and 2080 is predicted as 1.58, 1.61 and 1.61 mg g^{-1} respectively. Under the RCP 4.5 scenario, the fruit ascorbic acid content for the crop transplanted in the year 2030, 2050 and 2080 is predicted as 1.58, 1.64 and 17 mg g^{-1} respectively. Under the RCP 6.0 scenario, the fruit ascorbic acid content for the crop transplanted in the year 2030, 2050 and 2080 is predicted as 1.61, 1.62 and 1.74 mg g^{-}

[1] respectively. Under the RCP 8.5 scenario, the fruit ascorbic acid content for the crop transplanted in the year 2030, 2050 and 2080 is predicted as 1.62, 1.7 and 1.86 mg g^{-1} respectively. The fruit ascorbic acid content showed an increasing trend from 2030 to 2050 irrespective of the different RCP scenarios figure (38).

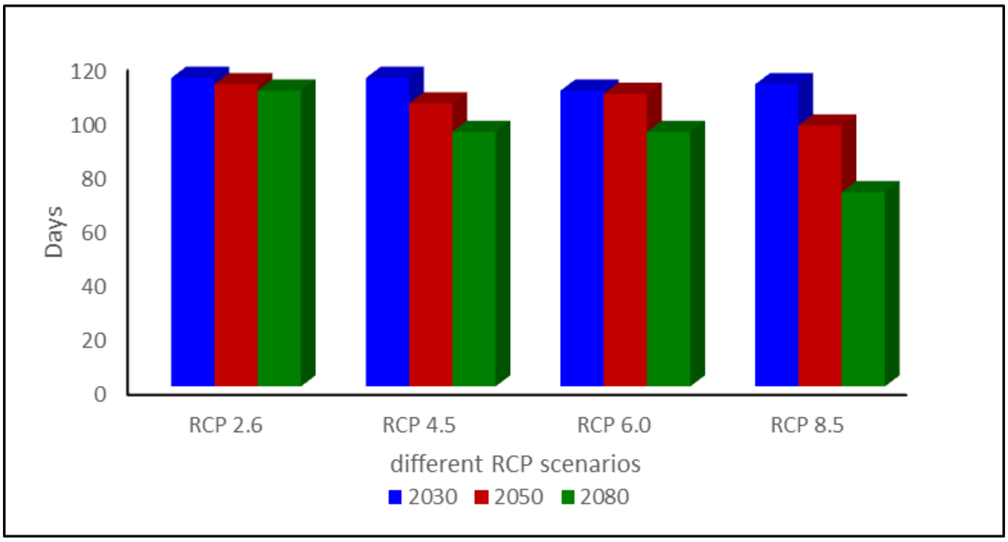


Fig 37. Duration of crop under different RCP scenarios

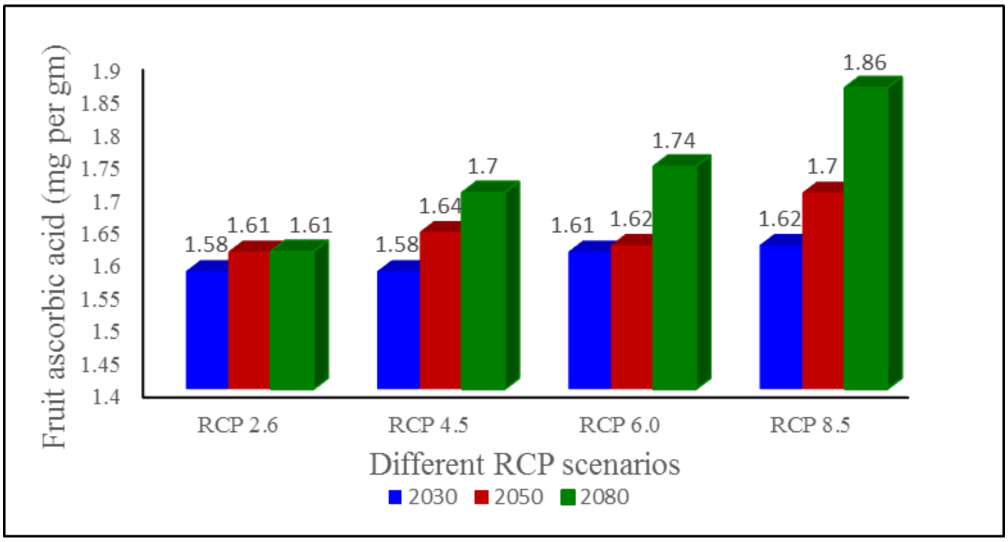


Fig 38. Variation in ascorbic acid content under different RCP scenarios

Discussion

This study was taken up to study the effect of different growing environment and climate change on the physiology of tomato, *Lycopersicon esculentum* Mill. The results presented in the previous chapter are discussed here.

5.1 PHENOLOGICAL CHARACTERS

5.1.2 Days to first flower

The days to first flower was significantly influenced by date of transplanting and the growing environment (Fig 40). The days to first flower was found to be highest (23 days) in the plants transplanted inside the polyhouse on 1 December 2014. The crops planted in the open field transplanted on 20 January 2015 took the least number of days to flower. It was found that as the dates of transplanting shifted from December to January, the days taken to first flower invariably reduced in all the crops regardless of the growing environment. The days taken to first flower was significantly less in the crops planted in the open field.

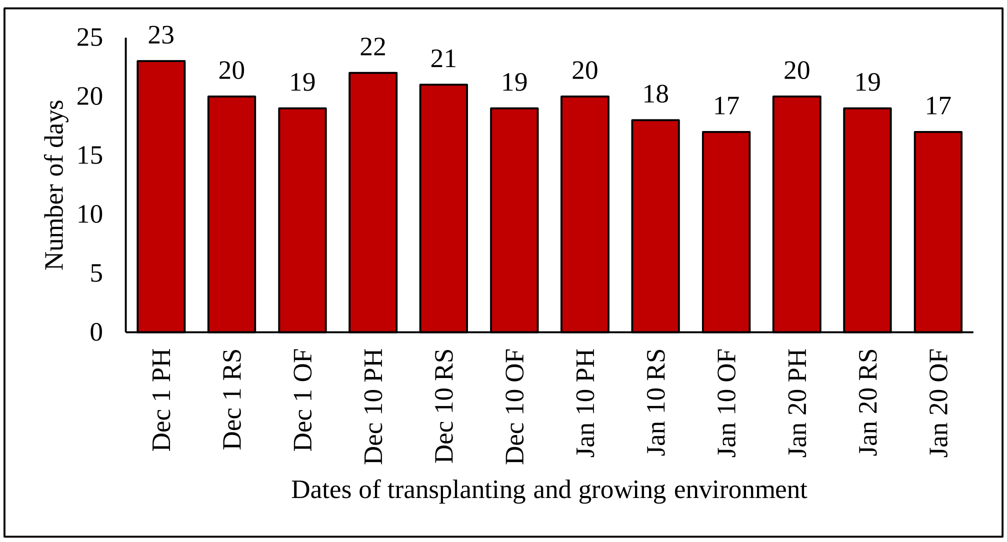


Fig 40. Days to first flowering

It had significant negative correlations with photosynthetically active radiations, maximum and minimum temperatures, canopy air temperature difference and UV radiation. Positive correlations were seen with maximum relative humidity, minimum soil temperatures and average soil moisture.

In tomato temperature is the major factor that affects floral initiation and its affect is closely associated with light condition. The optimum temperature for floral initiation was found to be below 24°C and solar radiation below 600 Wm^{-2}. This is in confirmation with the findings of Grimstad (1995) and Ho (1996).

5.1.2 Days to first harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest. In all the dates of transplanting, crops inside the polyhouse condition took more number of days to first harvest (Fig 41). The days taken for the fruits to mature reduced as the delay in transplanting occurred, regardless of the growing environment.

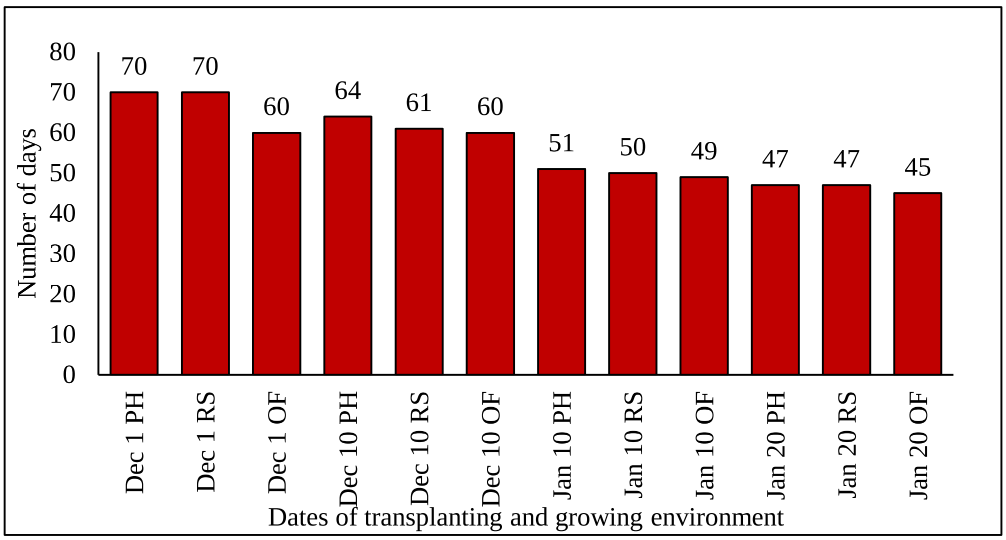


Fig 41.Days to first harvest

The minimum and maximum temperature and the maximum relative humidity were the crucial factors which determined the days taken to first harvest. Higher temperatures hasten the fruit maturity. Within the polyhouse and rain shelter although the temperatures were high but the days taken for first harvest were also higher. This is due to the reason that the minimum and maximum relative humidity were lower within the polyhouse and rain shelter during the harvesting stage and it negatively influenced the otherwise possible hastened maturing of fruits and delayed the first harvest. These are in confirmation with the findings of Slack and Calvert (1978), Gent (1988), Grimstad and Frimanslund (1993), Thangam *et al* (2002).

5.1.3 Days to last harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest (Fig 42). In all the dates of transplanting, crops inside the polyhouse condition took more number of days to first harvest. Days to last harvest was reduced by high solar radiation above 250 W m^{-2} during the first, second, eighth and ninth week and during the harvesting stage, minimum temperature greater than 26°C during the vegetative, flowering, fruiting stage, lower minimum relative humidity during the harvesting stage, maximum soil temperature above 30°C during the vegetative, fruiting and harvesting stage, UV radiation above 40 W m^{-2} and canopy air temperature difference above -1°C during the vegetative, flowering, fruiting and harvesting stage. This is in consonance with the reports of Grimstad (1993), Moccia *et al* (1999), and AVRDC (2000).

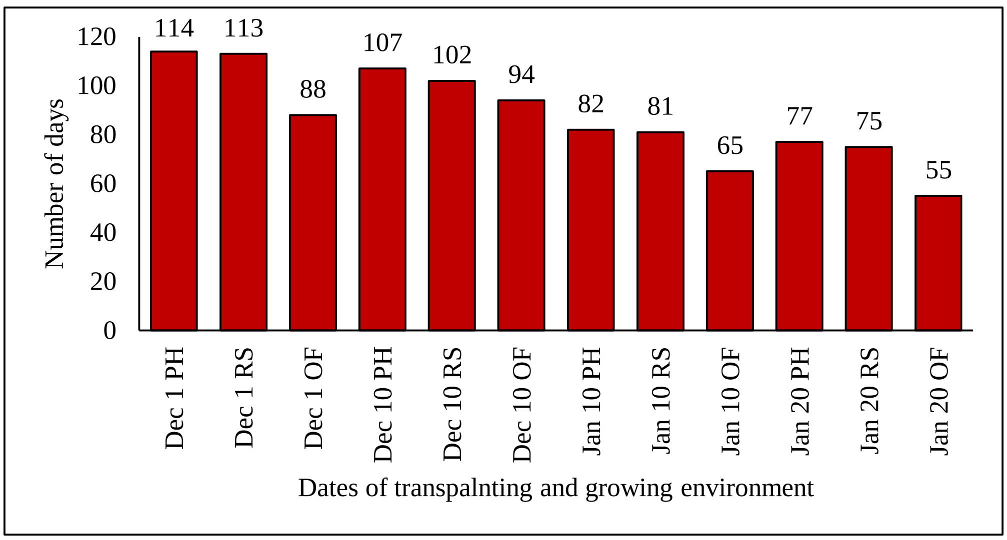


Fig 42. Days to last harvest

5.2 FLORAL CHARACTERS

5.2.1 Mean length of style and relative position of stigma and stamen

The growing environment and the dates of transplanting had significant influence on the mean length of the style and stamen and their relative position (Fig 43and 44). Among all the dates of planting mean style and stamen length reduced with delay in transplanting from 1 December 2014 to 20 January 2015 in all the crops regardless of the growing environment.

The mean stamen length showed a significant positive correlation with the solar radiation, minimum and maximum relative humidity, maximum soil temperature, and average soil moisture and canopy temperature. It showed significant negative correlations with minimum and maximum temperature, UV radiation and canopy air temperature difference.

The mean style length showed a significant positive correlation between solar radiation, average soil moisture and canopy temperature. It had significant negative correlations with the minimum and maximum temperature, the UV radiation and canopy air temperature difference.

Although the length of the style and stamen reduced simultaneously, the mean difference between the position of stigma and stamen increased with delayed transplanting. Style elongation was prominent with the increase in temperature and reduced relative humidity. Higher temperatures and reduced relative humidity resulted in style elongation, flower abortion, flower drop, production of empty flowers and persistent flowers which resulted in lesser fruit set and reduction in yield. A mere increase in the stigma position by more than 0.05 mm relative to the stamen resulted in lowered yield under all the growing environments.

This is at par with the findings of Charles and Harris (1972) and Rudich *et al* (1977), Abdul Baki (1991), Rao and Sreevijayapadma (1991) and Lohar and Peet (1998).

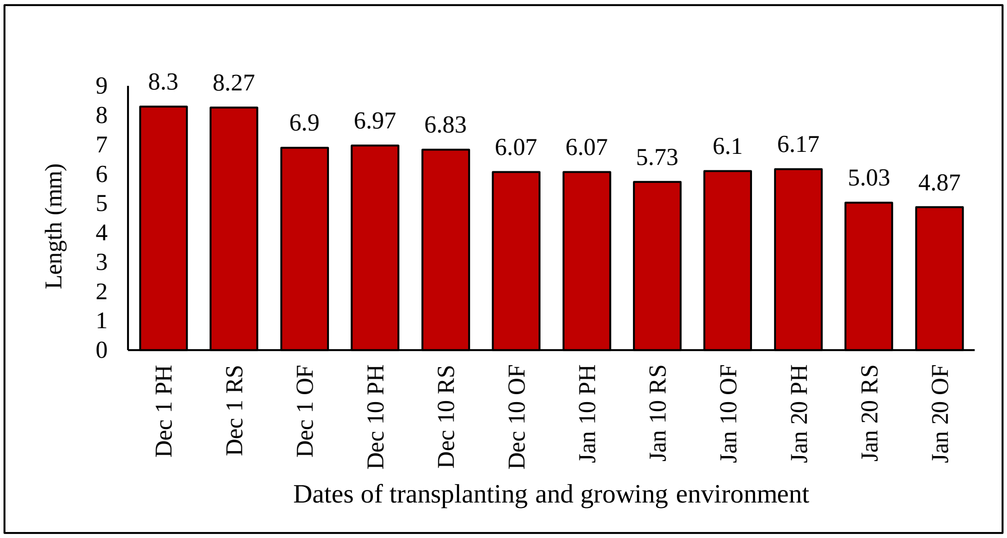


Fig 43. Mean stamen length (mm)

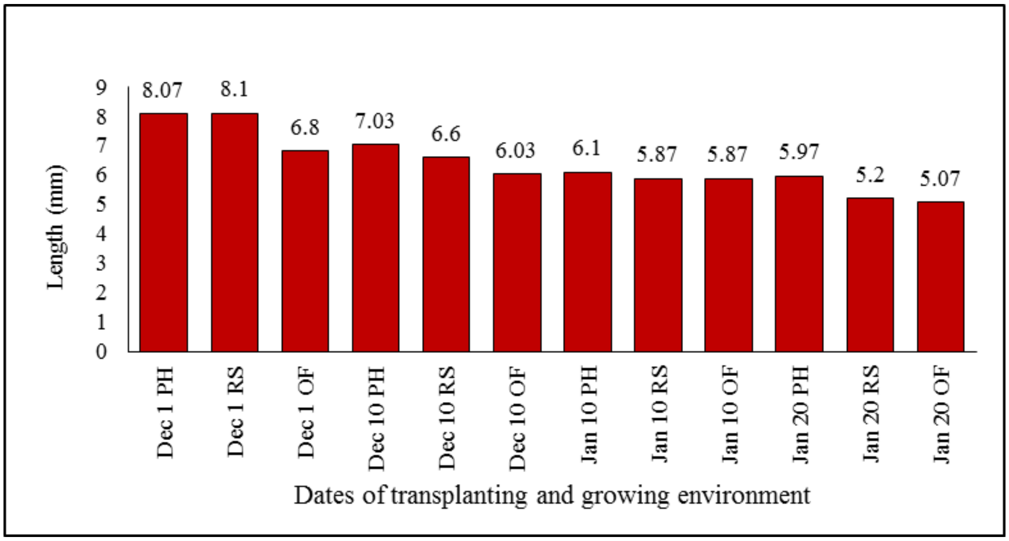


Fig 44. Mean style length

5.3 PHYSIOLOGICAL PARAMETERS

5.3.1 Leaf area index

LAI was significantly influenced by the growing environment and dates of transplanting (Fig 45, 46, 47 and 48). Crops grown inside the polyhouse and rain shelter yielded maximum LAI values. The maximum values of LAI were obtained during the flowering and fruiting stage. The maximum LAI value of 3.8 was observed among the crops transplanted in the open field on 1 December 2014 and in the crops transplanted inside the rain shelter and polyhouse on 20 January 2015.

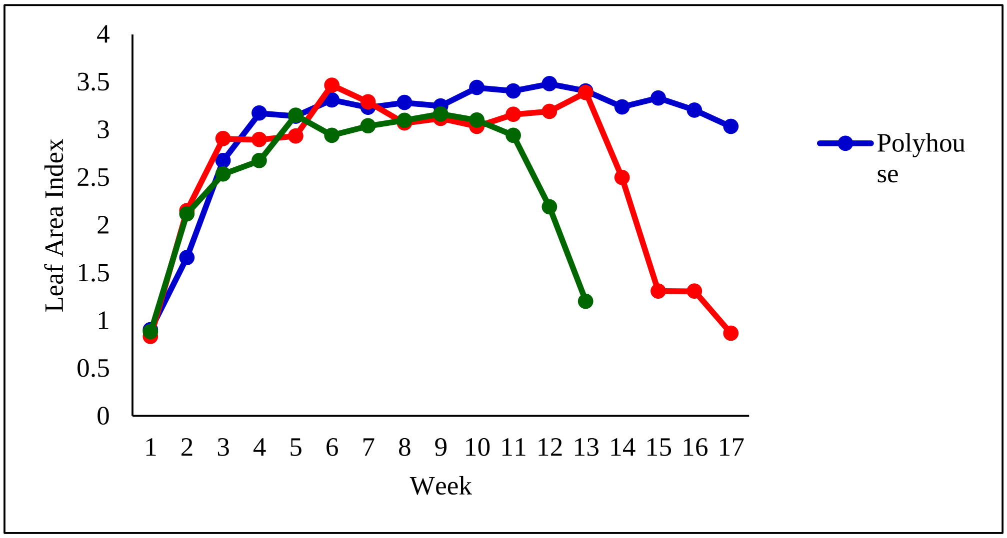


Fig 45 .Weekly variation in LAI, Date of transplanting 01 December 2014

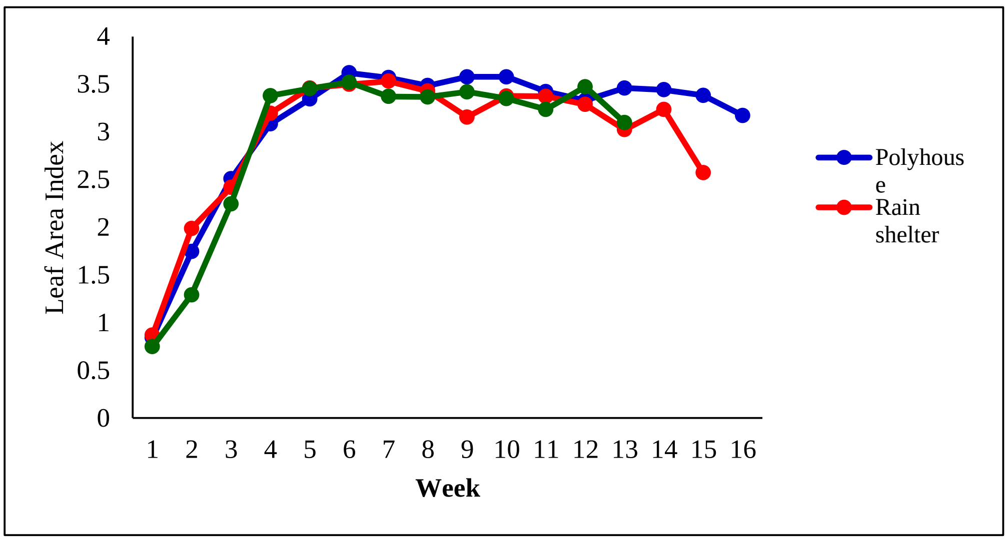


Fig 46.Weekly variation in LAI, Date of transplanting 10 December 2014

LAI showed a significant negative correlation with solar radiation, minimum relative humidity, minimum and maximum soil temperature, average soil moisture, UV radiation, canopy temperature and canopy air temperature difference. The LAI of the crops in the protected structures were consistently higher and prolonged, thus exhibiting more vegetative vigour when compared to the crops in the open field.

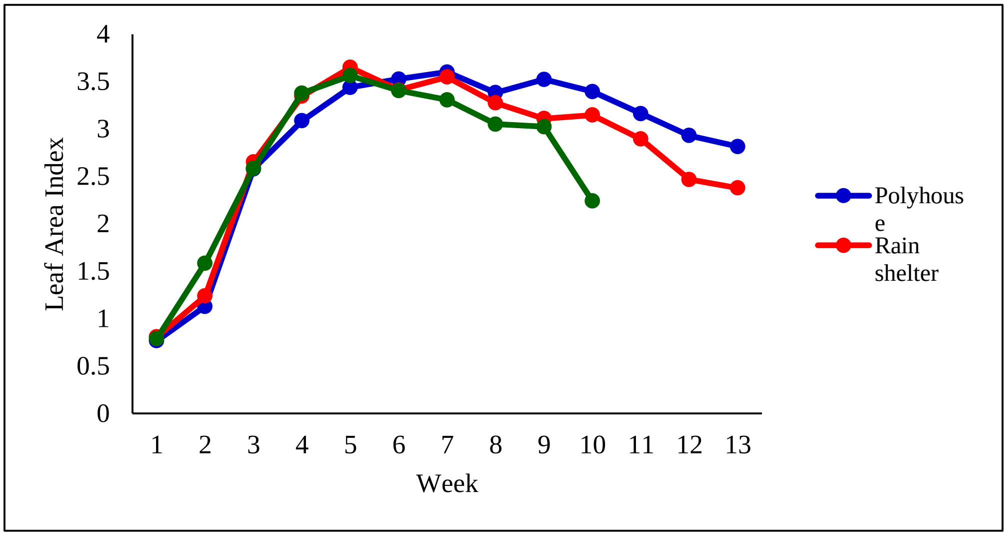


Fig 47.Weekly variation in LAI, Date of transplanting 10 January 2015

The higher LAI in the crops under the rain shelter and polyhouse may be due to lower solar radiation within the rain shelter and polyhouse. Lower solar radiations throughout the different growth stages promote leaf expansion which is needed for better light interception. Similar results were reported by Watson (1952), Milthorpe (1959) and Cockshull (1992).

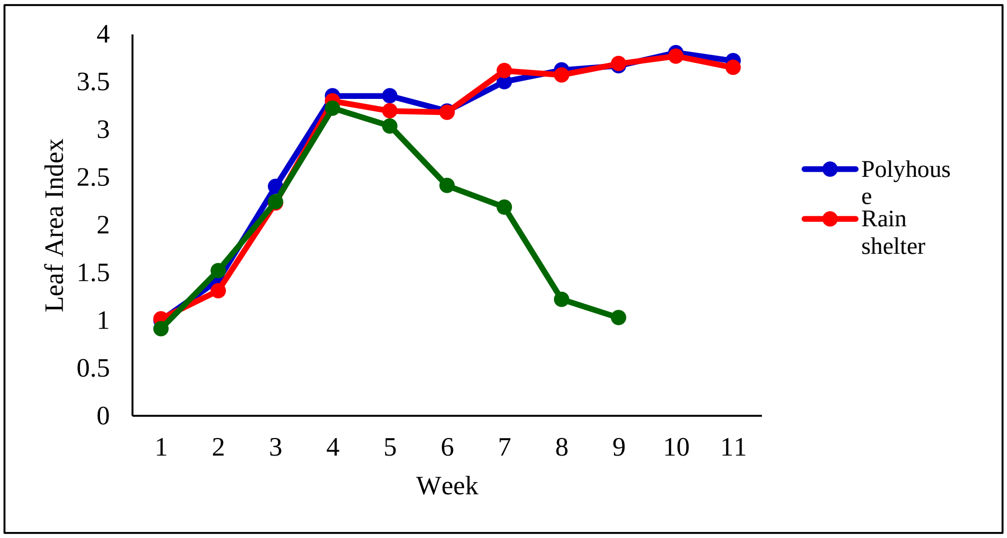


Fig 48.Weekly variation in LAI, Date of transplanting 20 January 2015

5.3.2 SPAD index

The SPAD index value was highest in the open field crops regardless of the dates of transplanting (Fig 49). The highest SPAD index value was recorded in the crops transplanted in the open field and the least values of were recorded in the crops transplanted inside the polyhouse irrespective of the dates of transplanting.

The average SPAD index values showed significant positive correlations with the solar radiation, the minimum relative humidity, the maximum soil temperature, the canopy air temperature difference. It showed a significant negative correlation with minimum temperature.

The higher SPAD index value in the crop planted in the open field is due to the higher light intensities and increased stress levels. The SPAD index value was significantly increased by the high solar radiation above 400 W m^{-2} and high canopy air temperature difference above -3.5 °C. This is supported by the findings of William and Naylor (1967), Camejo and Torres (2001), Chu *et al* (1974) and Sun and Zhang (2008).

5.3.3 Relative water content

The leaf relative water content was significantly influenced by the growing environment and dates of transplanting (Fig 50). Lowest values of leaf relative water content was recorded in the crops planted in the open field condition as compared to the crops inside the polyhouse and rain shelter, irrespective of the dates of transplanting. This is due to the fact that in the open field condition the rate of transpiration is higher and the loss of water is more, which results in lower leaf relative water content in the plants.

Higher amount of solar radiations above 300 Wm^{-2} coupled with high maximum soil temperature above 40°C and UV radiation above 35 Wm^{-2} was responsible for lower leaf relative water content in the crops transplanted in the open field.

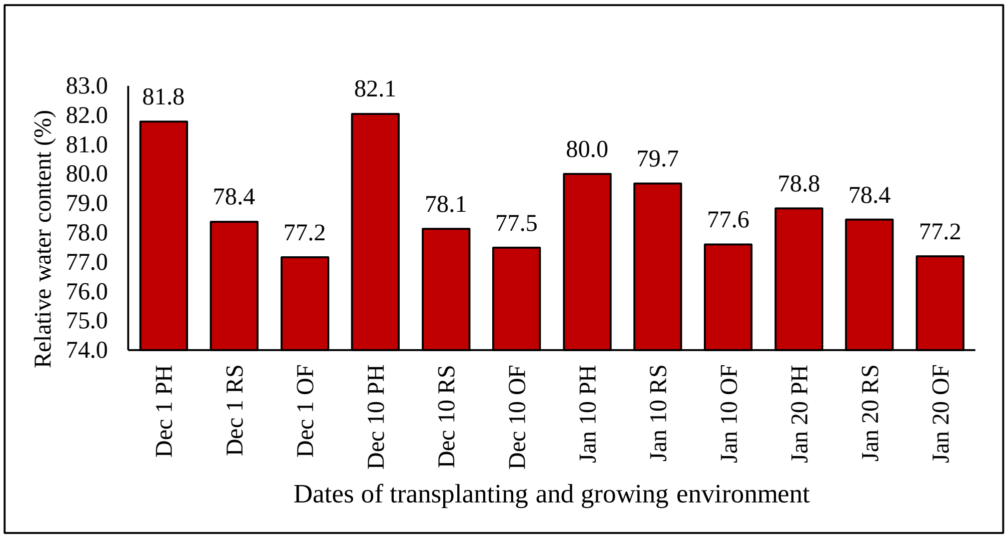


Fig 50. Leaf relative water content (%)

The total yield obtained was greatly affected by the leaf relative water content and the total yield obtained was also lowest among the crops under open field condition wherein the leaf relative water content was also the lowest. This is in confirmation with the findings of Anderson and Naughton (1973).

5.3.4 Total soluble proteins (TSP)

The total soluble protein content in the leaves showed significant positive correlation with the maximum temperature and maximum soil temperature, the minimum temperature, maximum soil temperature, UV radiation. It had negative correlations with relative humidity and average soil moisture (Fig 51 and 52).

In most of the cases, the total soluble protein content analyzed on the 30th day after transplanting showed that it was significantly increased by higher solar radiation above 400 W m^{-2}, maximum soil temperature above 40°Cduring the vegetative stage, UV radiation above 20 W m^{-2} and CATD above -3.5°C during the vegetative and flowering phase. The temperature as expected had a significant effect on the total soluble protein content. This is in confirmation with the findings of Camejo and Torres (2001), Ryo and Chieri (2010).

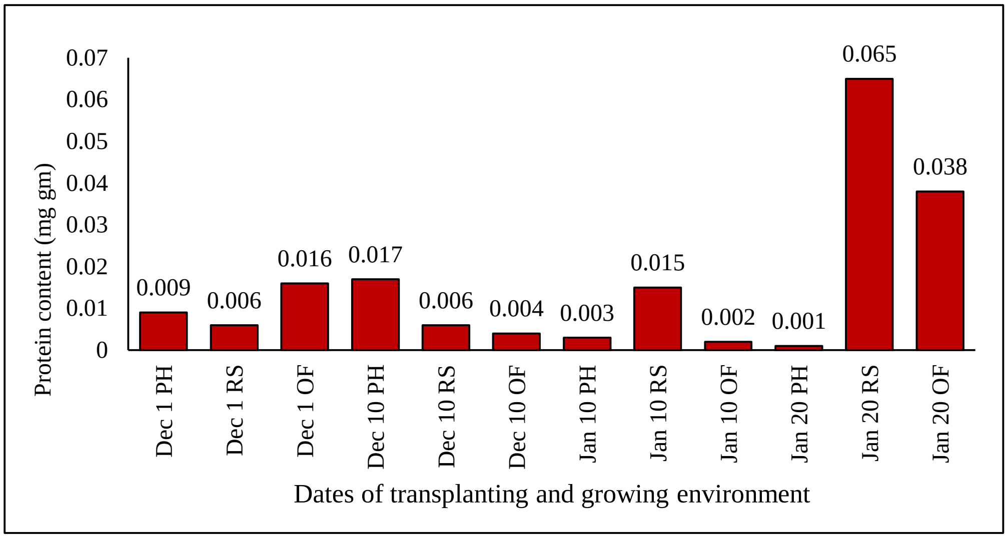


Fig 51. Total soluble protein 30 days after planting

The total soluble protein content in the leaves at day 45 showed significant positive correlation with the maximum temperature, maximum soil temperature, the minimum temperature, UV radiation. It had negative correlations with relative humidity, average soil moisture during the vegetative and fruiting stage.

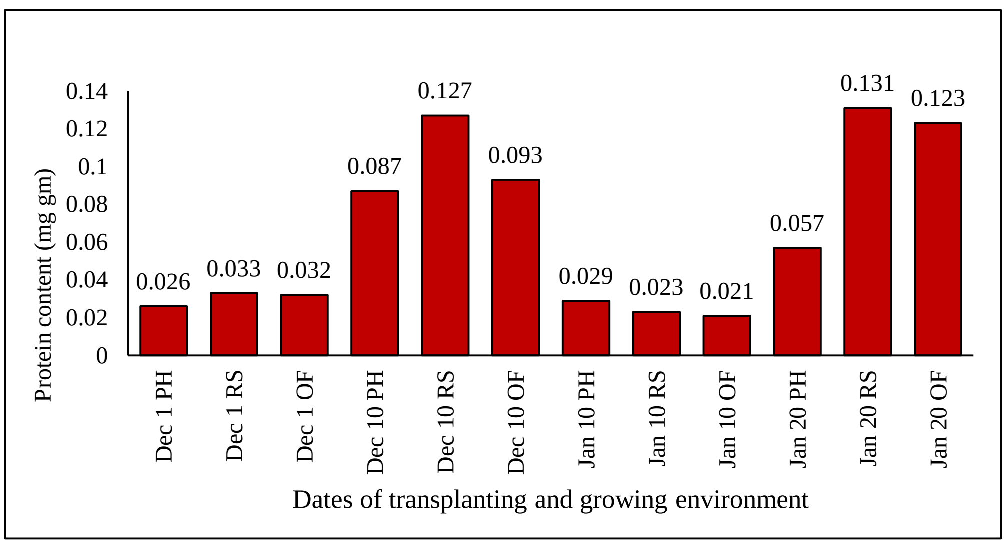


Fig 52. Total soluble protein 45 days after planting

The total soluble protein content analyzed on the 45th day showed that among the crops transplanted in the different environment, the TSP in plants in the open field and rainshelter were more affected by the fluctuating weather parameters. Higher maximum air temperatures above 36° C and maximum soil temperature above 30°C during the vegetative, flowering and fruiting stage, higher canopy temperature above 32°C and CATD above -3.5° C during the harvesting stage significantly increased the total soluble protein content. Higher temperatures associated with delayed transplanting and higher temperatures within the rainshelter resulted in higher TSP content.d These results are in confirmation with the findings of and Gulen and Eris (2004) and Essra *et al* (2010).

5.3.5 Ascorbic acid

The fruit ascorbic acid content showed a significant negative correlation with soil moisture during fruiting. It had a positive correlation with maximum temperature, maximum soil temperature and canopy temperature (Fig 53).

The fruit ascorbic acid content was significantly influenced by the lower temperatures during the vegetative, flowering and harvesting stage, higher maximum soil temperature during the flowering stage, and high canopy temperature during the flowering and fruiting stage, lower soil moisture during the fruiting and harvesting stage. This in tune with the findings of Hamnee *et al*, (1945), Crane and Zilva (1949), Harshad *et al* (1960), Lee and Kader (2000) Gautier *et al* (2008), and Pollard (2010).

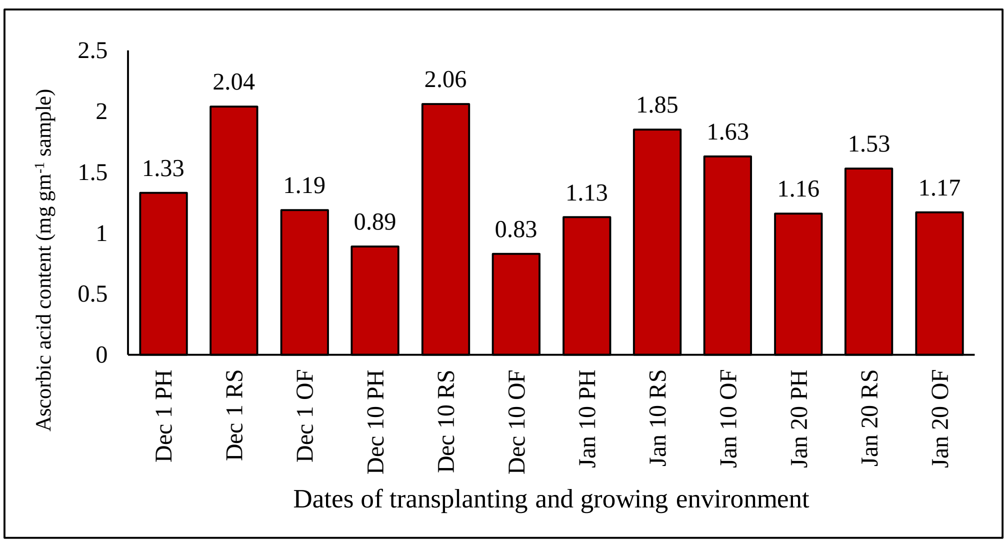


Fig 53. Fruit ascorbic acid content (mg g^{-1})

5.3.6 Fruit lycopene content

The dates of transplanting and the growing environment had a significant effect on the fruit lycopene content. Highest amount of lycopene was recorded in the fruits obtained from the polyhouse and the least values were recorded in the fruits procured from the crops in the open field, regardless of the dates of transplanting (Fig 54).

Lycopene showed a significant negative correlation with solar radiation, minimum relative humidity, maximum soil temperature, UV radiation, CATD, minimum soil temperature and canopy temperature. It had a positive correlation with minimum temperature and maximum relative humidity.

The fruits in the crops planted in the open field were exposed to higher solar radiation and UV radiation and this increased the fruit temperature immensely. When the temperature of leaves exceeds 30°C, the lycopene synthesis is inhibited. Lycopene synthesis was maximum when the temperatures were below 26°C, solar radiation was below 450 Wm^{-2} and UV radiation below 40 Wm^{-}2. The observations are in confirmation with the findings of Helyes *et al* (2007), Maharaj *et al* Rosales *et al* (2011 and Enríquez *et al*, (2013).

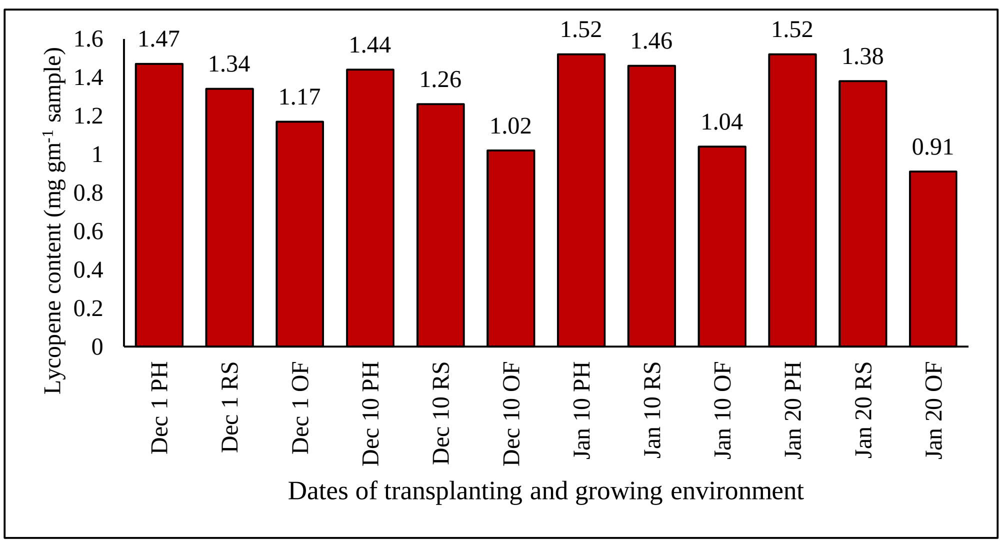


Fig 54. Fruit lycopene content

5.4 YIELD AND YIELD ATTRIBUTES

5.4.1 Number of harvests

The number of harvests was significantly influenced by the growing environment and the dates of transplanting. The greatest number of harvests was obtained from the crops grown inside the polyhouse while the least was obtained among the crops transplanted in the open field (Fig 55).

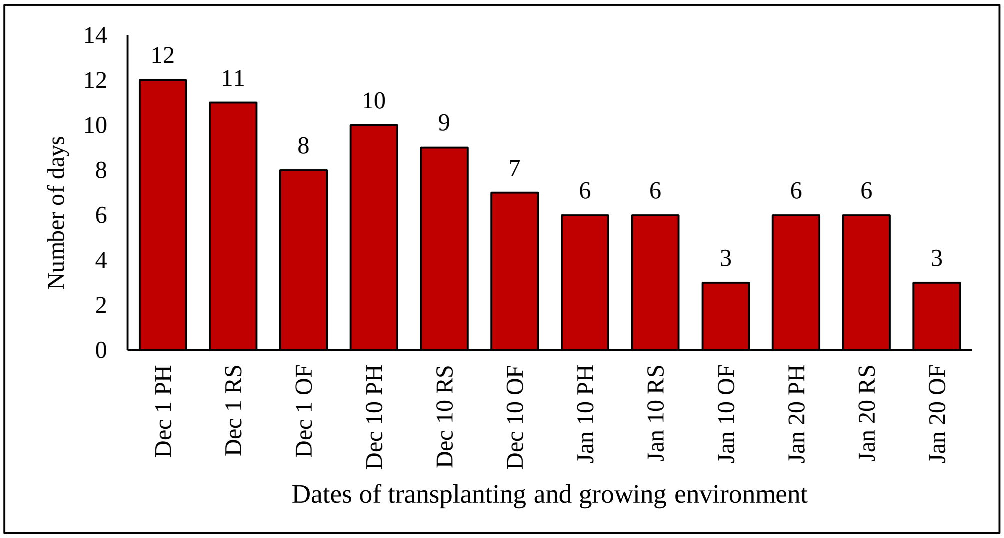


Fig 55. Number of harvest

The number of harvests was significantly reduced to less than half in all the growing environments as the transplanting were delayed and this may be due to poor fruit set and lesser number of fruit development under relatively higher temperature and reduced early morning relative humidity regimes. This was in confirmation with the findings of Shaheen *et al* (1995), Thomas (2004).

5.4.2 Percentage fruit set

The highest percentage of fruit set (61.7 and 50.1 percent respectively) was observed in the plants transplanted inside the polyhouse on 1 and 10 December 2014. Whereas, the least fruit set percentage was observed in crops planted in the open field on 10 and 20 January 2015 (Fig 56).

The per cent of fruit set occurred had significant negative correlation with the solar radiation, minimum temperature, maximum temperature, minimum relative humidity, minimum soil temperature, maximum soil temperature, UV radiation, PAR and canopy air temperature difference. Similarly, it had significant positive correlations with the solar radiation during the flowering stage, maximum relative humidity and minimum soil temperature.

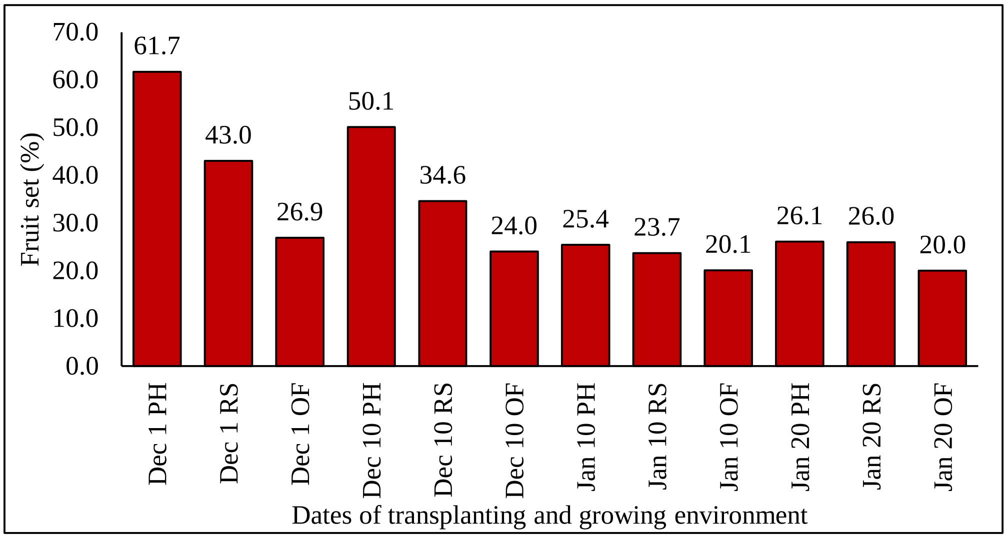


Fig 56. Percentage fruit set (%)

Irrespective of the dates of transplanting the highest and lowest fruit set consistently occurred within the polyhouse and in the plants in the open field respectively. The percentage of fruit set dropped drastically regardless of the growing environment as the dates of transplanting delayed. The failure of fruit set may be contributed to the increased minimum and maximum temperatures which resulted in style elongation, flower abortion, flower drop, production of empty flowers and persistent flowers. The same results were reported by many workers like Rao and Sreevijayapadma (1991), Bertin and Gary (1992), Lohar and Peet (1996).

5.4.3 Average fruit weight

The highest average fruit weight was recorded in the crop inside rain shelter transplanted on 20 January 2015 (59g), 10 January 2015 (56g) and 10 December 2014 (53g) followed by fruit obtained from the crop transplanted on 10 December 2014, 10 January 2015 and 20 January 2015 inside polyhouse. The lowest fruit weight was consistently obtained in the open field except for the first season (Fig 5).

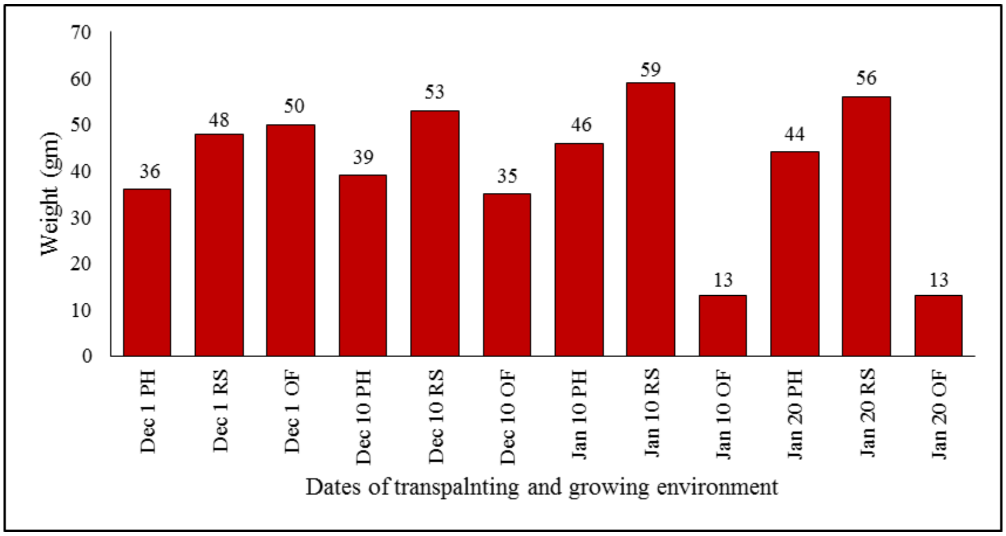


Fig 57. Average fruit weight (g)

Average fruit weight had significant negative correlations with solar radiation, low minimum relative humidity, low minimum soil temperature, low maximum soil temperature, low UV- B and CATD and low PAR. It had significant positive correlations with canopy temperature. This is in consonance with the reporting of Bakker and Van Uffelen (1988), De Konning (1994), AVRDC (2000).

5.4.4 Fruit yield per plant and total yield

The total yield in tons per hectare was found to be significantly influenced by the date of transplanting and the growing environment. The maximum yield of 111.5 tons/hectare and 111.2 tons per hectare were obtained from the crops transplanted inside the polyhouse on 1 and 10 December 2014 respectively. The yields from the crops transplanted inside the polyhouse on 1 and 10 December 2014 and the yield from the crops transplanted inside the rain shelter on 1 December 2014 were statistically similar. Regardless of the dates of transplanting the yields from the crops inside the polyhouse were consistently highest followed by the crops inside the rain shelter and open field. The lowest yields were obtained from the crops in the open field transplanted on 20 January 2015. The total yield obtained showed a declining trend with the delayed transplanting regardless of the growing environment (Fig 58 and 59).

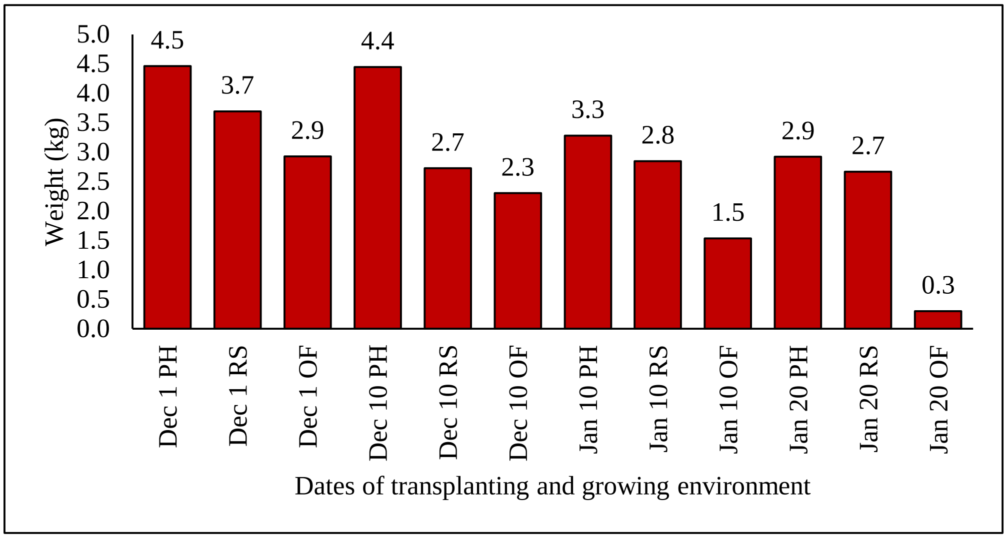


Fig 58. Fruit yield per plant (kg)

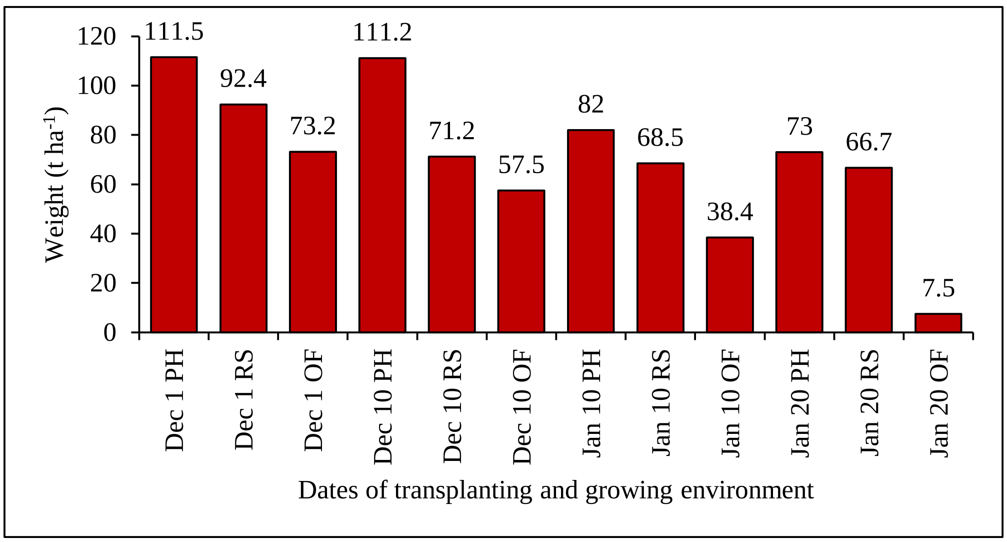


Fig 59.Total yield (t ha^{-1})

The total yield obtained had a significant negative correlation with the solar radiation, minimum air temperature, maximum air temperature, minimum soil temperature, maximum soil temperature, UV radiation, canopy air temperature difference, minimum relative humidity and PAR.

The total yield had significant positive correlations with maximum relative humidity, minimum soil temperature during the vegetative stage. The leaf area index and SPAD index value had significant positive correlation with the total yield obtained.

Whereas, total soluble proteins at day 30 and 45 after transplanting had significant negative correlations with the total yield obtained.

Lower fruit yield per plant and total yield with delay in transplanting is due to lower leaf area index in the crops which had delayed transplanting which resulted in lower light interception and photosynthate assimilation and hence lesser dry matter allocation. Lower fruit set percentage owing to increased mean temperatures and reduced humidity regimes resulting floral abnormalities, flower abortions, production of persistent and empty flowers. This is at par with the findings of Papadopoulos and Tiessen (1981), Khayat *et al* (1985), De Konning (1988), Heuvelink (1989), Muthuvel *et al* (1999).

Polyhouses being framed structures create a barrier between the plant microclimate and ambient climate, and in a way manipulate the surrounding environment congenial enough for the crops to thrive better. Within a polyhouse, it is possible to create a microclimate which is better suited for the development of crop than the outside environment, thus giving better production and uniform quality.

Polyhouse environment has a profound effect on several environment parameters particularly temperature, light, Carbon dioxide and humidity. The plant response to specific environmental parameter is related to the physiological process and to yield and quality.

Air temperature is the main environmental component influencing the vegetative growth, flower initiation, fruit setting, fruit development, fruit ripening and fruit quality.

The humidity regimes within the polyhouse were optimum for the flower initiation and fruit set and maintaining higher LAI values.

Even though, the light intensities were comparatively very less inside the polyhouse, this was the major substantiating reason for greater vegetative vigour of the plants, both in terms of height and leaf area index. Lower light intensities delayed auxin destruction and promoted cell division and expansion. Low solar radiations within the polyhouse kept the fruit temperatures in check as compared to the open field condition and this helped in the active and uniform biosynthesis of lycopene content in the fruit.

Higher LAI values, higher CO_2 content which ensured relatively higher net photosynthesis rates and higher photosynthate formations and assimilation, higher percentage fruit set, optimum soil temperature and moisture altogether resulted in better quantity and quality of tomatoes.

5.5 CLIMATE CHANGE IMPACTS ON THE PHYSIOLOGY OF TOMATO

Under the projected climate change scenarios i.e. RCP 2.6, 4.5, 6.5 and 8.0 the net SPAD index values showed an increasing trend, this is perhaps due to the fact that, temperature is increasing considerably under the different scenarios and the thermal stress expressed as a form of the canopy air temperature difference tends to attain more values. Whereas, qualitatively speaking the ascorbic acid content increased in the fruit owing to higher temperature and lower soil moisture availability.

The lycopene content remained unaffected as the UV concentration is changing negligibly for the region where the study was conducted.

The total duration of the crop will also be reduced due to increased temperature regime during the different RCP scenarios in 2030, 2050 and 2080

Summary

An experiment was conducted at the Central Nursery, Vellanikkara to study the effect of growing environment and climate change on the physiology of tomato, *Lycopersicon esculentum* Mill.

1. The results of the study showed that the dates of transplanting and the growing environment had a significant effect on the floral characters, phenological, physiological and yield parameters.
2. The crop transplanted on 1 December 2014 had the longest duration (114 days).

   Maximum leaf area index (3.8) was observed in in the crop transplanted in open field, polyhouse and rain shelter on different dates on different dates (1 December 2014 and 20 January 2015 respectively).
3. The highest values of leaf relative water content was observed in the first week following transplanting and the lowest values appeared prior to the last harvest regardless of the dates of transplanting and growing environment.
4. The lycopene content was consistently highest in the crops inside the Polyhouse. The highest value for the same was 1.52 mg gm^{-1} was recorded in crops inside the polyhouse transplanted on 10 January 2015.
5. The fruit ascorbic acid content (2.06 mg gm^{-1}) was highest in the crop inside rain shelter transplanted on 10 December 2014.
6. The highest mean length of style was documented in the flowers of the crop transplanted inside rain shelter (8.08 mm) on 1 December 2014 whereas, the highest mean stamen length was recorded in the flowers of the crop transplanted inside polyhouse (8.30 mm) on 1 December 2014).
7. The difference in the length of the style and stamen and its relative position significantly affected the total yield obtained. A difference of more than -0.05 mm considerably reduced the yield.
8. The highest yield (111.5 tons ha^{-1}) was recorded inside the polyhouse in the crops transplanted on 1 December 2014.
9. The net photosynthesis rate was highest in the rain shelter crops regardless of the dates of transplanting. The highest values recorded was 19.7 in the rain shelter and poly house for the crops transplanted on 10 and 20 January 2015.

The temperature prevalent was the most crucial factor determining the rate of photosynthesis followed by Carbon dioxide.

10. The lycopene content remained unaffected as the UV concentration is changing negligibly for the region where the study was conducted.
11. The duration of the crop reduced drastically from 2030 to 2080 under all the scenarios.
12. The results also showed that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO_2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in temperature.

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EFFECT OF GROWING ENVIRONMENT AND CLIMATE CHANGE ON THE PHYSIOLOGY OF TOMATO, *Lycopersicon esculentum* Mill.

By

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ABSTRACT OF THE THESIS

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The present world production of tomato stands at 100 million tons fresh fruits produced on 3.7 million hectares. Even though productivity levels of tomato have increased, it will not be sufficient enough to the increasing population.

Global climate change is any significant long term change in expected patterns of weather over a region which may be naturally induced or anthropogenic. The effect of climate change on crop and terrestrial food production are evident in several regions of the world. Negative impacts of climate trends have been more common than positive ones.

Objectives of the study were to study the effect of different growing environment and climate change on the physiological traits of tomato development of crop weather relationships for the selected rice varieties and assessment of possible change in yield due to climate change. The studies were conducted during December 2014- March 15at the Central Nursery, Vellanikkara in the bacterial wilt resistant variety Anagha by providing three different growing environments namely polyhouse, rainshelter and open field conditions with four dates of transplanting.

The results showed that the dates of transplanting and growing environment had a significant effect on the physiology of tomato. The crop transplanted inside the polyhouse took the longest duration. Maximum leaf area index (3.8) was observed in in the crop transplanted in open field, polyhouse and rain shelter on different dates on different dates (1 December 2014 and 20 January 2015 respectively). The highest values of leaf relative water content was observed in the first week following transplanting and the lowest values appeared prior to the last harvest regardless of the dates of transplanting and growing environment. The lycopene content was consistently highest in the crops inside the Polyhouse. The highest value for the same was 1.52 mg gm^{-1} was recorded in crops inside the polyhouse transplanted on 10 January 2015.The fruit ascorbic acid content (2.06 mg gm^{-1}) was highest in the crop inside rain shelter transplanted on 10 December 2014. The highest mean length of style was documented in the flowers of the crop transplanted inside rain shelter (8.08 mm) on 1 December 2014 whereas, the highest mean stamen length was recorded in the flowers of the crop transplanted inside polyhouse (8.28 mm) on 1 December

2014). The difference in the length of the style and stamen and its relative position significantly affected the total yield obtained. A difference of more than -0.05 mm considerably reduced the yield. The highest yield (111.5 tons ha^{-1}) was recorded inside the polyhouse in the crops transplanted on 1 December 2014. The net photosynthesis rate was highest in the rain shelter crops regardless of the dates of transplanting. The highest values recorded was 19.7 in the rain shelter and poly house for the crops transplanted on 10 and 20 January 2015. The temperature prevalent was the most crucial factor determining the rate of photosynthesis followed by Carbon dioxide.

Under the projected climate change scenarios i.e. RCP 2.6, 4.5, 6.5 and 8.0, the ascorbic acid content increased in the fruit owing to higher temperature and lower soil moisture availability. The lycopene content remained unaffected as the UV radiation concentration is will be changing negligibly for the region where the study is conducted. The duration of the crop will be reduced drastically from 2030 to 2080 under all the scenarios. The results also showed that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO_2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in temperature.

Appendices

	SR	Tmin	Tmax	RHmin	RHmax	STmin	STmax	SM
01-12-14	1208	24.8	32.9	44	76	24.6	33.8	40.25
02-12-14	1208	22.7	32.9	80	86	22.1	22.7	40.3
03-12-14	987	20.8	36.7	45	97	20.4	43.6	40.35
04-12-14	1059	22.2	34.7	45	100	22.5	38.5	40.4
05-12-14	1117	20	33.4	50	85	21.1	34.6	40.35
06-12-14	1016	19.6	34.5	46	90	20.8	36.2	40.35
07-12-14	988	21.9	35.3	54	97	22.6	37.3	40.4
08-12-14	1035	23.2	35.7	54	99	24.1	36	40.4
09-12-14	970	23.8	35.9	54	99	25.1	36.8	40.45
10-12-14	1133	24.4	33.6	62	99	25.3	33.8	40.4
11-12-14	892	24.2	32.9	66	98	24.5	32.3	40.35
12-12-14	1054	23.6	35.3	58	99	24.4	35.4	40.4
13-12-14	1072	24.3	36	54	99	24.6	36.7	38.45
14-12-14	1099	23.3	36.3	55	100	24.3	38	39.05
15-12-14	1041	24.7	36.2	50	98	25.4	38.1	39.2
16-12-14	1028	22.8	36.1	49	100	24.1	38.6	40.4
17-12-14	1016	24.9	35.5	52	81	25	38.5	40.45
18-12-14	1013	25.6	31.3	64	85	24.6	29.6	40.35
19-12-14	909	25.6	33.4	60	86	24.6	33.9	39.05
20-12-14	988	24.5	32.1	61	81	24	32.7	36.05
21-12-14	1005	22.8	35	52	95	24	40.7	35.25
22-12-14	936	22.4	34.1	51	96	23.4	53.5	28.45
23-12-14	987	22.9	35.2	53	93	23.4	36.3	32.35
24-12-14	1033	23.8	34.9	52	85	23.8	53.1	36.2
25-12-14	998	23.4	35.1	52	93	24	34.9	39.3
26-12-14	853	21.9	30.8	58	97	24	30.3	40.3
27-12-14	1116	21.8	33.1	48	84	23.5	32.4	40.35
28-12-14	735	23.8	32.7	56	86	23.5	30.7	40.4
29-12-14	1018	22.4	36.8	49	95	23.8	34.8	40.45
30-12-14	929	24.5	34	59	98	23.8	33.3	40.45
31-12-14	935	24.4	33	66	99	25.6	40.1	40.4
01-01-15	1085	22.4	33.5	60	99	25.6	48.8	40.35
02-01-15	1009	22.4	34.8	35	99	21.9	56.9	40.35
03-01-15	1083	21.2	33.9	50	99	21.9	34.8	40.35
04-01-15	1047	21.6	35.4	47	99	22.8	53.2	40.4
05-01-15	1016	21.4	35.8	50	98	23.4	33.9	38.8
06-01-15	990	21.8	36.2	41	99	23.4	48.3	35.85
07-01-15	1061	26	35.5	46	70	26.5	46.7	27.05
08-01-15	902	26	33.8	56	86	26.5	33.3	25.6
09-01-15	915	26	35.6	50	81	24.5	35.2	25.9
10-01-15	972	26.1	36	41	73	24.1	53.8	30.15

11-01-15	1046	24.6	35	29	57	21.7	33.2	29.85
12-01-15	1010	24.3	33.5	37	65	21.7	32.4	29.7
13-01-15	1016	23.1	33.8	39	70	22.5	47.6	38.1
14-01-15	970	21.2	34.3	42	93	22.7	44.5	30.45
15-01-15	948	20.5	34.3	43	95	20.7	51	27.2
16-01-15	983	20.2	35.1	39	96	20.5	45.2	29.1
17-01-15	973	21	35.2	47	97	22.3	46.3	31.6
18-01-15	956	21.7	35.2	46	94	22.3	36.2	30.7
19-01-15	944	22.3	35.1	46	91	21.4	37.9	26.3
20-01-15	945	22.4	35.5	39	87	21.5	37.3	29.6
21-01-15	920	25.3	35	41	55	22.5	39.3	29.3
22-01-15	994	24.8	35.6	34	70	23.7	39.5	28.75
23-01-15	1041	25.3	35	43	75	24.5	42.1	25.65
24-01-15	1027	23.8	36.2	46	70	24.3	38	34.25
25-01-15	1026	24.6	37.1	39	75	24.3	44.7	29.75
26-01-15	1050	24.7	35.9	38	69	25	48.9	29.75
27-01-15	1028	25.1	35.4	39	65	28.8	49.3	29
28-01-15	1021	25.7	36.3	45	70	25	55.8	29.8
29-01-15	1005	25.5	35.7	47	75	26.9	53	28.3
30-01-15	985	26.1	35.2	51	72	24.5	35.6	28.25
31-01-15	994	25.7	35.7	39	72	24.5	37.7	28.85
01-02-15	1031	24.8	35.6	41	67	22.8	49.6	27.4
02-02-15	1059	26.9	36.1	37	63	24.6	34.1	27.6
03-02-15	1107	25.3	35.7	38	63	21.2	37.5	33.7
04-02-15	1223	27.4	35.6	36	61	25	46.2	35.1
05-02-15	878	22.8	34.2	37	68	25.5	43.6	29.35
06-02-15	1044	25.5	37.5	27	59	23.6	52.5	28.05
07-02-15	1034	24.9	37.2	35	60	25	35.5	24.7
08-02-15	1033	24.5	37.2	36	72	22.9	37.1	26.95
09-02-15	1088	24.5	37.8	28	76	24.4	34.8	30.35
10-02-15	1094	24.8	36.1	35	72	22.3	33.9	34.4
11-02-15	1049	24.8	36.9	37	72	22.3	35.4	27.2
12-02-15	1047	24.8	37.6	37	70	24.3	36.9	27.5
13-02-15	1031	24.8	36.4	40	73	24.3	38	28.55
14-02-15	1077	27.7	37.8	41	82	24.3	37.5	32.95
15-02-15	1030	27.7	37.5	30	65	25.2	51.8	31.55
16-02-15	1087	27.1	38.1	25	73	29	57.3	27.35
17-02-15	1069	27.1	37.4	30	78	29	55.9	31.45
18-02-15	1066	26.6	35.5	46	69	32.7	52.3	34.5
19-02-15	1151	26.6	37.2	38	83	28.6	56.7	33.05
20-02-15	1133	25.8	38.5	21	68	27.5	55.1	33.75
21-02-15	1141	26.6	37.7	27	63	26.6	52.6	31.2
22-02-15	1160	26.3	38.6	21	60	26.2	55.9	30.1

23-02-15	1154	26.7	39.2	21	45	23.3	60	37.85
24-02-15	1165	26	39	19	46	22.1	51.5	30.9
25-02-15	1113	26.3	38.4	31	57	24	56.8	30.8
26-02-15	1075	27.8	34.7	52	76	25	35.5	29.7
27-02-15	1086	27.8	36.1	53	85	25	35.4	35.8
28-02-15	1066	27.6	36.4	48	74	25.8	36.9	30.6
01-03-15	1221	28.1	36.6	48	73	26.5	38.3	29.5
02-03-15	1206	28.1	35.6	59	80	29.5	52.5	35.2
03-03-15	1203	24.2	35.6	51	77	25.4	53.8	33.75
04-03-15	1104	24.2	36.9	45	69	25.4	59.5	31.15
05-03-15	1178	28.1	38.8	48	68	27.4	56.8	37.95
06-03-15	1241	28.1	38.4	42	65	20.3	56.2	31.6
07-03-15	1111	29	37.5	50	77	30.3	56.4	30.95
08-03-15	1189	28.5	38.3	48	73	28.2	60.8	32.9
09-03-15	1227	27.2	37.6	40	87	29.8	61.9	32.75
10-03-15	1113	29	38.6	36	69	29.6	60.6	33.8
11-03-15	1186	27.9	39.3	28	62	28.1	65.3	36.6
12-03-15	1184	21.6	38.8	36	65	26.2	63.6	30.1
13-03-15	1170	29.1	39.2	33	62	28.4	64.5	30.3
14-03-15	1262	28.4	38.6	39	71	28.2	60.6	33.65
15-03-15	1241	29.5	38.1	44	79	29.5	61.4	32.1
16-03-15	1239	27.6	39.6	44	93	29.4	57.5	31.55
17-03-15	1228	30.3	37.4	50	83	30.6	50	31.65
18-03-15	1191	30.2	38.4	47	78	30.2	51.9	32.25
19-03-15	1216	30.2	38.7	49	82	24.7	56	31.65
20-03-15	1204	29.7	40.4	28	85	30.4	43.1	28.45
21-03-15	1184	29.7	41.4	21	77	27.9	43.5	27.4
22-03-15	1137	21.8	42.2	26	86	19.2	42.7	31.6
23-03-15	1146	28.2	37.9	50	86	27.1	39.6	30.9
24-03-15	1123	24.9	37.2	50	82	27.6	39.4	28
25-03-15	977	29.2	37.9	50	84	28.3	39.9	26.5
26-03-15	1148	29	40.6	28	83	27.9	41.4	30.1
27-03-15	1171	28.3	41.4	22	75	26.9	43	26.85
28-03-15	1145	28.3	41	27	78	26.9	43.9	23.35
29-03-15	1157	27.5	41.1	31	73	27.4	43.9	26.45
30-03-15	1227	29.9	40	44	83	29	41.5	30.2
31-03-15	1045	29.4	38.6	56	79	28.2	39.3	30.3
01-04-15	1045	29.4	38.6	54	87	28.1	39.3	27.85

Daily weather data (open field)

	SR	Tmin	Tmax	RHmin	RHmax	STmin	STmax	SM
01-12-14	631	25	32.6	44	78	24.6	35.4	40.55
02-12-14	631	22.7	23.5	84	88	24.3	24.5	40.55
03-12-14	311	21.1	36.9	34	94	22.5	34.1	32.8
04-12-14	344	22.2	34.9	32	94	23.7	32.6	40.75
05-12-14	375	20.9	34.2	35	93	22.5	31.2	40.7
06-12-14	350	20	34.6	34	93	22	31.8	40.7
07-12-14	342	22.6	35.5	38	93	23.6	33.3	40.75
08-12-14	353	22.9	36.4	41	94	24.9	33.3	40.8
09-12-14	346	23.5	36.1	41	94	25.6	33.9	40.8
10-12-14	386	24.1	34.5	50	94	26	31.9	40.75
11-12-14	322	24.2	33	55	93	25.5	30.1	40.75
12-12-14	331	23.4	35.5	45	94	25.3	32.5	40.8
13-12-14	355	24.2	36.1	38	93	25.8	32.8	40.8
14-12-14	384	23	36.3	40	93	25.3	33.7	40.8
15-12-14	357	24.4	36.3	37	93	26.1	33.4	40.85
16-12-14	354	22.8	36.1	37	93	25.3	33.6	40.8
17-12-14	342	25.3	35.5	40	86	26.1	33	40.8
18-12-14	352	25.7	31	62	84	25.6	27.7	40.75
19-12-14	328	25.7	33.3	50	85	25.3	29.6	40.8
20-12-14	1166	24.9	32.3	50	86	25.1	29.4	40.7
21-12-14	574	23	35.8	37	92	23.8	32.9	29
22-12-14	1345	22.4	35	38	93	24.5	32.2	32.25
23-12-14	1483	23	35.9	39	93	24.4	31.6	28.85
24-12-14	1245	24.2	35.1	37	93	24.7	32.5	32.4
25-12-14	1241	23.6	35.5	37	92	24.9	31.7	32.4
26-12-14	1076	22.6	30.9	49	93	24.3	28.2	28.9
27-12-14	1355	22	33.4	35	91	23.2	30.1	28.35
28-12-14	791	23.9	32.9	44	91	24.2	29.8	29.4
29-12-14	1488	22	37.1	36	93	24	31.8	30.95
30-12-14	730	24.2	34.4	44	93	25.6	32	29.45
31-12-14	1461	24	33.1	54	92	25.7	30.7	30.55
01-01-15	884	21.9	33.4	51	92	25.4	30.1	28.95
02-01-15	1463	19.4	35.7	30	93	22.9	30.7	31.7
03-01-15	1460	20.8	34.9	39	92	23.4	30.2	31.65
04-01-15	1455	21.4	35.8	33	90	24	30.8	32.8
05-01-15	1446	21.3	35.8	37	91	24	30.5	28.25
06-01-15	980	21.6	36	30	90	24	30.1	28.65
07-01-15	363	27.3	35.9	33	74	24.1	30.5	31.95
08-01-15	722	27.3	34.4	43	88	24.1	29.9	31.3
09-01-15	335	27.1	35.7	37	83	24.8	30.5	28.65
10-01-15	1505	27.5	35.8	30	75	24.6	30.5	29.7

11-01-15	383	25.7	35.4	22	57	23	28.9	27.6
12-01-15	373	25	33.9	29	65	22.2	28	31.75
13-01-15	954	24.2	34	27	70	21.5	27.5	35
14-01-15	433	21.4	34.4	30	89	21	28.8	26.2
15-01-15	1121	20.6	34.3	32	89	22.4	28.6	29.65
16-01-15	1402	20.1	35.6	29	88	22.2	29	24.65
17-01-15	1037	21	35.5	34	89	23.2	29.3	25.3
18-01-15	1415	21.9	35.4	33	88	23.6	29.5	25.6
19-01-15	742	22.3	35.6	31	88	23.2	28.7	25.3
20-01-15	1167	22.6	35.7	28	88	23.3	29.1	27.1
21-01-15	758	26.2	35.2	30	55	23.1	28.1	27.9
22-01-15	368	25.5	36.4	23	71	23.4	28.8	27.95
23-01-15	365	27.1	35.9	29	78	23.3	29.2	26
24-01-15	885	27.2	36.2	31	77	23.8	29.5	33.15
25-01-15	409	22.3	36.9	29	75	23.8	29.6	26.8
26-01-15	385	25.7	35.6	28	68	23.5	28.9	24.75
27-01-15	607	26.3	35.8	28	67	23.6	29	24.4
28-01-15	352	27.2	36.3	31	73	23	29.2	25.85
29-01-15	344	26.1	36.4	34	75	24	29.4	29.8
30-01-15	608	27.3	35.5	38	73	24.2	29.5	29.4
31-01-15	336	26.7	36.1	30	71	23.9	28.8	29
01-02-15	1006	26	36.5	30	68	23.4	28.8	31.5
02-02-15	483	28	35.5	33	64	23.4	28.4	31.35
03-02-15	390	27.7	36.1	28	63	23.4	28.5	28.45
04-02-15	843	28.5	36.4	30	61	24	29.5	32.2
05-02-15	301	28.5	35.1	33	67	24.4	28.2	31.7
06-02-15	339	26.6	37.7	23	59	16.6	28.7	32.3
07-02-15	340	25.9	37.2	26	59	23.3	29.3	31.95
08-02-15	348	25.3	37.5	26	72	23.4	29.9	32.85
09-02-15	385	25.3	37.7	20	76	24	29.1	36.8
10-02-15	347	25.7	36.4	25	72	23	28.9	36.75
11-02-15	359	25.7	37.4	25	71	23	29.3	31.3
12-02-15	486	21.2	38.2	26	71	24.3	29.6	35.55
13-02-15	334	23.4	37.8	28	74	24.3	30.1	36.35
14-02-15	845	26.3	38.4	30	85	24.3	30.7	32.8
15-02-15	1311	30	38.8	22	73	25.6	30.2	32.5
16-02-15	373	29.8	38.7	18	82	25	30.1	30.45
17-02-15	342	23.7	38.2	23	84	25	29.9	31.45
18-02-15	669	31	35.9	36	72	25.2	30.3	33.4
19-02-15	367	27.2	38.7	33	87	25	30.6	33.2
20-02-15	375	27.2	38.4	33	71	24.5	29.5	32.15
21-02-15	383	27.9	37.9	23	67	23.6	28.8	29.7

22-02-15	384	27.9	38.8	23	63	23	29.2	29.25
23-02-15	630	28.5	38.5	23	51	21.7	28.9	33.15
24-02-15	368	27.8	39.4	23	49	21.9	28.9	28.2
25-02-15	370	28.2	38.8	24	49	22.4	29.9	29.5
26-02-15	657	29.3	35.1	42	82	23.7	28.4	28.4
27-02-15	356	28.1	36.2	44	85	24.9	29.1	32.5
28-02-15	374	28.8	36	39	79	24.7	29.6	29.55
01-03-15	690	29.5	36.3	41	80	24.7	30.1	29.8
02-03-15	415	28.5	35.6	50	83	24.7	30	31.95
03-03-15	1028	28.2	36.6	41	80	24.9	30.3	30.4
04-03-15	365	19.6	36.8	37	79	19.8	30.2	29.85
05-03-15	377	29.8	38.6	36	80	24.7	30.5	30.7
06-03-15	858	29.8	39.4	33	72	24.7	30.8	31.25
07-03-15	371	30.2	37.4	41	80	26.1	30.3	29.35
08-03-15	405	31.4	37.7	37	81	25.8	30	30.35
09-03-15	1046	28.5	37.8	32	84	25.9	31.4	32.6
10-03-15	488	30.4	39.3	27	72	26	30.5	34
11-03-15	417	29.3	39.7	19	64	25	29.9	36.85
12-03-15	416	23.8	39	25	67	24.9	30.1	30.5
13-03-15	468	30.6	39.6	24	69	25.4	31.1	30.45
14-03-15	435	29.2	39	28	73	25.8	29.8	34.1
15-03-15	414	31.3	38.7	32	73	25.9	29.6	33.15
16-03-15	745	27.7	39.4	31	85	25.9	31.5	31.7
17-03-15	766	31.3	37.4	39	78	26.4	30.7	32.3
18-03-15	755	31.4	37.8	37	85	26.5	32.2	32.6
19-03-15	760	19.2	37.9	38	84	16.9	31.9	32.25
20-03-15	763	31	39.8	20	84	26.7	32.6	31.9
21-03-15	733	31.1	41	20	81	26.8	33.1	31.8
22-03-15	709	31.1	41.2	18	84	21.6	32.1	33.35
23-03-15	682	29.1	37.4	44	83	26.7	32.4	32.15
24-03-15	710	25.7	36.9	45	84	23.8	32.8	31.4
25-03-15	615	30.2	36.9	47	83	27.8	33.4	31.35
26-03-15	709	30	40.9	24	83	27.4	34.2	31.25
27-03-15	759	29.5	40.9	19	77	26.9	34.8	33.35
28-03-15	713	29.5	40.8	20	80	26.9	35.9	26.7
29-03-15	725	30.7	40.7	24	81	27.2	35.5	21.1
30-03-15	768	30.9	38.9	44	84	28.2	35.4	25.5
31-03-15	626	30.6	38.3	48	83	27.5	33.5	22.1
01-04-15	124	30.3	38.3	48	75	27.5	33.5	22.1

Daily weather data (Poly house)

	SR	Tmin	Tmax	RHmin	RHmax	STmin	STmax	SM
01-12-14	631	24.4	31.4	44	73	22.1	50.8	40.35
02-12-14	631	22.5	31.4	44	84	22.5	50.8	40.35
03-12-14	311	20.9	38.9	42	88	20.9	51.5	40.35
04-12-14	344	22.4	35.3	43	89	23	32.2	40.4
05-12-14	375	20.5	34.7	46	87	21.6	31.5	40.4
06-12-14	350	19.9	34.8	43	87	21.3	32.1	40.35
07-12-14	342	22.1	36.7	49	87	23	32.9	40.4
08-12-14	353	23.4	37.3	51	88	24.2	33.5	40.5
09-12-14	346	24.1	36.9	50	89	25.1	33.6	40.5
10-12-14	386	24.7	34.9	60	88	25.3	31.8	40.45
11-12-14	322	24.3	33.5	63	88	24.8	31.4	40.4
12-12-14	331	23.8	36.1	54	88	24.7	32.9	40.45
13-12-14	355	24.5	37.1	51	88	25.1	33.6	40.45
14-12-14	384	23.6	37.1	51	89	24.6	33.9	40.5
15-12-14	357	25	37.2	47	87	25.5	33.8	40.5
16-12-14	354	23.3	36.8	46	89	24.4	33.5	40.45
17-12-14	342	24.8	36.3	47	81	25.4	33.7	40.5
18-12-14	352	25.7	29.9	60	83	24.9	28.4	40.4
19-12-14	328	25.7	32.8	57	83	24.6	30.4	40.45
20-12-14	1166	24.4	31.8	58	81	24.2	30.1	35.4
21-12-14	574	23.1	38.1	47	87	23	39.6	31.35
22-12-14	1345	23	35.6	48	87	23.6	48	38.2
23-12-14	1483	23.3	36.9	50	87	23.5	36.4	32.5
24-12-14	1245	23.8	36.1	50	85	23.9	50.2	36.65
25-12-14	1241	23.6	37.2	48	87	24	35.5	35.1
26-12-14	1076	22.2	30.9	56	88	23.4	43.8	34.85
27-12-14	1355	22.2	34.3	45	85	22.4	32	32.05
28-12-14	791	23.8	32.9	53	85	23.6	46.9	29.4
29-12-14	1488	22.6	39.4	43	87	23.3	38.7	34.15
30-12-14	730	24.7	37	55	89	25.1	44.4	32.85
31-12-14	1461	24.6	35.3	61	89	25	41.9	37.45
01-01-15	884	23	34.8	59	89	24.6	37.3	34.15
02-01-15	1463	20.9	38.7	33	90	21.9	48.7	41.15
03-01-15	1460	21.7	36.9	49	89	22.4	36	34.2
04-01-15	1455	22.3	38.9	45	90	23	52.1	39.6
05-01-15	1446	22	36.9	47	89	23.1	33.1	36.15
06-01-15	980	22.1	36.8	41	89	23.1	54.4	29.9
07-01-15	363	26	38.4	41	72	23.9	45.7	28.65
08-01-15	722	26	36.7	54	83	23.9	30.6	29.3
09-01-15	335	26.1	37.3	46	82	24.1	32.2	26.5

10-01-15	1505	26	36.7	40	74	24	49.6	23.95
11-01-15	383	24.8	35.1	30	58	22.1	30	21.85
12-01-15	373	24.2	34.9	37	64	21.4	29.1	30
13-01-15	954	23.1	34.5	38	72	20.5	29.6	31.5
14-01-15	433	22	37.1	38	86	20.2	34	25.85
15-01-15	1121	21.2	36.7	40	87	21.1	50.1	26.4
16-01-15	1402	20.8	36.7	37	87	20.9	31.7	31.15
17-01-15	1037	21.4	37.3	43	88	22.3	52.8	23.5
18-01-15	1415	22.4	36	42	87	22.4	34.5	29.3
19-01-15	742	22.6	34.9	41	85	22.1	51.7	28.7
20-01-15	1167	22.8	36.7	37	85	22.1	36.3	24.95
21-01-15	758	25.4	36.2	39	56	22.1	51.8	26.3
22-01-15	368	24.8	37.4	31	69	22.5	30.1	23
23-01-15	365	25.6	38.3	39	77	22.8	39.4	21.9
24-01-15	885	25.1	37	41	74	23.2	31	26.5
25-01-15	409	25.1	37	36	75	23.2	31.9	20.75
26-01-15	385	24.9	35.5	35	69	22.7	43.1	18.85
27-01-15	607	25.3	36.2	37	66	22.7	31	18.75
28-01-15	352	25.7	37.1	43	71	22.2	32.1	18.25
29-01-15	344	25.4	36.9	46	74	23.7	47.2	23.1
30-01-15	608	26.3	35.5	47	72	24.2	31.4	20
31-01-15	336	26.1	35.8	38	71	23	30.4	19.6
01-02-15	1006	24.8	36.3	38	67	23.8	52.8	19.5
02-02-15	483	26.7	35	36	65	23.8	30.8	20.1
03-02-15	390	26.4	36.2	36	62	23.8	30.9	24
04-02-15	843	27.2	35.9	34	61	24	31.4	20.5
05-02-15	301	27.5	34.6	36	68	24.1	29.7	19.65
06-02-15	339	25.7	37.3	27	62	22.6	47.2	22.45
07-02-15	340	25.1	37.8	35	61	22.7	31.7	20.3
08-02-15	348	24.5	38.7	33	72	22.9	53.4	22.65
09-02-15	385	24.5	38.2	27	71	24.1	31.3	25.95
10-02-15	347	24.8	37.6	33	71	22.5	30.5	30.75
11-02-15	359	24.8	37.8	35	71	22.5	49.7	21.85
12-02-15	486	22.3	38.8	36	69	23	34.2	25.85
13-02-15	334	26.9	39.2	37	72	23	33.8	24.45
14-02-15	845	25.4	41	39	81	26.8	52.9	20.85
15-02-15	1311	28	39	27	65	26.8	57.9	19.65
16-02-15	373	26.8	38.3	24	74	26	34.4	20.8
17-02-15	342	26.8	38.7	29	78	26	43.1	23.1
18-02-15	669	28.8	37.3	43	69	27.8	33.4	29.1
19-02-15	367	26.8	40.3	35	82	26.3	35.6	23.65

20-02-15	375	25.5	38.3	21	70	25.4	50.2	24.4
21-02-15	383	26	37.4	25	64	25.5	34.8	23.2
22-02-15	384	25.5	38	20	61	25	36.7	19.4
23-02-15	630	26.4	38.9	20	48	24.6	56.2	24
24-02-15	368	25.5	39.6	19	49	24.4	37.3	17.45
25-02-15	370	27	40	28	64	25.4	54.1	18.85
26-02-15	657	27.9	36.5	47	74	27.2	31.6	15.65
27-02-15	356	27.9	37.1	50	83	26	30.6	20.3
28-02-15	374	27.4	37.6	46	74	24.9	51.8	18.9
01-03-15	690	27.9	37.5	47	73	24.9	31.4	20.55
02-03-15	415	27.9	36.9	55	78	25.5	31.9	26.1
03-03-15	1028	25.1	37.6	48	74	25.1	48.8	26.6
04-03-15	365	25.1	38.2	41	69	25.1	32	25.65
05-03-15	377	27.2	40.3	43	67	24.6	44	32.35
06-03-15	858	27.2	39.4	43	66	24.6	56.5	29.8
07-03-15	371	29	40	49	77	26.4	31.9	27.55
08-03-15	405	30.2	39.5	45	75	26	41.8	31.4
09-03-15	1046	27.7	40.2	37	84	26	54.8	32.25
10-03-15	488	28.8	39.7	33	70	26	33.4	33.05
11-03-15	417	27.3	39.6	26	62	25	33.5	33.7
12-03-15	416	21.7	38.9	32	63	24.8	47.6	26.7
13-03-15	468	26.8	41.3	32	63	25.3	34.2	28.85
14-03-15	435	28.2	39.6	39	70	25.9	32.7	29.65
15-03-15	414	29	40	41	74	26.1	53.6	29.8
16-03-15	745	27.8	40.4	42	85	26.3	36.6	26.5
17-03-15	766	29.4	39.1	47	79	27.5	34.1	26.75
18-03-15	755	29.1	40.6	43	77	26.9	35.3	25.25
19-03-15	760	19.8	40.9	45	78	26.9	35.9	23.35
20-03-15	763	29	42.4	25	79	27.2	37.9	23.05
21-03-15	733	28.9	42.1	19	74	27.3	38.4	21.65
22-03-15	709	20.6	41.7	23	82	22.3	37.5	22.05
23-03-15	682	28	39.1	47	82	26.8	34.6	21.25
24-03-15	710	25.7	38.1	49	82	24.1	35.6	19.35
25-03-15	615	29.2	38.6	49	81	27.8	36.7	18.45
26-03-15	709	28.7	42.1	26	81	27.6	38.4	18.85
27-03-15	759	28.1	41.9	22	74	26.8	38.9	19.2
28-03-15	713	28.1	42.4	26	77	26.8	39	23.6
29-03-15	725	28.7	43.7	27	75	27.2	38.7	19.8
30-03-15	768	29.9	42.3	42	80	28.3	38.4	20.5
31-03-15	626	29.8	40.1	51	77	27.7	35.4	20.45

Daily weather data (rain shelter)