IMPACT OF CLIMATE CHANGE ON PRODUCTION AND NUTRITIONAL QUALITIES OF RICE

by

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(2018-11-130)

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KERALA, INDIA

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THESIS

Submitted in partial fulfillment of the requirement for the degree of

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2020

DECLARATION

I hereby declare that this thesis entitled **"IMPACT OF CLIMATE CHANGE ON PRODUCTION AND NUTRITIONAL QUALITIES OF RICE"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Aswathi K.P.

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(2018-11-130)

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Date : 27/08/2020

CERTIFICATE

Certified that this thesis entitled **"IMPACT OF CLIMATE CHANGE ON PRODUCTION AND NUTRITIONAL QUALITIES OF RICE"** is a bonafide record of research work done independently by **Ms. Aswathi K. P. (2018-11-130)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Date: 27.08.2020

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We, the undersigned members of the advisory committee of **Ms. Aswathi K. P. (2018-11-130)**, a candidate for the degree of **Master of Science in Agriculture** with major field in **Agricultural Meteorology**, agree that this thesis entitled **"IMPACT OF CLIMATE CHANGE ON PRODUCTION AND NUTRITIONAL QUALITIES OF RICE"** may be submitted by **Ms. Aswathi K. P.** in partial fulfillment of the requirement for the degree.

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ASWATHI K. P.

I WOULD LIKE TO DEDICATE THIS THESIS TO MY TEACHER

DR. SUNIL K. M.

FOR THE UNSEEN PRESENCE AND GUIDANCE WHENEVER I STUMBLE ON A BLOCK

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Introduction

1. INTRODUCTION

Climate change is the defining issue of our time and we are at a defining moment. Climate change results in rising average temperature of earth's climate system, changes in rainfall patterns, extreme weather *etc*. IPCCs fourth assessment report forecasted that global temperature will increase by 1.1–6.4 °C by the end of this century (IPCC, 2007). The scientific community made a good effort to reduce the hunger and malnutrition around the globe and climate change can have ability to reverse all these processes. Temperature in the atmosphere may increase or decrease in the regions according to different places. The amount of carbon dioxide in the atmosphere also expected to increase due to climate change.

Rice (*Oryza sativa* L.) is the major staple food for more than half of the world's population (FAO, 2013), accounting for approximately 30 per cent of the total dietary intake, globally and in South Asia (Lobell *et al*., 2008). Rice production in the tropics is vulnerable to climatic factors (temperature, rainfall, and solar radiation) which affect the crop in various ways during different stages of its growth (Yoshida, 1973). Rice yield decreases under climate change alone due to increase in temperature that shortens the growing period in rice. Rainfall during flowering is also an important factor that contributes to reduced yield. Thereby, shifting weather pattern threatens food production.

Increased temperature has negative effects on most of the nutritional characters of rice like fat, protein, carbohydrate *etc*. Rising levels of carbon dioxide could make crops less nutritious and damage the health of millions of people. People living in some of the world's poorest regions are likely to be at hardest hit. Dietary deficiencies of zinc and iron are a substantial global public health problem. An estimated two billion people suffer these deficiencies (Tulchinsky, 2010) causing a loss of 63 million life-years annually (Caulfield and Black, 2004). Most of these people depend on C_3 grains and legumes as their primary dietary source of zinc and iron. According to Myers *et al*. (2014), C_3 grains and legumes have lower concentrations of zinc and iron when grown under field conditions at the elevated atmospheric CO_2 concentration predicted for the middle of this century. C_3 crops other than legumes also have lower concentrations of protein, whereas C_4 crops seem to be less affected (Myers *et al*., 2014).

Tirado *et al*., (2013) studied climate change and nutrition using a cross sectorial analysis guided by an analytical framework of the interaction between climate change, vulnerability, adaptation and mitigation and showed that climate change has a direct impact on food and nutrition security. High temperature may result in a lower yield but a higher palatability analyzer score of rice grains mainly due to lower amylose content (Huang and Lur, 2000).

Less is known about the role of climate change for food availability and quality of food we consume which is considered as two major dimensions of nutritional security. This information will be decisive for the ability to cope up with problems of food and nutritional security caused by climate change. The study is chosen with the following objectives:

- To study the impact of climate change on yield parameters
- To study the impact of climate change on nutritional qualities of rice

Review of literature

2. REVIEW OF LITERATURE

Agriculture is always vulnerable to unfavorable weather events and climatic conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agriculture productivity. The rising temperatures and carbon dioxide and uncertainties in rainfall associated with climate change may have serious direct and indirect consequences on rice production and hence food security. This review of literature comprises:

1) Importance of rice cultivation
2) Climate change and global warming
3) Global population increase and demand for rice
4) Climate change and rice
5) Effect of high temperature on growth and development of rice
6) Effect of high temperature on biometric characters
7) Effect of high temperature on phenophase duration
8) Effect of high temperature on grain filling
9) Effect of high temperature on grain yield
10) Nutritional parameters in rice
11) Effect of high temperature on nutritional quality of rice

2.1) Importance of rice cultivation

Rice is the most important food crop grown in Kerala. It occupies 7.46 per cent of the total cropped area of the state. The area under rice cultivation has been falling at an alarming rate ever since the 1980s. In 1974-75 the area under paddy cultivation was 8.82 lakh hectare. The production has also concomitantly declined from 13.76 lakh MT in 1972-73 (peak of production) to 5.49 lakh MT in 2015-16.

Aggarwal *et al*. (2008) reported that paddy is grown in a wide range across India except in some arid eastern regions of Rajasthan state. Rice can be cultivated in extremely diverse hydrological environments such as irrigated, rain-fed uplands, lowlands, as well as under deep-water conditions.

Rice (*Oryza sativa* L.) is a major staple food crop in the world which contributes to both food security and income generation, particularly within developing countries (Krishnan *et al.*, 2011). India is one of the world's largest producers of rice, including white rice and brown rice, grown mostly in the eastern and southern parts of the country.

2.2) **Climate change and global warming**

Over the period of 1950–1993, minimum temperature increased at a rate of 0.18 °C per decade, while maximum temperature increased by 0.08 °C per decade in Libya. In the past century, the daily minimum temperature has increased faster than the daily maximum (daytime) temperature (Easterling *et al*., 1997; Kukla and Karl, 1993).

In the past 150 years, the global average surface air temperature has increased significantly by 0.1-0.2 °C per decade (Jones *et al*., 1999). Jones *et al*. (1999) showed global surface air temperature rise by 0.57 °C from 1861 to 1901 and by 0.62 °C from 1901 to 1997.

Peng *et al*. (2004) has reported a 1.13 °C increase in night time temperature over a period of 25 years (1979-2003) at the International Rice Research Institute (IRRI), Manila, Philippines.

According to IPCC (2007) the atmospheric CO_2 concentration is estimated to rise from 380 µmol mol^{-1} to between 485 and 1000 µmol mol^{-1} by 2100. As a consequence of greenhouse effects warming of earth may occur in the future. Climate models project that global surface air temperatures may increase by 1.1-6.4 °C in the next few decades (IPCC, 2007).

IPCC (2007) estimated a rise in the global average surface air temperature at the end of the twenty-first century relative to 1980–1999 projected to be around 1.4 - 5.8 °C due to the increases in the concentrations of all greenhouse gases.

Ray *et al.* (2015) stated that annual yield loss of 32 per cent due to climate extremes and the majority of yield variability can be explained by variations in climate conditions.

Global circulation models project that the temperature is likely to increase by 1.1 to 6.4°C by the end of the 21^{st} century (IPCC, 2007). Temperature stress and drought are predicted to increase to a higher extent in tropical and subtropical regions (The 2016 Report on Future Climate of Africa, 2019).

2.3) Global population increase and demand for rice

In developing countries, nearly one-third of children are underweight and under nutrition is the cause of more than one-third of deaths among children fewer than 5 years of age. Rising levels of temperature could make crops less nutritious and damage the health of millions of people. People living in some of the world's poorest regions are likely to be hardest hit.

Rice is cultivated as summer crop in many regions where relatively high temperatures occur during its growth cycle (Sung *et al*., 2003).

Khush (2005) reported that the shortage of land and water for rice cultivation, accompanied by increase in food demand, has forced cultivation to extend beyond normal monsoon periods, in summer season, where high temperature is an important constraint.

As the world's population continues to grow up toward 10 billion by 2050, the demand for rice will grow more rapidly than for other crops because population growth is greatest in the rice-consuming and rice-producing regions of Asia, Africa and America (Dawe, 2007; Easterling *et al*., 2007).

According to the population projections by Battisti and Naylor (2009), the world population will continue to grow until at least 2050.

Climate change further worsens the enormous existing burden of under nutrition. It affects food and nutrition security and weakens the current efforts to reduce hunger and enhance or increase nutrition security. Under nutrition remains one of the world's most serious but least addressed socio-economic and health problems, hitting the poorest, especially women and children. The number of people suffering from hunger stood at 925 million in 2010.

2.4) Climate change and rice

Yield simulated by the CERES-Rice model for an increase of 1°C temperature and increase in precipitation by 100mm in South China showed an increase of 10 per cent in grain yield (Zhang, 1989).

Based on CERES-Rice simulation studies, Zhiqing *et al.* (1994) showed that only an increase in temperature would reduce rice yield but an elevated photosynthesis due to enhanced CO_2 production can compensate the effect of increased temperature.

Saseendran *et al*. (2000) reported that by the middle of the next century in the state of Kerala, an increase in rice yields (under rainfed conditions) is possible under the projected climate change scenario.

Change in climate without adaptation is exposed to impact crop growth and water use in a number of ways. The increase in temperature accelerates the growth process of most crops, resulting in less time for biomass accumulation (Hawkins *et al*., 2013). At the same time short periods of drastic increase in temperature during critical growth stages such as flowering and grain filling leads to severe yield loss in rice.

Ding *et al.,* (2020) showed that shifting sowing date is useful strategy that deals with the effect of climate change in China. It is reported that shifting sowing dates helps to overcome the yield reduction.

2.5) Effect of high temperature on growth and development of rice

Baker *et al*. (1992) observed a yield reduction of about 7–8 per cent in rice for each 1 °C increase in day time maximum/night time minimum temperature from 28/21 to 34/27 °C.

Wahid *et al*. (2007) observed that high-temperature stress in plant is a complex function of intensity, duration and rate of increase in temperature.

According to Krishnan *et al*. (2011), the physiological response of plants to temperature stress can be tolerance or avoidance. Tolerance is due to mechanisms that maintain high metabolic activity under mild stress and reduced activity under severe stress. Avoidance involves a reduction of metabolic activity, resulting in a quiescent state upon exposure to extreme stress. Rice originated in tropical or subtropical areas and is a low-temperature sensitive crop, where crop growth and development are severely damaged below 15 °C. But, extreme temperatures are also destructive to plant growth.

Nowadays, most of the rice is currently cultivated in regions where temperatures are already above the optimum range for growth of rice. Therefore, any further raise in temperature during sensitive stages of the crop may adversely affect the growth and yield of rice.

2.6) Effect of high temperature on biometric characters

Kondo and Okamura (1931) and Osada *et al*. (1973) reported that the plant height increased with the rise of temperature within the range of 30–35 °C. Yoshida (1973) reported that higher temperatures increased tiller numbers. Tiller per plant determine panicle number which is a key element of grain yield (Yoshida *et al.*, 1981).

Tillers are branches that develop from main shoot or from other tillers during vegetative growth, growing independently by means of its own adventitious roots. Tillering is a two-stage process including the formation of axillary buds at each leaf axil and its subsequent growth. Yield potential of a rice cultivar may be characterized by tillering capacity. But, rice plants with more tillers can show a greater discrepancy in mobilizing assimilates and nutrients among tillers, ensuing variations in grain development and yield among tillers (Yoshida *et al.*, 1981). High temperatures may affect this synchronization and in the mobilization of assimilates and nutrients among tillers.

In a recent study, Oh-e *et al*. (2007) found that the increase in plant height was steeper under high temperature than under ambient temperature condition.

2.7) Effect of high temperature on phenophase duration

Normally as temperature increases, development generally accelerates as a linear function of daily average temperature. High temperature accelerates and low temperature delays heading (Ahn and Vergara, 1969; Hosoi and Tamagata, 1973). A study conducted by Yoshida *et al.* (1981) showed that number of days to heading for IR26 increased from 96 days at 24 °C to 134 days at 21 °C.

An increase in temperature by 4°C during the growing season resulted in earlier maturation of the crop by five and six days for wet and dry seasons, respectively (Ziska *et al*., 1997).

Lalitha *et al*. (1999) observed that that daily mean temperature above 26 °C restricted the duration of tillering period to five weeks after planting.

The rise in atmospheric temperature is having detrimental effects on growth, yield and quality of the rice crop by affecting its phenology, physiology and yield components (Singh (2001); Sheehy *et al*. (2005); Peng *et al*. (2004)).

The sensitivity of rice to high temperature varies with growth phase, an increase in day/night temperature and genotype (Peng *et al*., 2004).

The range of reduction in duration of rice ranged from 9 to 14 days at the end of the century (Ramaraj *et al*., 2013).

An experiment was conducted by Arthi and Maragatham (2013) during *kharif* 2012 under temperature control chamber, in which temperature is elevated from the ambient level (2 °C and 4 °C) for the entire crop growth period. The results showed that the days taken to attain maturity was less under elevated temperature of 4 °C (96 days) and 2 °C (102 days) when compared to the ambient temperature (108 days).

Dias *et al.* (2016) conducted a study to identify the yield and growth changes in two rice varieties (At362 and Bg357) cultivated in Nilwala river basin at Yala season under the global climate change scenario and they found that, both yield and growth of rice affected by increasing temperature and solar radiation and decreasing rainfall in mid-centuries. For both the varieties growth period showed a decreasing trend in increased temperature condition compared to present conditions.

2.8) Effect of high temperature on grain filling

High temperatures above 30 °C are generally not favorable for ripening (Osada *et al*., 1973). Morita *et al*. (2004) reported that in rice, high minimum temperatures were more harmful to grain weight compared to high day temperatures.

Oh-e *et al*. (2007) found that the duration of grain filling (number of days required to reach maximum weight) was found to be 13 days at a mean temperature of 28 °C, and 33 days at 16 °C for indica rice cultivar IR20. But, the cultivar Fujisaka 5, japonica rice, took 18 days at a mean temperature of 28 °C and 43 days at 16 °C for grain filling.

Oh-e *et al*. (2007) observed that the cultivar IR20 was well adapted to high temperatures during ripening while the final grain weight of cultivar Fujisaka 5 at 28 °C was about 15 per cent less than that at 16 °C, suggesting that certain cultivars may show the detrimental effect of high temperature.

High temperatures at flowering and grain-filling stages reduces yield by causing spikelet sterility and shorten the duration of grain-filling phase (Tian *et al*., 2007). For a particular cultivar, the growing degree days required for flowering is relatively the same at different growing temperatures within the temperature range between the base temperature and the optimum temperature. Oh-e *et al*. (2007) found that the rate of grain growth was faster and the grain-filling period was shorter at higher temperatures.

Final grain weight is the product of the rate and duration of grain growth, which is affected by high temperatures. High temperature increases growth rate in the early ripening period but reduce the duration of grain growth and ultimately result in decreased final grain weight. Krishnan *et al*. (2011) stated that the length of the ripening period is inversely correlated with daily mean temperature and grain filling is reduced when temperature is above optimum.

2.9) Effect of high temperature on grain yield

In 1959, Matsushima and Tsunoda observed that the mean optimum temperature for ripening of japonica rice in Japan was about 20–22 °C. Although temperature during ripening affects the weight per grain, the thousand grain weight of a particular cultivar is considered to be almost constant under different environments and cultural practices.

Then Murata (1976) conducted a study in Kyushu, southern Japan in the same variety and observed that the thousand grain weight varied from about 24 g at a mean temperature of 22 °C in the 3-week period after heading to 21 g at a mean temperature of 28 °C.

Temperature suitable for ripening is considered to be 24 °C at which the maximum grain weight is observed (Kobata and Uemuki, 2004). There may be differences among cultivars in the ratio of imperfect rice incidence, suggesting that the cultivar difference in the pattern and severity of the incidence and the ripening capability at high temperature are genetically controlled.

Wahid *et al*. (2007) noticed the impact of high temperature on growth stages of rice and reported that if the growth stage exposed to more high temperature, it results more damages. It was also concluded that, during vegetative as well as reproductive stages the low and high temperatures will lead to less productive tillers and poor seed set in rice.

The yield of rice is significantly influenced by temperature throughout the crop growth period and was more pronounced from flowering to anthesis period (Chahal *et al*., 2007).

According to Wahid *et al*. (2007), high temperature affects almost all the growth stages of rice from emergence to ripening and harvesting. The developmental stage at which the plant is exposed to heat stress determines the severity of the possible damage to the crop.

High temperature stress above the optimum of 25–30 °C (Wopereis *et al*., 2008) or drought conditions have negative effects on plant development, including irreversible injury to growth and development of the plant, reduction of photosynthesis (Oh-e *et al*., 2007), reduction in number of panicles per plant and peduncle elongation, limitations of pollen production (The 2016 Report on Future Climate of Africa, 2019), no swelling of pollen grains, and increased spikelet sterility (Jagadish *et al*., 2007).

In the future climatic conditions, the yields of rice would be reduced depending on the growing-season environmental conditions as present-day high temperatures have been implicated to cause reductions in rice yield in many rice-growing areas (Nagarajan *et al*., 2010; Welch *et al*., 2010).

High-temperature stress (+2.5 °C) during the vegetative and reproductive growth phases caused greater and almost equal reduction in biomass (23 per cent and 26 per cent) and grain yield (23 per cent and 27 per cent). As compared with that, during the ripening growth phase, this showed eight per cent and seven per cent reduction in biomass and grain yield respectively. Among yield components, the number of panicles per square meter and grains per panicle showed greater sensitivity to high-temperature stress, whereas thousand grain weight was least affected by the same level of heat stress (Singh *et al.*, 2010).

Shah *et al*. (2011) predicted an expected decrease in grain yield in rice by 41 per cent due to increased temperature by the end of the 21st century.

The elevated temperature on rice crop affects the crop duration by attaining the phenological stages earlier with low accumulated growing degree days. This reduction in grain yield may be due to the direct effect of temperature on rice development especially high temperature at flowering stage leading to spikelet sterility and therefore, yield loss (Rani and Maragatham, 2013). GRiSP (2013) reported that generally a 10 per cent decrease in rice grain yield is expected for each 1°C temperature increase above the optimal temperature.

The yield capacity of rice is primarily dependent on both vegetative and reproductive stages. Temperature affects rice yield directly by affecting the physiological processes implicated in grain production.

An experiment was conducted by Arthi and Maragatham (2013) during *kharif* 2012 under temperature control chamber, in which temperature is elevated from the ambient level (2 °C and 4 °C) for the entire crop growth period. The results showed under elevated temperature of 4 °C and 2 °C, the grain yield was 23 and 13.3 percent less from the ambient. The highest grain yield is from the treatment under ambient temperature with 6.2 t ha^{-1} followed by 5.3 t ha^{-1} under 2 °C level and 4.7 t ha^{-1} at 4° C level. The yield loss under higher temperature is due to sterile florets and lesser crop duration.

Nyang'Au *et al*. (2014) evaluated the effects of change in weather conditions on the yields of Basmati 370 and IR 2793-80-1 cultivated under System of Rice Intensification (SRI) in Mwea and Western Kenya irrigation schemes through sensitivity analysis using the CERES-Rice model v 4.5 of the DSSAT modeling system and they observed that an increase of both maximum and minimum temperatures affects Basmati 370 and IR 2793-80-1 grain yield under SRI.

Dias *et al.* (2016) conducted a study to identify the yield and growth changes of two rice varieties (At362 and Bg357) cultivated in Nilwala river basin at Yala season under the global climate change scenario and they found that, both yield and growth of rice affected by increasing temperature and solar radiation and decreasing rainfall in mid-centuries. For both the varieties grain yield in mid-centuries shows decreasing trend by 25 per cent to 35 per cent than the yield at 2014.

Biswas *et al.* (2018) reported a reduction of 5-10 per cent yield of rice transplanted in normal date (4^{th} week of May) with increase in temperature up to 2^{0}C. The reduction in yield may due to reduced crop growth period under raised thermal condition.

Drastic reduction in grain yield components, including a repression in panicle exertion and spikelet fertility may resulted due to occurrence of drought at the reproductive stage (Mukamuhirwa *et al*., 2019; Sarvestani *et al*., 2008).

Climate change in recent times in some areas causes rising temperatures and that may intensify storms, flooding and other extreme weather events worldwide, and eventually affect food production. A very reliable feature of global climate is changes in temperatures and rainfall that vary from year to year and oscillate widely over a period of time.

2.10) Nutritional parameters in rice

Rice is primarily composed of carbohydrate, which makes up almost eighty percent of its total dry weight. Most of the carbohydrate in rice is starch, which is the most common form of carbohydrate in foods. Starch is made up of long chains of glucose called amylose and amylopectin. In an experiment conducted by Vijayakumari *et al*. (1997) for determining the chemical composition little-known legume *Bauhinia purpurea* they followed the procedure given by Sadasivam and Manikkam (1992).

Rice is a nutritional pack and it provides many vitamins and minerals. Rice grain is relatively low in some essential micronutrients such as iron (Fe), zinc (Zn) and calcium (Ca) as compared to other staple crops (Adeyeye *et al*., 2000). Jackson and Lee in 1988 conducted a study to determine chemical forms of iron, calcium, magnesium and zinc in coffee and they adopted the standard procedure given by Perkin-Elmer in 1982. Kumari *et al*. (2017) Conducted a study in Rangareddy district of Telangana to see the effect of physico-chemical properties on soil enzyme acid phosphatase activity of some soils in vegetable growing soils used the method suggested by Jackson in 1973.

Rice has one of the lowest protein contents among the cereals. A study conducted by Setyaningsih *et al*. (2020) used the standard procedure given by AOAC (1998) to determine different food quality parameters.

Removal of the bran increases the shelf life of rice grains. White rice is produced by milling the rice to separate the outer portions of the grain (husk, bran, and aleurone) as well as the germ from the endosperm. Bassuony and Lightfoot (2019) adopted the method suggested by Adair (1952) for determining hulling per cent, milling per cent and head rice per cent by using Satake testing machines. Muthu *et al*. (2020) used the gelatinization temperature index obtained by measuring the alkali spreading value of five whole milled kernels in 10 ml of 1.7% KOH solution in a Petri dish for 24 hours at 30°C and scored on a 1–7 scale suggested by Little *et al.* (1958).

2.11) Effect of high temperature on nutritional quality of rice

In rice under high-temperature stress, high chalkiness and poor edible quality are closely related with starch synthesis in endosperm during grain filling (Umemoto and Terashima, 2002).

High temperatures also induce an accumulation of sucrose and a decrease in carbon and nitrogen transport from the shoots to the ears via the phloem. The enzymatic activity of starch synthesis is closely related to the formation and filling of grains (Jeng *et al*., 2003).

In another study, gelatinization temperature decreased in drought stressed rice grains, whereas it increased under heat stress (Vidal *et al*., 2007).

White and Broadley (2009) observed that the mineral elements present in rice are mainly iron, zinc, copper and selenium, among which iron and zinc are very important micronutrients for human health.

Rice is a good source of carbohydrates, being the main food for more than half of the world's population (Chen *et al.*, 2014).

Besides affecting growth and grain yield, water and temperature stresses change the quality and chemical composition of rice. Levels of starch, phenols, flavonoids, and phytic acid were shown to decrease, whereas antioxidant capacity, content of amylose, oxalic acid, calcium and iron seemed to increase in drought-stressed grains (Emam *et al*., 2014).

Extreme high day temperatures during the grain-filling period may reduce starch synthesis in the grains and, especially so under N-deficient conditions (Ito *et al*., 2009). Shortening of the ripening period in rice due to high temperature is caused by higher activity of enzymes involved in starch synthesis during the early grain growth stage (Oh-e *et al*., 2007).

Even when rice panicles are exposed to heat stress at later developmental stages there is a significant repression in starch biosynthesis because of the reduction in the activity of these enzymes (Kobata and Uemuki, 2004).

Under high temperature stress, the expression of SBE genes as well as the expression difference of each isoform gene during grain filling may determine the structure of starch in rice endosperm and the quality of rice grains (Wei *et al*., 2009).

High nighttime temperatures during grain development can cause an increase in amylose content (Resurreccion *et al*., 1977) and the proportion of long chains of amylopectin can decrease (Counce *et al*., 2005).

Umemoto *et al*. (1995) and Jiang *et al*. (2003) observed that rice plants grown under high temperature have low amylose content compared to those grown under low temperatures.

Seneweera and Conroy (1997) reported a significant increase in amylose content of ground grains of short duration rice cultivar with elevated CO_2 in a growth chamber experiment. A chamber study conducted by Zhang *et al*. (1998) found that total amino acid concentration of rice grain at elevated CO_2 was about 30 per cent lower than that at ambient CO_2. High temperature may result in a relative lower yield but a higher palatability analyzer score of rice grains, due to mainly the lower amylose content (Huang and Lur, 2000).

Rising carbon dioxide emissions are set to make the world's staple food crops less nutritious, according to new scientific research, worsening the serious ill health already suffered by billions of malnourished people. The field trials of wheat, rice, maize and soybeans showed that higher CO_2 levels significantly reduced the levels of the essential nutrients iron and zinc, as well as reducing protein levels. The increased CO_2 associated with climate change is projected to significantly reduce the nutritional content (especially the zinc and iron content) of the grains and legumes that form the basic diet of the world's most vulnerable populations.

Tirado *et al*. (2013) studied climate change and nutrition using a cross sectorial analysis guided by an analytical framework of the interaction between climate change, vulnerability, adaptation and mitigation and showed that climate change has a direct impact on food and nutrition security.

Dietary deficiencies of zinc and iron are a substantial global public health problem. An estimated two billion people suffer these deficiencies, causing a loss of 63 million lives annually. Most of these people depend on C_3 grains and legumes as their primary dietary source of zinc and iron. Here we report that C_3 grains and legumes have lower concentrations of zinc and iron when grown under field conditions at the elevated atmospheric CO_2 concentration predicted for the middle of this century (Myers *et al*., 2014).

Ahmed *et al*. (2014) reported that high temperature treatment during grain filling had a considerable influence on amylose content and the starch component in hulled rice endosperm. Starch content per milligram of hulled rice at maturity on an equal dry weight basis at 22 and 32 $^{\circ}$C was 16.5 (77.2 per cent) and 14.9 (74.1 per cent) respectively – 3.1 per cent lower at 32 $^{\circ}$C than that at 22 $^{\circ}$C. Amylose content per milligram of hulled rice grain at maturity at 22 $^{\circ}$C was 4.2 (25.1 per cent) and 3.2 (21.7 per cent) at 32 $^{\circ}$C. Increasing the temperature significantly lowered the amylose content in hulled rice by
0.91 mg (28.1 per cent) hulled rice grain.

Manoj *et al*. (2012) conducted a study on elevated carbon dioxide and temperature effect on phosphorus efficiency of wheat grown under subtropical India and observed that total P uptake decreased under elevated temperature condition.

Predicted increase in drought and heat stresses constitute a great threat to rice productivity and quality characteristics, and it may affect lives of millions of the world's population, especially in poor areas of the tropical and subtropical regions (The 2016 Report on Future Climate of Africa, 2019), where rice constitute a staple food. To attain sustainable development goals, food security achievement and nutritional improvement are the key factors. At the same time, climate change is already impacting agriculture and food security and this will make the challenge of ending hunger and malnutrition even more difficult (FAO, 2016). Hence more information has to be gained on impact of climate change on production and nutrition of rice. The present study may help to throw light to some of the aspects in this regard.

Materials and methods

3. MATERIALS AND METHODS

The study on “Impact of climate change on production and nutritional qualities of rice” was carried out during 2019-2020. The materials used and methods followed are described below:

3.1 DETAILS OF THE EXPERIMENT

3.1.1. Location of experiment

The pot culture experiments were conducted during May 2019 to May 2020 at Regional Agricultural Research Station, Pattambi, Kerala Agricultural University. The station is located at 10° 48’ N latitude and 76° 12’ E longitude at an altitude of 25.36 m above mean sea level.

3.1.2. Soil characters

Texture of soil for the experimental field was sandy loam. Table 3.1 shows the physical properties of soil.

Table 3.1. Mechanical composition of soil in the experimental field

Sl. No.	Particulars	Value
1	Sand (%)	62
2	Silt (%)	4
3	Clay (%)	34

3.1.3 Climate

The area selected for the experiment is a typical warm humid tropical region. Both southwest and northeast monsoons provide rain to the area and the location experienced a mean maximum temperature of 37.4 °C in 13th standard meteorological week and a mean minimum temperature of 18.3 °C in 2nd standard meteorological week in the year 2020 during the experimental period. The maximum rainfall of 665.6 mm was received during 32nd standard meteorological week in the year 2019. Weekly weather parameters during the period of experiment 2019-2020 presented in Table 3.2.

3.1.4 Season of the experiment

The field experiment was conducted from May 2019 to May 2020 during different seasons *virippu, mundakan* and *puncha*.

3.2 EXPERIMENTAL MATERIALS AND METHODS

3.2.1 **Variety**

The experiment was conducted using rice variety Jyothi which is the second most cultivated variety of rice in Kerala. Jyothi is a short duration variety with 110-115 days duration. Jyothi is cultivated in all the three seasons and in a wide range of field conditions because of its wide adaptability. It was evolved by the cross between PTB-10, the short duration improved local strain and IR 8, the internationally famous high yielding genotype.

3.2.2. Design and layout

Completely Randomized Design with two factors was used for the experiment with five dates of planting (from 1st June 2019 to 1st January 2020) as the first factor and two growing conditions including open condition and climate controlled greenhouse as second factor. Three replications were given with ten pots in each replication which carry three plants per pot.

3.2.3. Treatments

The treatments included five dates of planting starting from 1st June 2019 to 1st January and two growing conditions open condition and climate controlled greenhouse with rice variety Jyothi. These are given in the following Table 3.3.

Table 3.2. Weekly weather parameters during the period of experiment 2019-2020

SMW	Tmax (˚C)	Tmin (˚C)	RH1 (%)	RH2 (%)	RF (mm)	RD (Days)	BSS (h)	Ep (mm)
22	33.6	22.2	89.9	62.9	44	2	6.1	38.0
23	32.8	23.0	89.0	72.1	93.9	1	5.0	34.6
24	31.4	22.2	96.0	80.1	136.1	7	1.5	20.2
25	30.6	21.7	95.3	71.1	87.8	6	2.5	23.6
26	31.2	22.3	93.3	69.6	24.8	2	6.2	39.2
27	30.6	21.9	97.0	77.9	135.4	7	3.0	51.1
28	30.1	21.3	93.4	76.9	66.5	5	3.5	30.9
29	28.3	21.2	94.4	82.0	225.2	5	2.4	28.7
30	29.5	21.2	96.9	76.7	129.1	5	3.2	18.6
31	30.7	21.9	92.9	69.7	23.2	2	4.6	28.0
32	28.1	20.3	97.3	89.7	665.6	7	0.2	11.9
33	29.9	21.5	95.7	73.7	79	4	3.0	14.5
34	28.9	20.9	96.1	79.1	144.2	7	1.8	11.5
35	29.0	21.1	97.4	82.4	271.1	7	1.6	11.2
36	30.1	21.5	93.4	78.1	184.1	7	3.4	19.3
37	31.0	21.9	94.6	68.3	45.4	4	5.6	29.2
38	31.1	21.8	91.7	66.4	33.5	1	3.8	25.4
39	31.1	22.0	92.1	66.1	35.5	2	5.9	27.1
40	32.8	21.5	86.1	64.7	25.1	3	7.4	29.1
41	33.0	21.1	88.6	72.0	90.7	3	7.4	23.5
42	31.2	21.3	95.6	73.7	223.2	6	5.1	23.9
43	30.8	20.4	89.9	65.1	92.1	6	4.5	25.9
44	31.1	20.1	87.9	71.6	46.6	3	3.9	12.2
45	32.3	21.5	94.4	66.3	0.8	0	4.5	25.4
46	32.3	21.1	87.4	59.1	25.2	2	7.3	30.3

Table 3.2. Weekly weather parameters during the period of experiment 2019-2020 (Contd.)

SMW	Tmax (˚C)	Tmin (˚C)	RH1 (%)	RH2 (%)	RF (mm)	RD (Days)	BSS (h)	Ep (mm)
47	32.4	21.4	84.7	57.7	0	0	8.7	25.4
48	31.4	21.5	89.3	59.3	6	1	5.0	27.3
49	31.6	20.6	84.9	55.3	0	0	7.8	36.0
50	31.6	19.8	81.1	56.6	0	0	7.5	31.8
51	32.2	21.3	77.3	48.1	0	0	7.4	32.6
52	32.5	21.1	74.8	52.4	0	0	7.1	32.4
1	34.2	20.0	89.4	45.0	0	0	8.9	36.2
2	32.9	18.3	76.3	51.3	0	0	8.8	38.0
3	33.5	18.7	76.9	39.6	0	0	9.3	43.9
4	34.6	19.4	80.0	36.1	0	0	9.3	49.0
5	34.7	18.7	82.7	38.6	0	0	9.1	39.1
6	34.7	18.9	82.1	44.7	0	0	9.3	43.4
7	35.5	20.3	70.6	36.1	0	0	9.3	57.0
8	35.6	19.5	77.7	31.9	0	0	8.6	47.0
9	35.5	21.0	86.9	41.0	32.4	1	8.0	43.1
10	35.4	22.2	89.9	41.1	0	0	8.4	40.0
11	37.0	21.2	85.6	34.4	0	0	9.6	38.6
12	36.3	22.2	85.7	48.7	0	0	8.6	39.4
13	37.4	22.0	85.9	41.9	0	0	7.6	40.8
14	36.1	22.1	81.1	55.7	0	0	7.1	38.0
15	37.0	22.2	84.9	43.0	0	0	9.7	45.5
16	37.1	23.1	80.9	46.9	3.2	1	8.9	45.8
17	35.6	22.3	81.4	53.7	34.7	2	6.9	38.9

Tmax – Maximum temperature

Tmin– Minimum temperature

RH 1– Forenoon relative humidity

RH 2 – Afternoon relative humidity

SMW- Standard Meteorological Week

BSS – Bright sunshine hours

RF - Rainfall

RD – Rainy days

Ep – Pan evaporation

Table 3.3. Treatments in the experiment

Dates of planting	Growing conditions
1st June	GH-Climate Controlled Greenhouse
	O- Open condition
30th June	GH-Climate Controlled Greenhouse
	O- Open condition
1st October	GH-Climate Controlled Greenhouse
	O- Open condition
30th October	GH-Climate Controlled Greenhouse
	O- Open condition
1st January	GH-Climate Controlled Greenhouse
	O- Open condition

3.2.3.1. Climate controlled greenhouse

Under climate controlled greenhouse a temperature of ambient temperature plus or minus 5 °C is maintained. Fan and sprinklers are worked to maintain desirable temperature.

3.3. CROP MANAGEMENT

3.3.1. Nursery management

Nurseries were made eighteen days before transplanting. 2 to 3 seedlings were transplanted per pot and all the necessary provisions were made for adequate irrigation and drainage. In addition, necessary plant protection measures were also adopted in the field.

3.3.2. Land preparation and planting

Pots were filled with thoroughly mixed potting mixture.

3.3.3. Application of manures and fertilizers

Farm yard manure was applied in the pots at the rate of 5000 kg ha^{-1} during potting mixture preparation. To supply the required nutrients (70 N: 35 P_2O_5: 35 K_2O kg ha^{-1} for short duration rice variety) fertilizers like urea, rajphos and potash were used. The entire dose of P_2O_5, half dose of N and K_2O were applied as basal dose while remaining amount of fertilizers were top dressed at 30 days after transplanting.

3.3.4. After cultivation

Control of weeds were done manually.

3.4. OBSERVATIONS

3.4.1. Weather data

Different weather parameters on daily basis (maximum temperature, minimum temperature, rainfall, relative humidity, Photo synthetically active radiation (PAR), Canopy temperature and CATD at weekly interval) were collected from Agromet observatory of RARS, Pattambi and using different instruments like soil thermometer, hygrometer, line quantum sensor and infrared thermometer.

The data was converted to weekly basis.. The different weather parameters used in the study are presented in the Table 3.4.

Plate I. Nursery preparation

Plate II. Transplanting

Plate III. Climate controlled greenhouse

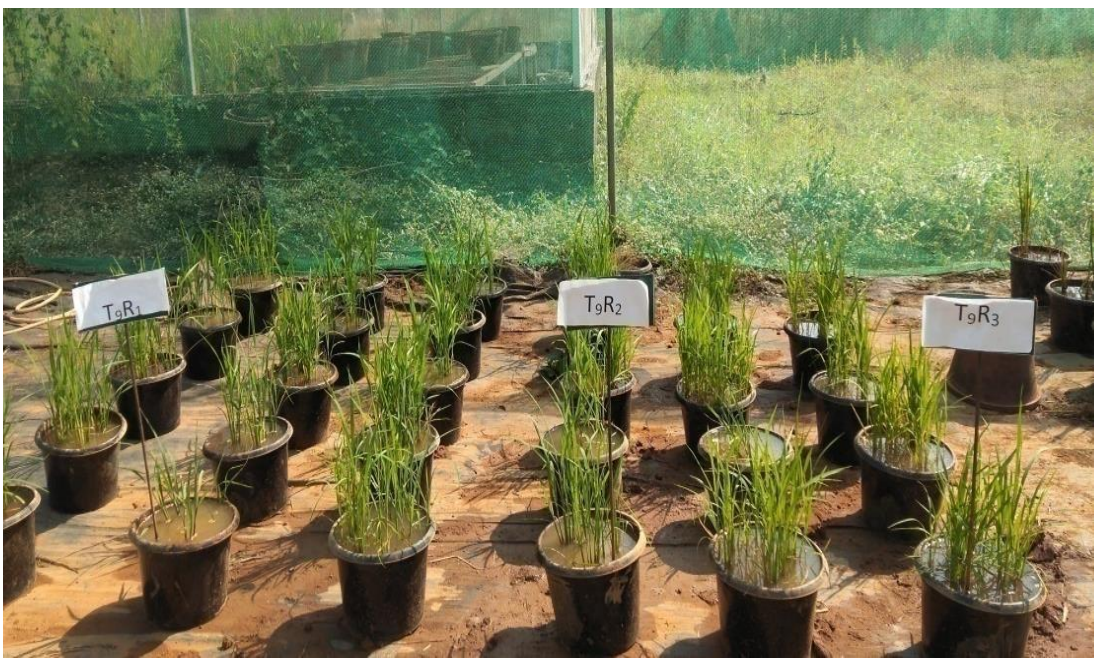
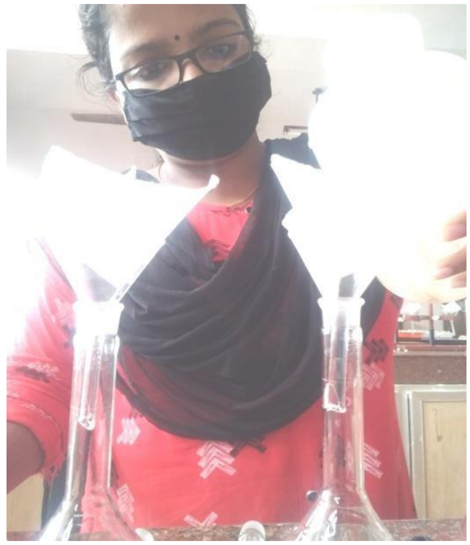
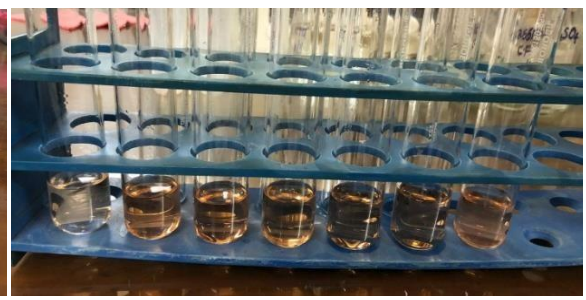


Plate IV. Open condition

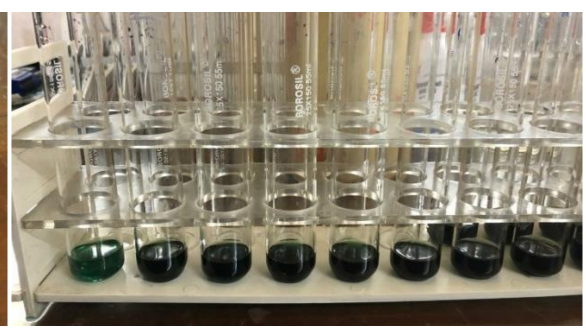


Phosphorus



Iron

Amylose



Starch

Plate V: Lab work

Table 3.4. Weather parameters used in the experiment

Sl. No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	^{0}C
2	Minimum temperature (Tmin)	^{0}C
3	Rainfall (RF)	mm
4	Relative humidity	%
5	Photo synthetically active radiation (PAR)	μ mol m^{-2} s^{-1}
6	Canopy temperature and CATD at weekly interval	ºC

3.4.2. Biometric characters

Random plant samples were taken from each replication of each treatment avoiding the border plants to take the observations at different phenological stages.

3.4.2.1. Plant height

The plant height was recorded at weekly intervals in cm. Measurement was done using a meter scale from the bottom of the culm to tip of the longest leaf or the ear head tip.

3.4.2.2. Number of tillers at weekly interval

Numbers of tillers per plant were counted randomly from five plants at active tillering stage.

3.4.2.3. Leaf area index

Leaf area index was measured at weekly intervals from transplanting to harvest from randomly selected plants as suggested by Williams in 1946.

$$Leaf\ Area\ Index = \frac{Total\ leaf\ area\ of\ plant}{Leaf\ area\ occupied\ by\ plant}$$

3.4.2.4. Dry matter accumulation at harvest

Straw obtained from each plot were dried uniformly, weighed and expressed in kg ha $^{-1}$.

3.4.3. Yield attributes

3.4.3.1. Number of panicles per unit area

Number of panicles per plant were counted randomly from three plants at the time of harvest.

3.4.3.2. Number of spikelets per panicle

Number of spikelets were counted randomly from three plants at the time of harvest.

3.4.3.3. Number of filled grains per panicle

Number of filled grains per panicle were counted at the time of harvest from three selected plants randomly from each replication.

3.4.3.4. Thousand grain weight

Thousand grains were counted from the cleaned dry grains from each plot and the weight was recorded in grams.

3.4.3.5. Straw yield

The straw from each replication was dried uniformly, weighed and expressed in kg ha $^{-1}$.

3.4.3.6. Grain yield

From each replication the produce was threshed and dried to 14 percent moisture, weighed and expressed as kg ha $^{-1}$.

3.4.4. Physical and cooking quality evaluation

3.4.4.1. Milling percentage

Milling percentage includes the weight of head rice and broken rice and is calculated as follows.

Milled rice (%) = $\frac{weight\ of\ milled\ rice}{weight\ of\ paddy} * 100$

3.4.4.2. Head rice recovery

Whole grains (head rice) were separated from the milled rice with a winnower. The resulting head rice was weighted to get head rice recovery (Adair, 1952).

Head rice recovery = $\frac{weight\ of\ head\ rice}{weight\ of\ paddy} * 100$

3.4.4.3. Gelatinization temperature index

An estimate of the gelatinization temperature was indexed by the alkali digestion test suggested by Little *et al*. (1958). It is measured by observing the degree of spreading of individual milled rice kernels in a weak solution of alkali (1.7% KOH). Six whole- milled kernels without cracks were selected and placed in a petridish and10 ml of 1.7

percent potassium hydroxide (KOH) solution was added. The samples were arranged to provide enough space between kernels to allow spreading. The petridishes were covered and incubated for 23 h at 30 °C in an oven. Starchy endosperm was rated visually to index the degree of spreading in alkali. Rice with a low gelatinization temperature disintegrates completely where as rice with an intermediate gelatinization temperature shows only partial disintegration. Rice with a high gelatinization temperature remains largely unaffected in the alkali solution.

3.4.5. Nutritional analysis

3.4.5.1. Carbohydrate (Starch, Amylose) (g per 100g)

3.4.5.1.1. Starch

The starch content was estimated colorimetrically using anthrone reagent (AOAC, 1998). Rice grains were powdered and the rice powder (0.5 g) was extracted with 80 percent ethanol to remove sugars. Residue was repeatedly extracted with hot 80 per cent ethanol to remove sugars completely. The residue was dried over water bath and 5 ml of water and 6.5 ml of 52 per cent perchloric acid were added and extracted at 0 ^{0}C for 20 minutes. The supernatant was pooled and made up to 100 ml. 0.2 ml of the supernatant was pipetted out and made up to 1 ml with water and 4 ml of anthrone reagent was added, heated for eight minutes, cooled and read the OD at 630 nm in a spectrophotometer.

A standard graph was prepared using serial dilution of standard glucose solution. From the graph, glucose content of the sample was obtained and multiplied by a factor of 0.9 to arrive the starch content.

3.4.5.1.2. Amylose

Amylose content was determined by the method suggested by Sadasivam and Manikkam (1992). To 100 mg of powdered rice sample, 2 ml of distilled ethanol and 10 ml of 1 N of NaOH were added and kept overnight and the volume was made up to 100 ml. The extract (2.5 ml) was taken and added about 20 ml of distilled water and three drops of phenolphthalein. Then 0.1 N HCl was added drop by drop until the pink colour disappeared. To this, 1 ml of iodine reagent was added and the volume was made up to 50 ml. The intensity of the colour developed was read at 590 nm in spectrophotometer. The amylose present in the sample was estimated from standard graph prepared using serial dilution of standard amylose solution and expressed in percentage.

3.4.5.2. Protein (g per 100g)

Protein content was estimated by the method of AOAC (1998). Rice (0.2 g) was digested with 6 ml Conc. H_2SO_4 after adding 0.4 g $CuSO_4$ and 3.5 g K_2SO_4 in a digestion flask until the colour of the sample turned green. After digestion, it was diluted with water and 25 ml of 40 per cent NaOH was pumped. The distillate was collected in 20 per cent boric acid containing mixed indicator and then titrated with 0.2 N HCL, to determine the nitrogen content. The nitrogen content obtained was multiplied with a factor of 6.25 to get the protein content and was expressed in grams.

3.4.5.3. Fat (g per 100g)

Fat content of rice was estimated by the method of AOAC (1998). Five gram of rice was powdered and taken in a thimble and plugged with cotton. The material was extracted with petroleum ether for six hours without interruption by gentle heating in a soxhelt apparatus. Extraction flask was then cooled, and ether was removed by heating and weight was taken. The fat content was expressed in grams.

3.4.5.4. Minerals (Ca, Fe, Zn, P) (mg 100g^{-1})

3.4.5.4. 1. Calcium

Calcium content was estimated by atomic absorption spectrophotometric method using the diacid extract prepared from the sample (Perkin-Elmer, 1982). The diacid was prepared by mixing 70 per cent perchloric acid in the ratio 9:4. Two gram of rice sample was digested in this diacid and the extract was made up to 100 ml. This solution was read directly using spectrophotometer. Calcium content was expressed in mg per 100 g of the sample.

3.4.5.4. 2. Zinc

The zinc content of the sample was estimated by atomic absorption spectrophotometric method using the diacid extract prepared from the sample (Perkin-Elmer, 1982). The diacid solution was directly read in atomic absorption spectrophotometer to find the zinc content and expressed in mg per 100 g of the sample.

3.4.5.4.3. Iron

Iron content of the sample was estimated by atomic absorption spectrophotometric method using the diacid extract prepared from the sample (Perkin-Elmer, 1982). The diacid solution was directly read in atomic absorption spectrophotometer to find the zinc content and expressed in mg per 100 g of the sample.

3.4.5.4.4. Phosphorous

The phosphorous content was analysed colorimetriclly as suggested by Jackson (1973), which gives yellow colour with nitric acid vandate molybdate reagent.

To 5 ml of pre-digested aliquot 5 ml of nitric acid vandate molybdate reagent was added and made up to 50 ml with distilled water. After 10 minutes, the OD was read at 430 nm. The content of phosphorous present in the sample was estimated from the standard graph prepared using serial dilution of standard phosphorous solution and expressed in mg per 100 g.

3.4.6. Phenological observations

3.4.6.1. Number of days for active tillering

Number of days taken for active tillering from transplanting was counted and recorded for each date of planting.

3.4.6.2. Number of days for panicle initiation

Number of days taken from transplanting to panicle initiation by both the varieties was noted for each date of planting .

3.4.6.3. Number of days for booting

Number of days taken from transplanting to booting was noted and for each date of planting.

3.4.6.4. Number of days for heading

Number of days taken from transplanting to heading was counted and recorded for each date of planting.

3.4.6.5. Number of days for 50% flowering

Number of days taken from transplanting to 50% flowering was counted and recorded for date each planting.

3.4.6.6. Number of days for physiological maturity

Number of days taken from transplanting to physiological maturity was counted and recorded for each date of planting.

3.4.7. Soil analysis

Soil samples were collected from the pot before planting. These samples were dried and powdered separately and were analyzed for pH, available phosphorous, available potassium and organic carbon content. Table 3.5 shows the results of chemical analysis.

Table 3.5. Chemical properties of the soil

Sl. No.	Parameter	
1	Organic carbon (%)	0.96
2	Soil pH	7.4
3	Electrical conductivity (dS m^{-1})	0.19
4	Available phosphorous (kg ha^{-1})	24.24
5	Available potassium (kg ha^{-1})	389.87

3.5. STATISTICAL ANALYSIS

Statistical analysis of the experimental data was done using the standard procedure for completely randomized design with two factors given by Fisher (1936). The existence of significant difference between first factor (dates of planting) and second factor (two growing conditions) and their interaction were analyzed by performing ANOVA. When significant difference was found between the above, the computed critical differences were used for the pair wise comparison.

Critical difference for comparing first factor (dates of planting) was calculated as,

$$CD_1 = t_1 \times SE_1$$

Where t_1 = t value at error degrees of freedom

SE_1 = standard error of difference between first factor means

$$SE_1 = \sqrt{\frac{2E_1}{rb}}$$

Where, E_1 = error mean square value in ANOVA

r = number of replications

b = number of second factor

Critical difference for the comparison of two growing conditions

$$CD_2 = t_2 \times SE_2$$

Where, t_2 = t value at error degrees of freedom

SE_2= Standard error of difference between second factor

$$SE_2 = \sqrt{\frac{2E_1}{ra}}$$

Where, E_1=Error mean square value in ANOVA

r = Number of replications

a = Number of first factor

Various statistical analyses were carried out using different software packages like Microsoft – excel and SPSS.

3.6. CROP GROWTH SIMULATION

Crop growth simulation models have become accepted tools for agricultural research. It simulates the crop growth and its development as a function of crop management, weather conditions and soil conditions. These crop simulation models have wider applicability in agricultural fields for assessing the yield in the changing climatic conditions and also helpful in modifying the management practices so as to get an optimum yield. Decision support system for agro technology transfer (DSSAT) and its crop simulation models can be used for this purpose as a research and teaching tool. The inputs required for these crop simulations include the daily weather data, soil surface and profile information and detailed crop management information.

DSSAT has the potential to reduce substantially the time and cost of experimentation necessary for the proper evaluation of new cultivars and new management systems. DSSAT contains crop specific file including the genetic information of the crop whereas the cultivar or variety information is to be given by the user in a separate file. The crop simulation models has to be integrated with the weather, soil and crop management files provided by the user to give simulated output. DSSAT also evaluates the simulated outputs with that of experimental data.

3.6.1. CERES-Rice model

Crop Estimation through Resource and Environment Synthesis (CERES) model has been applied to a range of areas, including crop management and shifting weather patterns. The ultimate aim of this model is to help farmers by identifying major yield limiting factors and developing research areas to improve cropping systems. This model simulate crop growth, development and yield as a function of weather, soil water, cultivar, planting density and nitrogen. CERES-Rice model also requires a common input and output data format.

Hunt and Boote (1994) proposed the minimum data set for the calibration and operation of the CERES- Rice models. In the present study, CERES-Rice model was run using the weather, soil, crop management practices and experimental data for the year 2019-2020 for variety Jyothi. The input and output files of CERES-Rice include the following given in Table 3.6 and Table 3.7.

3.6.1.1. Input files and experiment data files

The CERES-Rice model uses input files and experiment data files to run which is given in Table 3.6.

3.6.1.2. Output files

The output files helps the users to select the information required for a specific application which is listed in Table 3.7.

3.6.2. Running the crop Model

Once, all the desired files were created carefully, the model was run for all the treatments.

3.6.3. Model calibration and evaluation

The adjustment of parameters for comparing simulated and observed values is known as model calibration. Genetic coefficient calibration of CERES-Rice model was done with minimum data set such as planting date, plant density, spacing, fertilizer amount, irrigation levels, date of panicle initiation, physiological maturity, harvesting, harvesting method, yield and leaf area. To evaluate the goodness of fit and performance of the model, the statistical parameters like Normalized Root Mean Square Error (RMSE) and D-stat index were used as common tools.

Table 3.6. Input files of CERES-Rice model

Internal file name		External description	Name
Experiment	FILEX	Experiment details file for a specific experiment (e.g., rice at PTBI): Contains data on treatments, field conditions, crop management and simulation controls	PTBI1901.RIX
Weather and soil	FILEW	Weather data, daily, for a specific (e.g.,ATRA) station and time period (e.g., for one year)	PTBI1901.WTH
	FILES	Soil profile data for a group of experimental sites in general (e.g., SOIL.SOL) or for a specific institute (e.g., AGSANDLOAM.SOL)	SOIL.SOL
Crop and cultivar	FILEC	Cultivar/variety coefficients for a particular crop species and model; e.g., rice for the ‘CERES’ model, version 046	RICER046.CUL
	FILEE	Ecotype specific coefficients for a particular crop species and model; e.g., rice for the ‘CERES’ model, version 046	RICER046.ECO
	FILEG	Crop (species) specific coefficients for a particular model; e.g., rice for the ‘CERES’ model, version 046	RICERO46.SPE
Experiment data files	FILEA	Average values of performance data for a rice experiment. (Used for comparison with summary model results.)	PTBI1901.RIA
	FILET	Time course data (averages) for a rice experiment. (Used for graphical comparison of measured and simulated time course results.)	PTBI1901.RIX

Table 3.7. Output files of CERES-Rice model

Internal file name	External description	File name
OUTO	Overview of inputs and major crop and soil variables.	OVERVIEW.OUT
OUTS	Summary information: crop and soil input and output variables; one line for each crop cycle or model run	SUMMARY.OUT
SEVAL	Evaluation output file (simulated vs. observed)	EVALUATE.OUT
OUTWTH	Daily weather	Weather. OUT
OUTM	Daily management operations output file	MgmtOps. OUT
ERRORO	Error messages	ERROR.OUT
OUTINFO	Information output file	INFO.OUT
OUTWARN	Warning messages	WARNING.OUT

3.7. CLIMATE CHANGE PROJECTIONS

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, 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 characterised 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 W m^{-2}. The future climate was estimated using climate change projections generated using ECHAM model and GFDL-CM3 model for 2030, 2050 and 2080 based on RCP, 4.5, and 8.5. Venkat *et al.* (2017) reported that GFDL-CM3 model showed a good ability to simulate present climate over central zone of Kerala. Observed climate data for past 30 years were obtained for RCP 4.5 and RCP 8.5 in the year 2030, 2050 and 2080 using the GCM models (GFDL-CM3 and ECHAM). The 30 years period was chosen, considering that this is the minimum period needed to define a climate.

Table 3.8. Description of representative concentration pathway (RCP) scenarios (Moss *et al*., 2010)

RCP	Description
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.
RCP8.5	It is characterized by increasing GHG emissions over time and it is a representative of scenarios leading to high GHG concentration levels.

Climate change data projected by GCM's on daily basis was used for the present study. Daily data of following variables were taken

1. Rainfall

2. Maximum Temperature

3. Minimum Temperature

4. Solar radiation

The projected daily data incling precipitation, maximum temperature, minimum temperature and radiation were used as inputs for the CERES-Rice model. Crop simulation model DSSAT was used to study the impact of climate change on rice production under the projected climate change.

Result

4. RESULT

A study on 'Impact of climate change on production and nutritional qualities of rice' was conducted at RARS Pattambi during 2019-20. The effect of weather on growth, yield and nutritional aspects of rice variety Jyothi was studied under open condition and inside green house. Future climate was estimated using climate change projections for 2030, 2050 and 2080 based on RCP 4.5 and 8.5 generated using ECHAM model and GFDL-CM3 model and used in DSSAT Crop simulation model to study the impact of climate change on rice production under the projected climate change scenarios. The results are presented in this chapter.

4.1. WEATHER CONDITION PREVAILED DURING CROP GROWTH PERIOD UNDER OPEN CONDITION

Weather prevailed during crop growth stage was recorded on daily basis. Observations on maximum temperature, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall, number of rainy days, bright sunshine hours and evaporation were taken from agrometeorological observatory, Regional Agricultural Research Station, Pattambi and were converted to weekly observations. The weather parameters are averaged against standard meteorological weeks and are represented in Table 4.1.

4.1.1. Air Temperature

The temperature observed during the crop period under open condition against standard meteorological week is represented in Fig. 4.1. The maximum temperature, minimum temperature, mean temperature and temperature range were recorded. Late transplanted crop experienced more maximum and minimum temperature compared to early transplanted crop. Maximum temperature (37.4°C) was observed in 13th standard meteorological week and minimum temperature (18.3°C) was observed in 2nd standard meteorological week during 2020.

4.1.2. Relative Humidity

Forenoon and afternoon relative humidity for the entire crop period was recorded. The forenoon relative humidity, afternoon relative humidity and average relative humidity were plotted against standard meteorological week and are represented in Fig. 4.2. Forenoon relative humidity was highest (97.4%) during 35th standard meteorological week in the year 2019 and lowest (70.6%) in 7th standard meteorological week in the year 2020. Highest afternoon relative humidity (89.7%) was observed in 32nd standard meteorological week and lowest (31.9%) was recorded in 8th standard meteorological week. Both forenoon and afternoon relative humidity showed a decreasing trend towards late transplanted crop compared to early transplanted crop.

4.1.3. Rainfall and rainy days

The rainfall and number of rainy days for entire crop growth period were recorded and plotted against standard meteorological week and represented in Fig. 4.3. The highest amount of rainfall (665.6 mm) was observed in 32nd standard meteorological week. Amount of rainfall and number of rainy days showed a declining trend towards late transplanted crop. The total amount of rainfall received during entire crop period was 3004.4 mm. Total number of rainy days observed during entire crop period was 109 days.

4.1.4. Bright sunshine hours (BSS) and pan evaporation (Ep)

The bright sunshine hours and pan evaporation recorded during entire crop period were plotted against standard meteorological week in Fig. 4.4. Bright sunshine hours were found to be highest (9.7 h) in 15th standard meteorological week and lowest (0.2 h) in 32nd standard meteorological week. Pan evaporation showed a maximum value (57 mm) in 7th standard meteorological week and minimum value (11.2 mm) in 35th standard meteorological week. Bright sunshine hours and pan evaporation showed a declining trend towards late transplanted crop.

4.1.5. Soil Temperature

Soil temperature during entire crop period was recorded using soil thermometer. The soil temperature data is plotted against standard week in Fig. 4.5. Soil temperature recorded was highest (41.9 °C) in 11th and 16th week and lowest (31.4 °C) in 29th week. Soil temperature was showing an increasing trend towards late transplanted crop.

Table 4.1. Weather experienced during crop growth period under open condition

SMW	Tmax (°C)	Tmin (°C)	DTR (°C)	Tmean (°C)	RH1 (%)	RH2 (%)	ST (°C)	RF (mm)	RD (Days)	BSS (h)	Ep (mm)
22	33.6	22.2	11.4	27.9	89.9	62.9	35.3	44	2	6.1	38.0
23	32.8	23.0	9.9	27.9	89.0	72.1	35.2	93.9	1	5.0	34.6
24	31.4	22.2	9.2	26.8	96.0	80.1	34.1	136.1	7	1.5	20.2
25	30.6	21.7	8.9	26.2	95.3	71.1	33.3	87.8	6	2.5	23.6
26	31.2	22.3	8.9	26.8	93.3	69.6	33.8	24.8	2	6.2	39.2
27	30.6	21.9	8.7	26.3	97.0	77.9	32.9	135.4	7	3.0	51.1
28	30.1	21.3	8.9	25.7	93.4	76.9	33.1	66.5	5	3.5	30.9
29	28.3	21.2	7.1	24.8	94.4	82.0	31.4	225.2	5	2.4	28.7
30	29.5	21.2	8.2	25.4	96.9	76.7	32.1	129.1	5	3.2	18.6
31	30.7	21.9	8.8	26.3	92.9	69.7	33.8	23.2	2	4.6	28.0
32	28.1	20.3	7.8	24.2	97.3	89.7	31.6	665.6	7	0.2	11.9
33	29.9	21.5	8.4	25.7	95.7	73.7	33.6	79	4	3.0	14.5
34	28.9	20.9	8.0	24.9	96.1	79.1	31.9	144.2	7	1.8	11.5
35	29.0	21.1	8.0	25.0	97.4	82.4	31.9	271.1	7	1.6	11.2
36	30.1	21.5	8.6	25.8	93.4	78.1	33.8	184.1	7	3.4	19.3
37	31.0	21.9	9.1	26.5	94.6	68.3	34.8	45.4	4	5.6	29.2
38	31.1	21.8	9.3	26.5	91.7	66.4	34.9	33.5	1	3.8	25.4
39	31.1	22.0	9.1	26.6	92.1	66.1	34.9	35.5	2	5.9	27.1
40	32.8	21.5	11.3	27.2	86.1	64.7	36.6	25.1	3	7.4	29.1
41	33.0	21.1	11.9	27.1	88.6	72.0	36.8	90.7	3	7.4	23.5
42	31.2	21.3	9.9	26.3	95.6	73.7	35.0	223.2	6	5.1	23.9
43	30.8	20.4	10.4	25.6	89.9	65.1	34.6	92.1	6	4.5	25.9
44	31.1	20.1	11.0	25.6	87.9	71.6	34.9	46.6	3	3.9	12.2
45	32.3	21.5	10.8	26.9	94.4	66.3	36.1	0.8	0	4.5	25.4
46	32.3	21.1	11.2	26.7	87.4	59.1	36.1	25.2	2	7.3	30.3
47	32.4	21.4	11.0	26.9	84.7	57.7	36.2	0	0	8.7	25.4
48	31.4	21.5	9.9	26.4	89.3	59.3	35.2	6	1	5.0	27.3
49	31.6	20.6	11.1	26.1	84.9	55.3	35.5	0	0	7.8	36.0
50	31.6	19.8	11.8	25.7	81.1	56.6	35.5	0	0	7.5	31.8
51	32.2	21.3	10.9	26.7	77.3	48.1	36.3	0	0	7.4	32.6
52	32.5	21.1	11.4	26.8	74.8	52.4	36.6	0	0	7.1	32.4
1	34.2	20.0	14.3	27.1	89.4	45.0	38.4	0	0	8.9	36.2

Table 4.1. Weather experienced during crop growth period under open condition (Contd.)

SMW	Tmax (°C)	Tmin (°C)	DTR (°C)	Tmean (°C)	RH1 (%)	RH2 (%)	ST (°C)	RF (mm)	RD (Days)	BSS (h)	Ep (mm)
2	32.9	18.3	14.6	25.6	76.3	51.3	37.1	0	0	8.8	38.0
3	33.5	18.7	14.9	26.1	76.9	39.6	37.8	0	0	9.3	43.9
4	34.6	19.4	15.2	27.0	80.0	36.1	39.0	0	0	9.3	49.0
5	34.7	18.7	16.0	26.7	82.7	38.6	39.2	0	0	9.1	39.1
6	34.7	18.9	15.8	26.8	82.1	44.7	39.1	0	0	9.3	43.4
7	35.5	20.3	15.3	27.9	70.6	36.1	39.9	0	0	9.3	57.0
8	35.6	19.5	16.1	27.5	77.7	31.9	39.8	0	0	8.6	47.0
9	35.5	21.0	14.6	28.3	86.9	41.0	40.1	32.4	1	8.0	43.1
10	35.4	22.2	13.2	28.8	89.9	41.1	40.2	0	0	8.4	40.0
11	37.0	21.2	15.8	29.1	85.6	34.4	41.9	0	0	9.6	38.6
12	36.3	22.2	14.2	29.3	85.7	48.7	41.1	0	0	8.6	39.4
13	37.4	22.0	15.4	29.7	85.9	41.9	41.3	0	0	7.6	40.8
14	36.1	22.1	13.9	29.1	81.1	55.7	40.3	0	0	7.1	38.0
15	37.0	22.2	14.8	29.6	84.9	43.0	41.8	0	0	9.7	45.5
16	37.1	23.1	14.0	30.1	80.9	46.9	41.9	3.2	1	8.9	45.8
17	35.6	22.3	13.3	28.9	81.4	53.7	40.9	34.7	2	6.9	38.9

SMW : Standard meteorological week

Tmax : Maximum temperature

Tmin : Minimum temperature

Tmean : Mean temperature

DTR : Daily temperature range

RH 1 : Forenoon relative humidity

RH 2 : Afternoon relative humidity

BSS : Bright sunshine hours

Ep : Evaporation rate

RF : Rainfall

RD : Rainy days

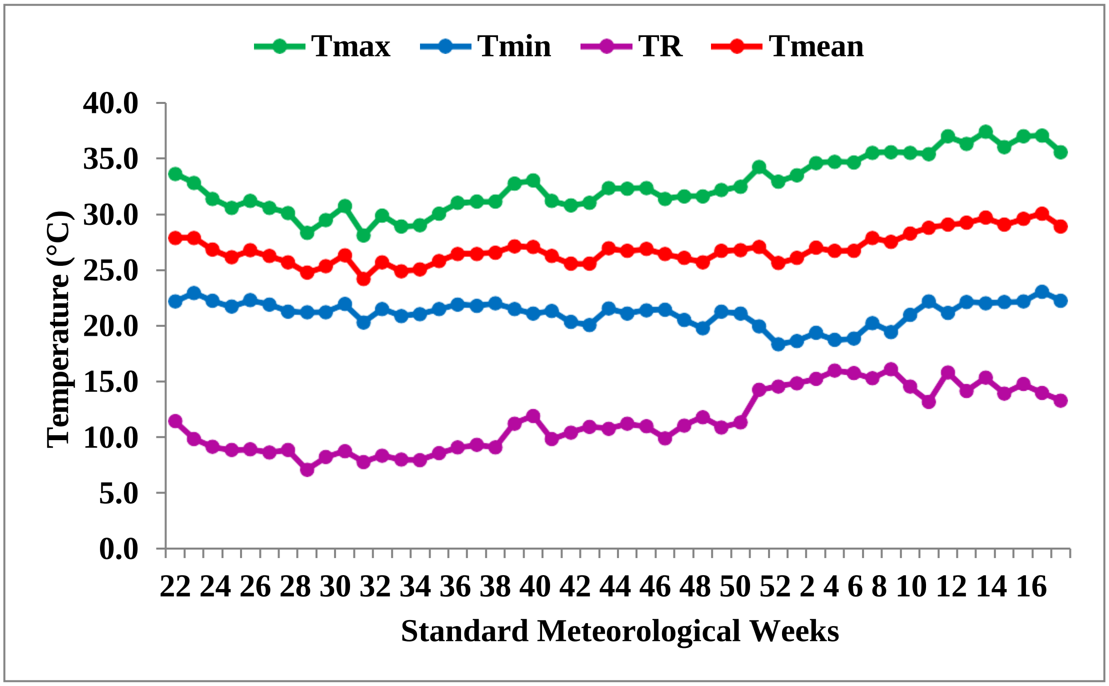


Fig.4.1. Weekly air temperature (^{0}C) during crop period under open condition

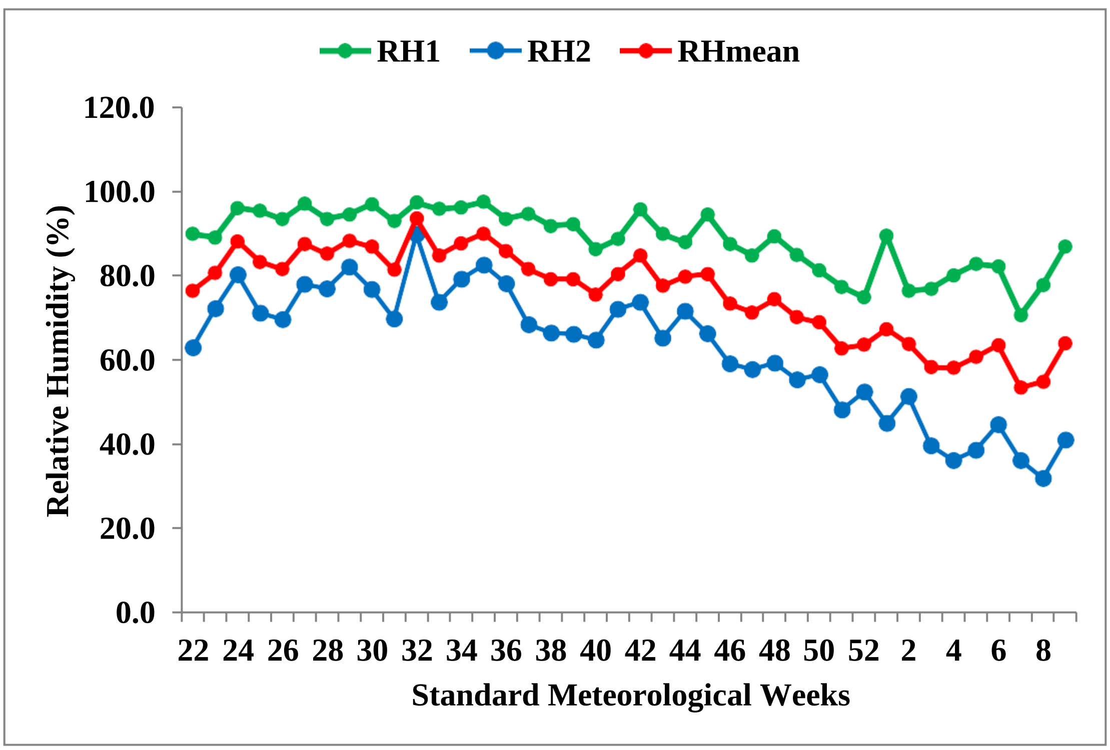


Fig.4.2. Weekly relative humidity (%) during crop period under open condition

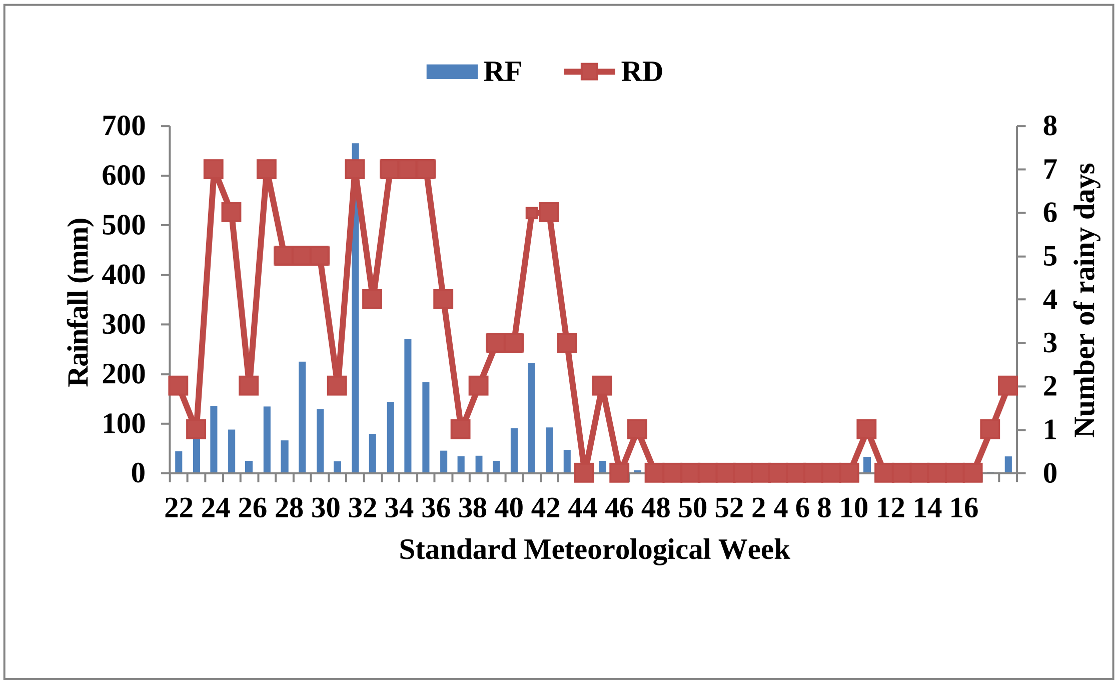


Fig. 4.3. Weekly rainfall (mm) during crop period under open condition

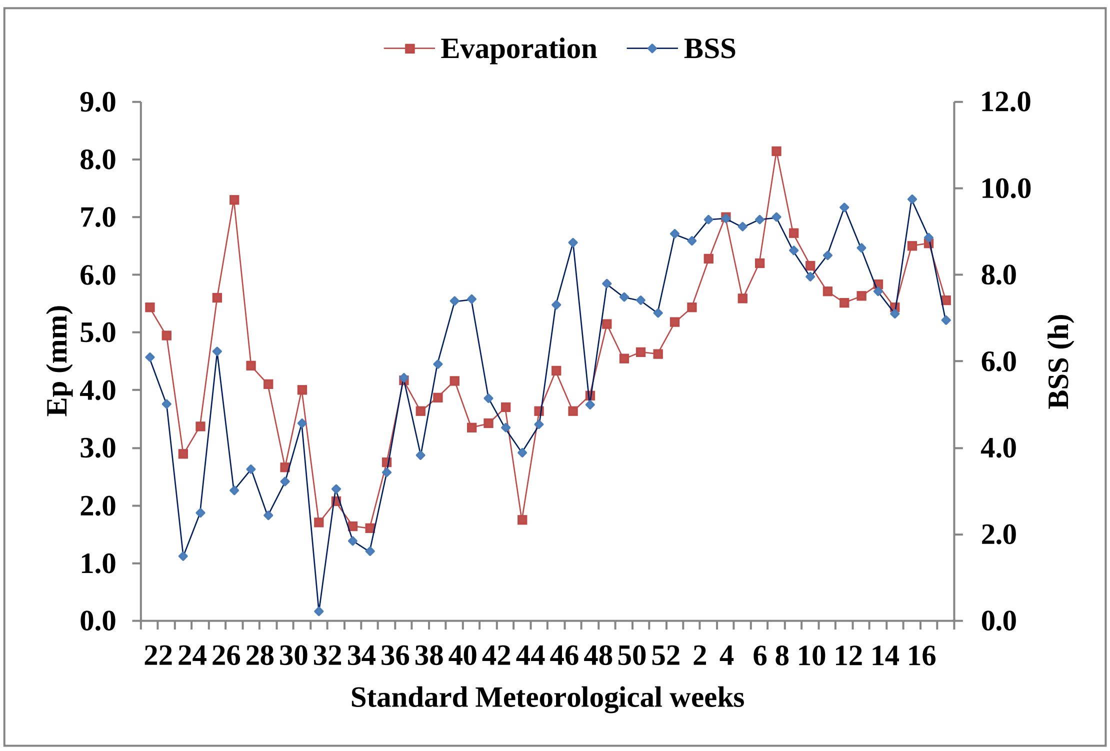


Fig. 4.4. Weekly bright sunshine hours (h) and evaporation (mm) during crop period under open condition

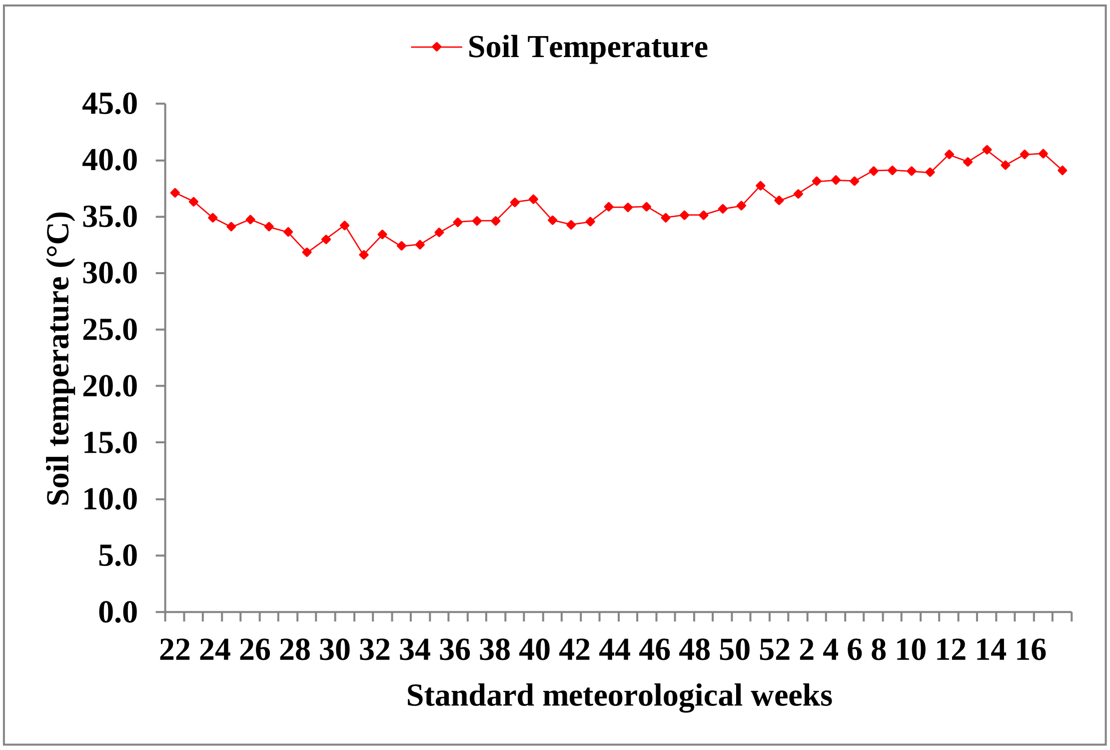


Fig. 4.5. Weekly soil temperature (°C) during crop period under open condition

4.2. WEATHER CONDITION PREVAILED DURING CROP GROWTH PERIOD UNDER CLIMATE CONTROLLED GREENHOUSE

Weather prevailed during crop growth stage under climate controlled greenhouse conditions was recorded. Observation on maximum temperature, minimum temperature, forenoon relative humidity, afternoon relative humidity and soil temperature were taken and converted to weekly observations. The weather parameters are averaged against standard meteorological week and are represented in Table 4.2.

4.2.1. Air Temperature

Air temperature observed during crop period under climate controlled greenhouse condition was plotted against standard meteorological week and is represented in Fig. 4.6. Late transplanted crops experienced more maximum and minimum temperature compared to early transplanted crop. Maximum temperature (40.9 °C) was observed in 11th, 13th and 15th standard meteorological week and minimum temperature (19.2 °C) was observed in 2nd standard meteorological week in the year 2020.

4.2.2. Relative Humidity

Forenoon and afternoon relative humidity for the entire crop period were recorded. The forenoon relative humidity, afternoon relative humidity and average relative humidity were plotted against standard meteorological week and are represented in Fig. 4.7. Forenoon relative humidity was highest (97%) during 37th standard meteorological week in the year 2019 and lowest (92%) in 41st standard week in the year 2020. Highest afternoon relative humidity (87%) was observed in 34th and 37th standard meteorological week and lowest (47%) was recorded in 1st and 2nd standard meteorological week. Afternoon relative humidity showed a decreasing trend towards late transplanted crop compared to early transplanted crop.

4.2.3. Soil Temperature

Soil temperature during entire crop period was recorded using soil thermometer. The soil temperature data is plotted against standard meteorological week in Fig. 4.8. Soil temperature recorded was highest (44.6 °C) in 13th week and lowest (32.2 °C) in 29th week. Soil temperature was showing an increasing trend towards late transplanted crop.

Table 4.2. Weather conditions prevailed during crop growth period under climate controlled greenhouse

SMW	Tmax (°C)	Tmin (°C)	DTR (°C)	Tmean (°C)	ST (°C)	RH1 (%)	RH2 (%)	RHmean (%)
22	35.7	23.4	12.4	29.6	37.6	93.0	83.0	88.0
23	35.7	23.7	12.0	29.7	37.6	93.4	83.9	88.6
24	33.3	22.7	10.6	28.0	35.7	94.4	84.6	89.5
25	32.3	22.1	10.2	27.2	34.7	94.6	84.9	89.7

Table 4.2. Weather conditions prevailed during crop growth period under climate controlled greenhouse (Contd.)

SMW	Tmax (°C)	Tmin (°C)	DTR (°C)	Tmean (°C)	ST (°C)	RH1 (%)	RH2 (%)	RHmean (%)
26	34.1	23.0	11.1	28.6	36.7	92.9	84.3	88.6
27	32.6	22.4	10.2	27.5	35.2	93.3	83.9	88.6
28	31.9	21.7	10.1	26.8	34.1	94.1	84.6	89.4
29	30.3	21.7	8.6	26.0	32.2	95.1	85.3	90.2
30	31.6	21.7	9.8	26.6	33.6	96.9	86.4	91.6
31	33.0	22.5	10.5	27.7	35.8	96.7	85.3	91.0
32	29.7	20.7	9.0	25.2	32.4	96.3	85.7	91.0
33	32.3	22.1	10.2	27.2	35.0	95.6	86.4	91.0
34	30.3	21.2	9.0	25.7	33.0	94.6	87.0	90.8
35	30.8	21.5	9.3	26.1	33.6	93.6	86.6	90.1
36	32.3	22.0	10.2	27.2	35.1	94.7	86.4	90.6
37	33.8	22.6	11.2	28.2	36.2	97.0	87.0	92.0
38	33.6	22.4	11.2	28.0	36.5	95.0	85.0	90.0
39	34.3	22.8	11.5	28.5	37.6	94.0	86.0	90.0
40	36.5	22.5	14.0	29.5	39.9	93.0	82.0	87.5
41	36.7	22.0	14.7	29.4	40.2	92.0	80.0	86.0
42	34.0	22.0	11.9	28.0	37.7	94.3	67.6	80.9
43	33.2	21.0	12.3	27.1	37.1	94.0	61.0	77.5
44	33.7	20.7	12.9	27.2	37.7	93.1	55.9	74.5
45	35.0	22.2	12.8	28.6	39.1	93.0	55.0	74.0
46	35.8	22.0	13.8	28.9	39.6	93.9	60.1	77.0
47	36.4	22.4	14.0	29.4	40.2	94.0	61.0	77.5
48	33.9	22.1	11.8	28.0	37.6	94.0	61.0	77.5

Table 4.2. Weather conditions prevailed during crop growth period under climate controlled greenhouse (Contd.)

SMW	Tmax (°C)	Tmin (°C)	DTR (°C)	Tmean (°C)	ST (°C)	RH1 (%)	RH2 (%)	RHmean (%)
49	35.2	21.5	13.8	28.3	38.6	93.0	57.0	75.0
50	35.6	20.8	14.8	28.2	40.4	93.0	57.0	75.0
51	35.7	22.2	13.5	28.9	40.4	93.0	57.0	75.0
2	36.4	19.2	17.2	27.8	40.9	93.0	47.0	70.0
3	37.3	19.6	17.7	28.4	41.7	93.0	52.0	72.5
4	38.4	20.3	18.0	29.3	43.0	93.0	56.3	74.6
5	38.4	19.6	18.7	29.0	42.5	94.0	63.0	78.4
6	38.4	19.8	18.6	29.1	42.2	94.0	64.0	79.0
7	39.3	21.2	18.1	30.3	42.8	94.0	64.0	79.0
8	39.0	20.3	18.7	29.6	42.6	94.0	64.0	79.0
9	38.6	21.7	16.9	30.2	42.3	93.5	63.3	78.4
10	38.7	23.0	15.7	30.9	42.5	93.0	62.0	77.5
11	40.9	22.1	18.8	31.5	44.4	93.3	62.4	77.8
12	39.8	23.0	16.7	31.4	43.3	94.0	65.0	79.5
13	40.9	22.9	18.0	31.9	44.6	94.0	65.0	79.5
14	39.7	23.0	16.6	31.3	43.3	93.1	64.3	78.8
15	40.9	22.9	18.0	31.9	44.5	93.0	64.0	78.5

SMW : Standard meteorological week

Tmax : Maximum temperature

Tmin : Minimum temperature

Tmean : Mean temperature

ST : Soil temperature

DTR : Diurnal temperature range

RH 1 : Forenoon relative humidity

RH 2 : Afternoon relative humidity

RHmean : Mean relative humidity

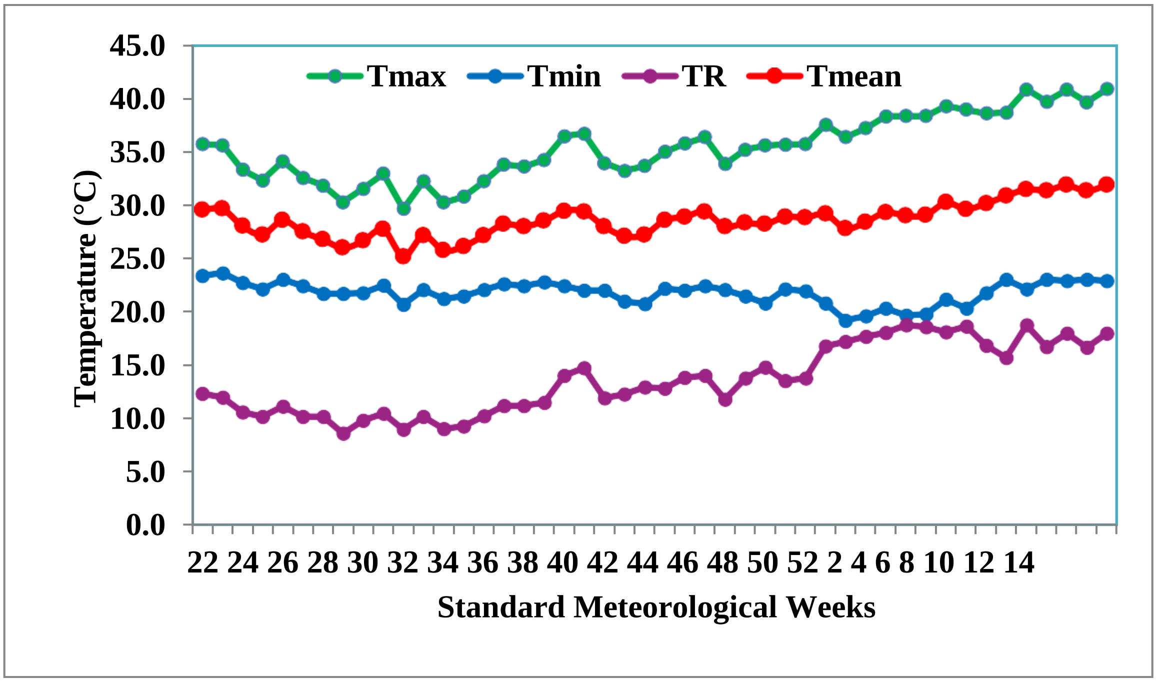


Fig. 4.6. Weekly air temperature (^{0}C) during crop period under climate controlled greenhouse

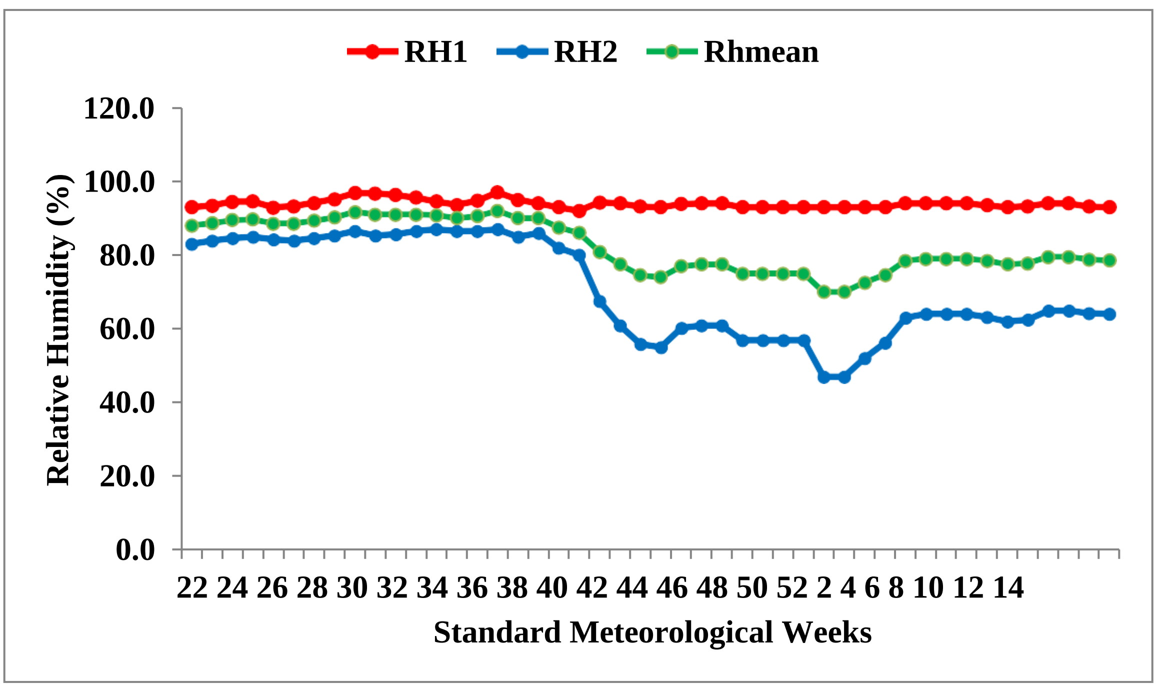


Fig. 4.7. Weekly relative humidity (%) during crop period under climate controlled greenhouse

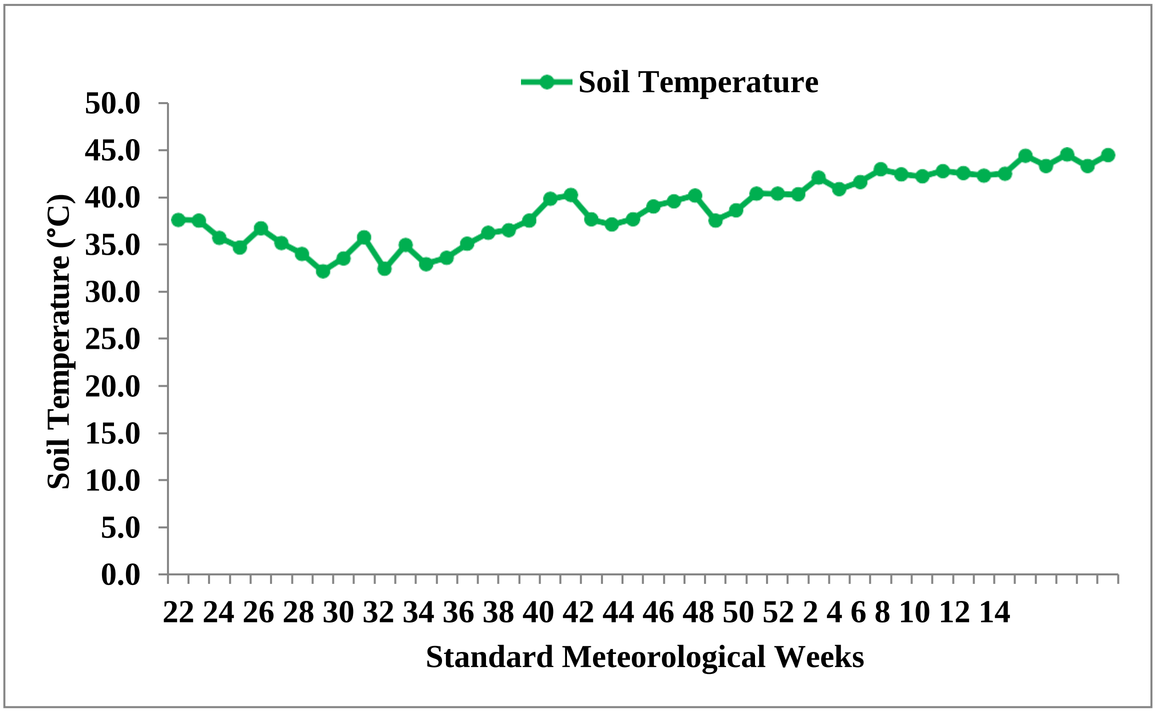


Fig. 4.8. Weekly soil temperature (^{0}C) during crop period under climate controlled greenhouse

4.3. PHENOLOGICAL OBSERVATIONS

Phenological observations for rice variety Jyothi for different dates of planting and different growing conditions were recorded. The duration of different phenological stages *viz*. active tillering, panicle initiation, booting, heading, 50% flowering and physiological maturity were given in Table 4.3.

4.3.1. Number of days for active tillering

Number of days taken for active tillering was less under climate controlled greenhouse compared to open condition. Period from transplanting to active tillering was 24 or 25 days in open condition, while it ranged from 19-22 days under climate controlled greenhouse.

4.3.2. Number of days for panicle initiation

Under open condition panicle initiation showed an increasing trend from first to third date of planting and then decreased. Compared to open condition, climate controlled greenhouse grown plants attained panicle initiation earlier.

4.3.3. Number of days for booting

Number of days taken for booting ranged from 51 to 55 days under open condition, whereas it was 47-52 days in climate controlled greenhouse. Crop grown under climate controlled greenhouse reached booting stage earlier compared to crop under open condition.

4.3.4. Number of days for heading

Number of days taken for heading ranged from 59 to 63 days under open condition and under climate controlled greenhouse, crop took about 54-59 days for attaining heading. Number of days taken for heading was less under climate controlled greenhouse.

Table 4.3. Duration of phenological stages in rice variety Jyothi

Phenophases	Date of transplanting									
	D1		D2		D3		D4		D5	
	O	GH	O	GH	O	GH	O	GH	O	GH
Active tillering	24	21	25	22	24	21	25	19	24	20
Panicle initiation	30	27	32	28	33	28	31	25	30	27
Booting	54	49	55	51	54	52	51	47	53	50
Heading	63	57	62	59	63	58	59	54	60	55
50% flowering	74	65	70	64	69	65	65	59	66	60
Physiological maturity	101	90	99	91	97	90	98	89	97	87

D1- June 1st D2- June 30th D3-October 1st D4-October 30th D5-January 1st

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

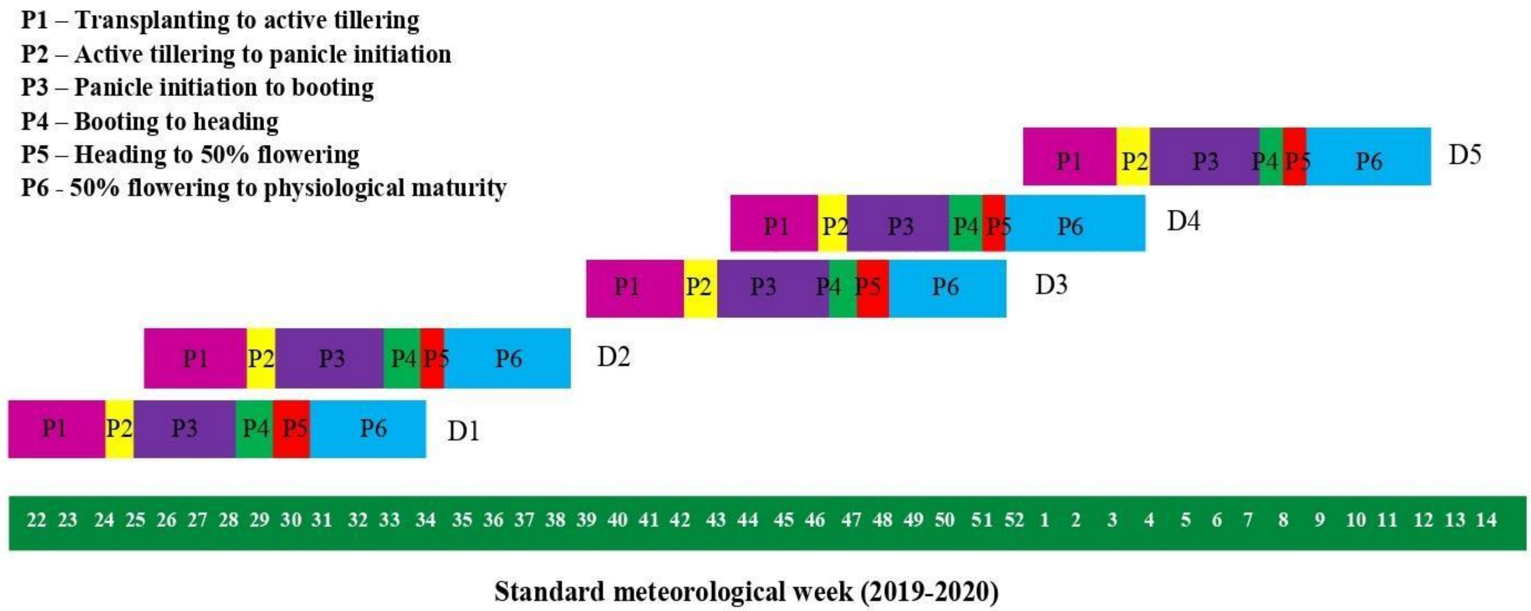


Plate VI. Phenological calendar of Jyothi under open condition

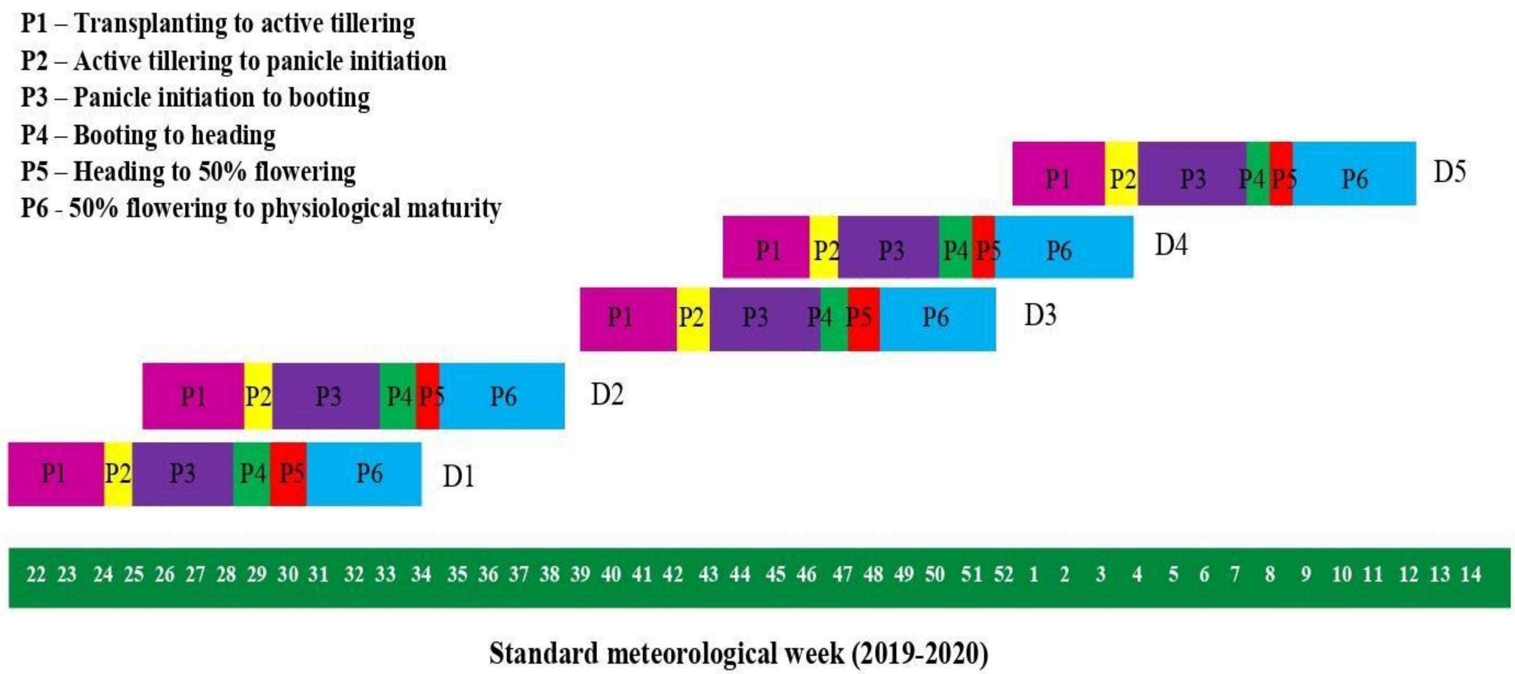


Plate VII. Phenological calendar of Jyothi under climate controlled greenhouse

4.3.5. Number of days for 50% flowering

Number of days taken for 50% flowering was less under climate controlled greenhouse compared to open condition. Period from transplanting to 50% flowering was 65 to 74 days in open condition, while it ranged from 59-65 days under climate controlled greenhouse.

4.3.6. Number of days for physiological maturity

Under open condition days to physiological maturity showed a decreasing trend from first to third date of planting and then increased in fourth planting and again decreased. Compared to open condition, climate controlled greenhouse grown plants attained physiological maturity earlier.

4.4. WEATHER PARAMETERS DURING DIFFERENT PHENOPHASES UNDER OPEN CONDITION

The weather parameters experienced during different phenophases of crop growth and development under open condition are presented below.

4.4.1. Weather during transplanting to active tillering stage under open condition

Weather prevailed during transplanting to active tillering stage is given in Table 4.4.

4.4.1.1. Temperature (Tmax, Tmin, DTR, Tmean)

Transplanting to active tillering stage of Jyothi experienced a maximum temperature of 33.7 °C and minimum temperature of 29.7 °C. Highest maximum temperature was experienced during fifth date of planting and lowest maximum temperature during second date of planting. Highest diurnal range of temperature of 14.6 °C was experienced in fifth date of planting and lowest diurnal temperature range of

8.3 °C was experienced during second date of planting. Mean temperature experienced during crop growth period ranged from 25.6 °C to 26.7 °C.

4.4.1.2. Relative humidity (RHI, RH2 and RHmean)

Forenoon relative humidity, afternoon relative humidity and mean relative humidity showed a decreasing trend from second date of planting towards fifth date of planting. Forenoon relative humidity was highest (95.2%) in second date of planting and lowest (80%) in fifth date of planting. Highest afternoon relative humidity (78.5%) was experienced in second date of planting and lowest (44.5%) in fifth date of planting. Mean relative humidity ranged from 62.2% to 86.8%.

4.4.1.3. Rainfall (RF) and rainy days (RD)

During transplanting to active tillering stage, amount of rainfall received showed a decreasing trend towards delayed planting. Highest amount of rainfall (505 mm) was received during second date of planting and no rainfall was received during fifth date of planting from transplanting to active tillering stage.

Similarly number of rainy days were showing a decreasing trend towards delayed date of planting. Highest numbers of rainy days (20 days) were experienced during second date of planting and no rainy day was experienced during fifth date of planting from transplanting to active tillering stage.

4.4.1.4. Bright sunshine hours (BSS)

There was an increasing trend in bright sunshine hours from first date of planting to last date of planting. Crop received maximum bright sunshine hours (9.1h) during fifth date of planting and minimum (3.1h) during second date of planting.

4.4.1.5. Pan evaporation (Ep)

The rate of evaporation was found to be highest (120.9 mm) in second date of planting and lowest (66.6 mm) in fourth date of planting.

4.4.1.6. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature experienced was found to be highest (31.8 °C) in fourth date of planting and lowest (29.3 °C) in first date of planting. Highest canopy air temperature depression (1.4 °C) was observed during first date of planting and lowest (0.4 °C) during second date of planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.4.1.7. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (314.3 µmol m^{-2} s^{-1}) in first date of planting and lowest (111.3 µmol m^{-2} s^{-1}) in third date of planting from transplanting to active tillering stage.

4.4.2. Weather during transplanting to panicle initiation stage under open condition

Weather prevailed during transplanting to panicle initiation stage is given in Table 4.5.

4.4.2.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature (33.9 °C) was experienced during fifth date of planting and lowest maximum temperature (29.9 °C) during second date of planting from transplanting to panicle initiation stage. Minimum temperature observed was highest (22.3 °C) during first planting and lowest (19.1 °C) during fifth planting. Highest diurnal range of temperature of 14.9 °C was experienced in fifth date of planting and lowest

Table 4.4. Weather during transplanting to active tillering stage under open condition

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	30.2	29.7	32.1	32.1	33.7
Tmin (˚C)	21.6	21.4	21.2	21.0	19.2
DTR (˚C)	8.6	8.3	10.9	11.1	14.6
Tmean (˚C)	25.9	25.6	26.7	26.6	26.4
RH 1 (%)	94.7	95.2	90.8	89.3	80.0
RH 2 (%)	75.9	78.5	69.5	64.0	44.5
RH mean(%)	85.3	86.8	80.1	76.6	62.2
RF (mm)	317.8	505.0	406.3	72.6	0.0
RD (days)	14.0	20.0	15.0	5.0	0.0
BSS (h)	3.5	3.1	6.5	6.1	9.1
Ep (mm)	83.9	120.9	78.2	66.6	118.4
CT (°C)	29.3	29.5	29.4	31.8	30.3
CATD (°C)	1.4	0.4	0.6	0.6	1.2
APAR (μmol m^{-2} s^{-1})	314.3	227.1	111.3	179.1	215.0

Table 4.5. Weather during transplanting to panicle initiation stage under open condition

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	31.7	29.9	31.7	32.1	33.9
Tmin (˚C)	22.3	21.5	20.9	21.1	19.1
DTR (˚C)	9.3	8.3	10.8	11.0	14.9
Tmean (˚C)	27.0	25.7	26.3	26.6	26.5
RH 1 (%)	93.1	95.3	89.4	88.3	81.3
RH 2 (%)	72.3	76.5	69.4	62.6	42.8
RH mean (%)	82.7	85.9	79.4	75.4	62.0
RF (mm)	342.6	550.9	473.3	72.6	0.0
RD (days)	16.0	23.0	20.0	5.0	0.0
BSS (h)	3.9	3.6	5.6	6.4	9.1
Ep (mm)	113.8	134.5	88.3	90.5	157.6
CT (°C)	29.1	29.4	29.5	31.7	30.8
CATD (°C)	1.6	0.5	0.5	0.7	1.2
APAR (μmol m^{-2} s^{-1})	277.2	210.5	127.7	192.7	243.3

D1- June 1st D2-June 30th D3-October 1st D4-October 30th D5-January 1st diurnal temperature range of 8.3 °C was experienced during second date of planting. Mean temperature experienced during crop growth period ranged from 25.7 °C to 27 °C.

4.4.2.2. Relative humidity (RH1, RH2 and RHmean)

Highest forenoon relative humidity (95.3%) experienced was in second date of planting and lowest (81.3%) in fifth date of planting. Afternoon relative humidity was found to be highest (76.5%) in second date of planting and lowest (42.8%) in fifth date of planting. Mean relative humidity ranged from 62% to 85.9%. Forenoon relative humidity, afternoon relative humidity and mean relative humidity showed a decreasing trend from second date of planting towards fifth date of planting.

4.4.2.3. Rainfall (RF) and rainy days (RD)

Amount of rainfall received showed a decreasing trend towards delayed planting during transplanting to panicle initiation stage. The highest amount of rainfall recorded was 550.9 mm during second date of planting and no rainfall was received in fifth date of planting during transplanting to panicle initiation stage. Number of rainy days experienced was highest (23 days) during second date of planting and no rainy day was experienced during fifth date of planting from transplanting to panicle initiation stage. Number of rainy days was showing a decreasing trend from second to fifth date of planting.

4.4.2.4. Bright sunshine hours (BSS)

Bright sunshine hours observed were highest (9.1h) on last date of planting and minimum (3.6h) during second date of planting. The bright sunshine hours showed increasing trend from second to last date of planting.

4.4.2.5. Pan evaporation (Ep)

Highest evaporation rate of rate of 157.6 mm was experienced during fifth date of planting and lowest rate of evaporation (88.3 mm) was observed in third date of planting.

4.4.2.6. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature was found to be highest (31.7°C) in fourth date of planting and lowest (29.1°C) in first date of planting. Highest canopy air temperature depression (1.6 °C) was observed during first date of planting and lowest (0.5 °C) during second and third date of planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.4.2.7. Absorbed photosynthetically active radiation (APAR)

Highest APAR (277.2 µmol $m^{-2} s^{-1}$) was recorded during first date of planting and lowest (127.7 µmol $m^{-2} s^{-1}$) in third date of planting from transplanting to panicle initiation stage.

4.4.3. Weather during transplanting to booting stage under open condition

Weather prevailed during transplanting to booting stage is given in Table 4.6.

4.4.3.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature during transplanting to booting stage was 34.4 °C and lowest maximum temperature was 29.6 °C for variety Jyothi under open condition. Highest minimum temperature (21.9 °C) was experienced for June 1st planting and lowest minimum temperature (19.1 °C) during January 1st planting. The mean temperature ranged from 25.5 °C to 26.7 °C, and was highest during January 1st planting and lowest during June 30th planting. Diurnal temperature range decreased from June 1st planting to June 30th planting and then showed an increasing trend towards January 1st planting.

4.4.3.2. Relative humidity (RH1, RH2 and RHmean)

Forenoon relative humidity showed a slight increase towards June 30th planting and thereafter decreased towards January 1st planting. The maximum forenoon relative humidity was found 95.4% for June 30th planting and minimum of 79.3% for January 1st planting. The afternoon relative humidity was showing a similar trend with slight increase upto June 30th planting and decrease towards January 1st planting. The maximum afternoon relative humidity was found to be 77.3% for June 30th planting and minimum of 40.8% for January 1st planting. The mean relative humidity ranged from 60% to 86.4% with maximum during June 30th planting and minimum during January 1st planting.

4.4.3.3. Rainfall (RF) and rainy days (RD)

Quantum of rainfall received showed an increase upto June 30th planting, then showed a steady decrease. The maximum amount of rainfall received was 1411.6 mm in June 30th planting and no rainfall was experienced during January 1st planting. Rainy days observed was maximum during June 30th planting and no rainy days were observed during January 1st planting.

4.4.3.4. Bright sunshine hours (BSS)

Bright sunshine hours varied between 2.9h to 9.1h from transplanting to booting stage. The duration was maximum for January 1st planting (9.1 h) and minimum for June 30th planting (2.9 h).

4.4.3.5. Pan evaporation (Ep)

Pan evaporation showed a decreasing trend from June 1st to October 1st planting, then increased towards January 1st planting. The value ranged from 183.1 mm to 315.7 mm. The maximum pan evaporation was observed for January 1st planting and minimum for October 1st planting.

4.4.3.6. Canopy temperature and canopy air temperature depression (CT and CATD)

Highest canopy temperature (31.9 °C) was experienced during January 1st planting and lowest (28.6 °C) in June 30th planting. Canopy air temperature depression was highest (1.4 °C) during June 1st planting and lowest (0.5 °C) during June 30th planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.4.3.7. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (281.5 µmol m^{-2} s^{-1}in June 30th planting) and lowest (155.1 µmol m^{-2} s^{-1}) in October 1st planting from transplanting to booting stage.

4.4.4. Weather during transplanting to heading stage under open condition

Weather prevailed during transplanting to heading stage is given in Table 4.7.

4.4.4.1. Temperature (Tmax, Tmin, DTR, Tmean)

Transplanting to heading stage of Jyothi experienced a maximum temperature of 34.6 °C during January 1st planting and minimum temperature of 29.6 °C during June 30th planting. Highest diurnal range of temperature of 15.3 °C was experienced in January 1st planting and lowest diurnal temperature range of 8.3 °C was experienced during June 30th planting. Mean temperature experienced during crop growth period ranged from 25.4 °C to 26.9 °C.

4.4.4.2. Relative humidity (RH1, RH2 and RHmean)

Forenoon relative humidity, afternoon relative humidity and mean relative humidity showed a decreasing trend from June 30th planting towards January 1st planting. Forenoon relative humidity experienced was highest (95.6%) in June 30th planting and lowest (79.6%) in January 1st planting. Highest afternoon relative humidity (78.3%) was

Table 4.6. Weather during transplanting to booting stage under open condition

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	30.8	29.6	32.0	31.9	34.4
Tmin (˚C)	21.9	21.4	21.1	20.9	19.1
DTR (˚C)	8.8	8.3	10.9	11.0	15.3
Tmean (˚C)	26.3	25.5	26.5	26.4	26.7
RH 1 (%)	94.0	95.4	89.7	86.7	79.3
RH 2 (%)	75.4	77.3	66.6	59.8	40.8
RHmean (%)	84.7	86.4	78.1	73.2	60.0
RF (mm)	851.1	1411.6	503.7	78.6	0.0
RD (days)	35.0	40.0	23.0	6.0	0.0
BSS (h)	3.5	2.9	6.0	6.6	9.1
Ep (mm)	230.4	197.3	183.1	188.6	315.7
CT (°C)	28.7	28.6	29.3	30.4	31.9
CATD (°C)	1.4	0.5	1.3	0.9	1.1
APAR (µmol m^{-2} s^{-1})	277.2	281.5	155.1	210.4	275.1

Table 4.7. Weather during transplanting to heading stage under open condition

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	30.7	29.6	31.9	31.9	34.6
Tmin (˚C)	21.9	21.3	21.1	20.9	19.3
DTR (˚C)	8.8	8.3	10.8	11.0	15.3
Tmean (˚C)	26.3	25.4	26.5	26.4	26.9
RH 1 (%)	94.3	95.6	89.3	85.3	79.6
RH 2 (%)	74.6	78.3	65.5	58.9	40.1
RH mean(%)	84.5	86.9	77.4	72.1	59.9
RF (mm)	903.5	1641.2	509.7	78.6	0.0
RD (days)	39.0	47.0	24.0	6.0	0.0
BSS (h)	3.7	2.8	6.0	6.6	9.0
Ep (mm)	255.9	219.9	205.6	215.3	350.7
CT (°C)	28.4	28.7	29.6	30.4	32.1
CATD (°C)	1.3	0.5	1.2	1.1	1.1
APAR (µmol m^{-2} s^{-1})	295.6	302.4	159.1	226.6	277.3

D1- June 1st D2-June 30th D3-October 1st D4-October 30th D5-January 1st

experienced in second date of planting and lowest (40.1%) in fifth date of planting. Mean relative humidity ranged from 59.9% to 86.9%.

4.4.4.3. Rainfall (RF) and rainy days (RD)

During transplanting to heading stage amount of rainfall received showed a decreasing trend towards delayed planting. The highest amount of rainfall (1641.2 mm) was recorded during June 30th planting and no rainfall was received in January 1st planting during transplanting to booting stage.

Similarly numbers of rainy days were showing a decreasing trend towards delayed date of planting. Highest numbers of rainy days (47 days) were experienced during June 30th planting and no rainy day was experienced during January 1st planting from transplanting to booting stage

4.4.4.4. Bright sunshine hours (BSS)

There was an increasing trend in bright sunshine hours towards last date of planting. Crop received maximum bright sunshine hours (9 h) during January 1st planting and minimum (2.8 h) during June 30th planting.

4.4.4.5. Pan evaporation (Ep)

The rate of evaporation was found to be highest (350.7 mm) in January 1st planting and lowest (205.6 mm) in October 1st planting.

4.4.4.6. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature experienced was found to be highest (32.1°C) in January 1st planting and lowest in June 1st planting (28.4°C). Highest canopy air temperature depression (1.3 °C) was observed during June 1st planting and lowest (0.5 °C) during June 30th planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.4.4.7. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (302.4 µmol m^{-2} s^{-1}) in June 30th planting and lowest (159.1 µmol m^{-2} s^{-1}) in October 1st planting from transplanting to active heading stage.

4.4.5. Weather during transplanting to 50% flowering stage under open condition

Weather prevailed during transplanting to 50% flowering stage is given in Table 4.8.

4.4.5.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature (34.6 °C) was experienced during January 1st planting and lowest maximum temperature (29.6 °C) during June 30th planting from transplanting to 50% flowering stage. Minimum temperature observed was highest (21.8 °C) during June 1st planting and lowest (19.5 °C) during January 1st planting. Highest diurnal range of temperature of 15.1 °C was experienced in January 1st planting and lowest diurnal temperature range of 8.3 °C was experienced during June 30th planting. Mean temperature experienced during transplanting to 50% flowering stage ranged from 25.4 °C to 27.1 °C.

4.4.5..2. Relative humidity (RH1, RH2 and RHmean)

Highest forenoon relative humidity (95.4%) experienced was in June 30th planting and lowest (80.7%) in January 1st planting. Afternoon relative humidity was found to be highest (78.2%) in June 30th planting and lowest (40.5%) in January 1st planting. Mean relative humidity ranged from 60.6% to 86.8%. Forenoon relative humidity, afternoon relative humidity and mean relative humidity showed a decreasing trend from June 30th planting towards January 1st planting.

4.4.5.3. Rainfall (RF) and rainy days (RD)

Amount of rainfall received showed a decreasing trend towards delayed planting during transplanting to 50% flowering stage. The highest amount of rainfall recorded was 1904 mm during June 30th planting and lowest rainfall (37 mm) was recieved in January 1st planting during transplanting to 50% flowering stage. Numbers of rainy days experienced were highest (55 days) during June 30th planting and only one rainy day was experienced during January 1st planting from transplanting to 50% flowering stage. Numbers of rainy days were showing a decreasing trend from second to fifth date of planting.

4.4.5.4. Bright sunshine hours (BSS)

Bright sunshine hours observed was highest (8.9 h) on January 1st planting and minimum (2.8 h) during June 30th planting. The bright sunshine hours showed an increasing trend from second to last date of planting.

4.4.5.5. Pan evaporation (Ep)

Highest evaporation rate of 377.3 mm was experienced during January 1st planting and lowest rate of evaporation (227.6 mm) was observed in June 30th planting.

4.4.5.6. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature was found to be highest (32.2°C) in January 1st planting and lowest (28.5°C) in June 1st planting. Highest canopy air temperature depression (1.2 °C)

Table 4.8. Weather during transplanting to 50% flowering stage under open condition

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	30.5	29.6	31.9	32.0	34.6
Tmin (˚C)	21.8	21.3	21.1	20.9	19.5
DTR (˚C)	8.7	8.3	10.8	11.1	15.1
Tmean (˚C)	26.1	25.4	26.5	26.5	27.1
RH 1 (%)	94.4	95.4	89.0	84.3	80.7
RH 2 (%)	75.9	78.2	64.8	57.8	40.5
RH mean (%)	85.1	86.8	76.9	71.1	60.6
RF (mm)	1723.5	1904.0	509.7	78.6	37.0
RD (days)	46.0	55.0	24.0	6.0	1.0
BSS (h)	3.3	2.8	6.1	6.7	8.9
Ep (mm)	286.8	227.6	239.1	244.2	377.3
CT (°C)	28.5	28.6	29.2	30.4	32.2
CATD (°C)	1.2	0.5	1.1	1.1	1.1
APAR (µmol m^{-2} s^{-1})	291.4	289.7	160.1	232.8	276.9

Table 4.9. Weather during transplanting to physiological maturity under open condition

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	30.2	30.1	32.0	32.7	35.3
Tmin (˚C)	21.6	21.5	21.0	20.3	20.3
DTR (˚C)	8.6	8.7	11.0	12.4	15.0
Tmean (˚C)	25.9	25.8	26.5	26.5	27.8
RH 1 (%)	94.8	94.2	86.1	83.2	82.0
RH 2 (%)	76.6	75.0	61.2	52.5	41.5
RH mean(%)	85.7	84.6	73.6	67.8	61.7
RF (mm)	1777.9	2019.9	642.3	273.8	217.8
RD (days)	72.0	66.0	24.0	6.0	1.0
BSS (h)	3.1	3.6	6.5	7.5	8.8
Ep (mm)	339.7	338.2	357.5	421.6	534.2
CT (°C)	28.7	29.4	29.7	31.2	32.8
CATD (°C)	1.0	0.6	1.1	1.1	1.2
APAR (µmol m^{-2} s^{-1})	317.1	324.4	208.7	284.9	329.0

D1- June 1st D2-June 30th D3-October 1st D4-October 30th D5-January 1st

was observed during June 1st planting and lowest (0.5 °C) during June 30th planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.4.5.7. Absorbed photosynthetically active radiation (APAR)

Highest APAR (291.4 μmol m^{-2} s^{-1}) was recorded during June 1st planting and lowest (160.1 μmol m^{-2} s^{-1}) in October 1st planting from transplanting to 50% flowering stage.

4.4.6. Weather during transplanting to physiological maturity stage under open condition

Weather prevailed during transplanting to physiological maturity stage is given in Table 4.9.

4.4.6.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature during transplanting to physiological maturity stage was 35.3 °C and lowest maximum temperature was 30.1 °C for variety Jyothi under open condition. Highest minimum temperature (21.6 °C) was experienced for June 1st planting and lowest minimum temperature (20.3 °C) during October 30th and January 1st planting. The mean temperature ranged from 25.8 °C to 27.8 °C, which was highest during January 1st planting and lowest during June 30th planting. Diurnal temperature range showed an increasing trend from June 1st planting towards January 1st planting.

4.4.6.2. Relative humidity (RH1, RH2 and RHmean)

The maximum forenoon relative humidity was found 94.8% for June 1st planting and minimum of 82% for January 1st planting. Forenoon relative humidity showed a decreasing trend from June 1st planting towards January 1st planting. The afternoon relative humidity also showed a similar trend. The maximum afternoon relative humidity was found to be 76.6% for June 1st planting and minimum relative humidity was 41.5%

for January 1^{st} planting. The mean relative humidity ranged from 61.7% to 85.7% with maximum during June 1^{st} planting and minimum during January 1^{st} planting.

4.4.6.3. Rainfall (RF) and rainy days (RD)

Quantum of rainfall received showed an increase upto June 30^{th} planting and then showed a steady decrease. The maximum amount of rainfall received was 2019.9 mm in June 30^{th} planting and 217.8 mm during January 1^{st} planting. Rainy days were maximum (72 days) during June 1^{st} planting and only one rainy day was observed during January 1^{st} planting.

4.4.6.4. Bright sunshine hours (BSS)

Bright sunshine hours varied between 3.1 h to 8.8 h from transplanting to physiological maturity stage. The duration was maximum (8.8 h) for January 1^{st} planting and minimum (3.1 h) for June 1^{st} planting.

4.4.6.5. Pan evaporation (Ep)

Pan evaporation showed a decreasing trend from June 1^{st} to June 30^{th} planting and then increased towards January 1^{st} planting. The value ranged from 338.2 mm to 534.2 mm. The maximum pan evaporation was observed for January 1^{st} planting and minimum for June 30^{th} planting.

4.4.6.6. Canopy temperature and canopy air temperature depression (CT and CATD)

Highest canopy temperature (32.8 °C) was experienced during January 1^{st} planting and lowest (28.7 °C) in June 1^{st} planting. Canopy air temperature depression was highest (1.2 °C) during January 1st planting and lowest (0.6°C) during June 30th planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.4.6.7. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (329 µmol m^{-2} s^{-1}) in January 1st planting and lowest (208.7 µmol m^{-2} s^{-1}) in October 1st planting from transplanting to physiological maturity stage.

4.5. WEATHER PARAMETERS DURING DIFFERENT PHENOPHASES UNDER CLIMATE CONTROLLED GREENHOUSE

The weather parameters experienced during different phenophases of crop growth and development under climate controlled greenhouse are presented below.

4.5.1. Weather during transplanting to active tillering stage under climate controlled greenhouse

Weather prevailed during transplanting to active tillering stage is given in Table 4.10.

4.5.1.1. Temperature (Tmax, Tmin, DTR, Tmean)

Transplanting to active tillering stage of Jyothi experienced a maximum temperature of 37 °C during January 1st planting and minimum temperature of 19.8 °C during January 1st planting. Highest diurnal range of temperature of 17.2 °C was experienced in fifth date of planting and lowest diurnal temperature range of 9.9 °C was experienced during second date of planting. Mean temperature experienced during crop growth period ranged from 27.1 °C to 28.9 °C.

4.5.1.2. Relative humidity (RH1, RH2 and RHmean)

Forenoon relative humidity, afternoon relative humidity and mean relative humidity were showed a decreasing trend from second date of planting towards fifth date of planting. Forenoon relative humidity experienced was highest (94 %) in June 1st planting and lowest (93 %) in January 1st planting.

Highest afternoon relative humidity (84.3 %) was experienced in June 30th planting and lowest (48.5 %) in January 1st planting. Mean relative humidity ranged from 70.8 % to 89.1 %.

4.5.1.3. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature experienced was found to be highest (36.7 °C) in October 1st planting and lowest (34.2 °C) in June 30th planting. Highest canopy air temperature depression (-0.3 °C) was observed during June 30th planting and lowest (-1.7 °C) during October 1st planting.

4.5.1.4. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (156.2 µmol m^{-2} s^{-1}) in January 1st planting and lowest (53.1 µmol m^{-2} s^{-1}) in October 1st planting from transplanting to active tillering stage.

4.5.2. Weather during transplanting to panicle initiation stage under climate controlled greenhouse

Weather prevailed during transplanting to panicle initiation stage is given in Table 4.11.

Table 4.10. Weather during transplanting to active tillering stage under climate controlled greenhouse

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	34.3	32.0	35.7	34.9	37.0
Tmin (˚C)	23.0	22.1	22.2	21.6	19.8
DTR (˚C)	11.2	9.9	13.6	13.3	17.2
Tmean (˚C)	28.7	27.1	28.9	28.3	28.4
RH 1 (%)	94.0	93.8	93.1	93.3	93.0
RH 2 (%)	84.0	84.3	76.5	56.6	48.5
RH mean(%)	89.0	89.1	84.8	74.9	70.8
CT (°C)	36.4	34.2	36.7	35.1	35.2
CATD (°C)	-1.4	-0.3	-1.7	-1.1	-1.2
APAR (μmol m^{-2} s^{-1})	84.7	120.8	53.1	131.9	156.2

Table 4.11. Weather during transplanting to panicle initiation stage under climate controlled greenhouse

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	34.0	31.6	35.1	35.3	37.4
Tmin (˚C)	22.9	21.9	21.9	21.8	20.0
DTR (˚C)	11.1	9.7	13.2	13.5	17.4
Tmean (˚C)	28.5	26.7	28.5	28.6	28.7
RH 1 (%)	94.0	94.6	93.3	93.4	93.0
RH 2 (%)	84.4	84.8	72.6	57.6	50.5
RH mean(%)	89.2	89.7	83.0	75.5	71.8
CT (°C)	35.8	34.0	35.7	35.1	33.8
CATD (°C)	-1.7	-0.6	-1.4	-1.1	-1.4
APAR (μmol m^{-2} s^{-1})	72.4	125.7	58.6	131.9	160.3

D1- June 1st D2-June 30th D3-October 1st D4-October 30th D5-January 1st

4.5.2.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature was experienced during fifth date of planting and lowest maximum temperature during second date of planting from transplanting to panicle initiation stage. Crop under climate controlled greenhouse experienced a highest maximum temperature of 37.4 °C (January 1st) and lowest maximum temperature of 31.6 °C (June 30th). Minimum temperature observed was highest (22.9 °C) during June 1st planting and lowest (20 °C) during January 1st planting. Highest diurnal range of temperature of 17.4 °C was experienced in January 1st planting and lowest diurnal temperature range of 9.7 °C was experienced during June 30th planting. Mean temperature experienced during crop growth period ranged from 26.7 °C to 28.7 °C.

4.5.2.2. Relative humidity (RH1, RH2 and RHmean)

Highest forenoon relative humidity (94.6 %) experienced was in June 30th planting and lowest (93 %) in January 1st planting. Afternoon relative humidity was found to be highest (84.8 %) in second date of planting and lowest (50.5 %) in fifth date of planting. Mean relative humidity ranged from 71.8 % to 89.7 %. Forenoon relative humidity, afternoon relative humidity and mean relative humidity were showing a decreasing trend from June 30th planting towards January 1st planting.

4.5.2.3. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature was found to be highest (35.8 °C) in fifth date of planting and lowest (33.8 °C) in first date of planting. Highest canopy air temperature depression (-0.6 °C) was observed during June 1st planting and lowest (-1.7 °C) during June 30th planting.

Table 4.12. Weather during transplanting to booting stage under climate controlled greenhouse

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	33.4	31.7	35.1	35.2	38.0
Tmin (˚C)	22.7	21.9	21.8	21.7	20.0
DTR (˚C)	10.8	9.8	13.3	13.4	17.9
Tmean (˚C)	28.0	26.8	28.5	28.4	29.0
RH 1 (%)	93.7	95.3	93.4	93.4	93.4
RH 2 (%)	84.2	85.3	65.7	58.1	56.6
RH mean(%)	89.0	90.3	79.5	75.8	75.0
CT (°C)	34.8	34.3	34.6	34.1	35.6
CATD (°C)	-1.4	-1.5	-1.2	-1.2	-1.2
APAR (µmol m^{-2} s^{-1})	107.7	141.1	118.9	172.9	216.5

Table 4.13. Weather during transplanting to heading stage under climate controlled greenhouse

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	32.9	31.5	35.2	35.2	38.0
Tmin (˚C)	22.4	21.8	21.8	21.7	20.1
DTR (˚C)	10.4	9.7	13.4	13.5	17.9
Tmean (˚C)	27.7	26.6	28.5	28.5	29.1
RH 1 (%)	94.2	95.2	93.4	93.4	93.5
RH 2 (%)	84.6	85.5	65.2	58.0	57.3
RH mean(%)	89.4	90.3	79.3	75.7	75.4
CT (°C)	34.5	34.1	34.7	34.2	35.8
CATD (°C)	-1.3	-1.4	-1.1	-1.2	-1.2
APAR (µmol m^{-2} s^{-1})	98.8	136.7	128.1	183.1	223.3

D1- June 1st D2-June 30th D3-October 1st D4-October 30th D5-January 1st

4.5.2.4. Absorbed photosynthetically active radiation (APAR)

Highest APAR (160.3 µmol m^{-2} s^{-1}) was recorded during January 1st planting and lowest (58.6 µmol m^{-2} s^{-1}) in June 1st planting from transplanting to panicle initiation stage.

4.5.3. Weather during transplanting to booting stage under open condition

Weather prevailed during transplanting to booting stage was given in Table 4.12.

4.5.3.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature during transplanting to booting stage was 38 °C and lowest maximum temperature was 31.7 °C for variety Jyothi under climate controlled greenhouse. Highest minimum temperature (22.7 °C) was experienced for June 1st planting and lowest minimum (20 °C) temperature during January 1st planting. The mean temperature ranged from 26.8 °C to 29 °C, which was highest during January 1st planting and lowest during June 30th planting. Diurnal temperature range decreased from June 1st planting to June 30th planting and then showed an increasing trend towards January 1st planting

4.5.3.2. Relative humidity (RH1, RH2 and RHmean)

Forenoon relative humidity showed a slight increase towards June 30th planting and thereafter showed a steady value towards January 1st planting. The maximum forenoon relative humidity was found 95.3 % for June 30th planting and minimum of 93.4 % for October 1st, October 30th and January 1st planting. The afternoon relative humidity was showing a similar trend with slight increase towards June 30th planting and decreased towards January 1st planting. The maximum afternoon relative humidity was found 85.3% for June 30th planting and minimum of 56.6 % for January 1st planting. The mean relative humidity ranged from 75% to 90.3% with maximum during June 30th planting and minimum during January 1st planting.

4.5.3.3. Canopy temperature and canopy air temperature depression (CT and CATD)

Highest canopy temperature (35.6 °C) was experienced during January 1st planting and lowest (34.1 °C) in October 30th planting. Canopy air temperature depression observed was lowest (-1.4 °C) during June 1st planting and lowest (-1.2 °C) during October 1st, October 30th and January 1st planting. Canopy temperature was showing an increasing trend towards delayed date of planting.

4.5.3.4. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (216.5 µmol m^{-2} s^{-1}) in January 1st planting and lowest (107.7 µmol m^{-2} s^{-1}) in June 1st planting from transplanting to booting stage.

4.5.4. Weather during transplanting to heading stage under climate controlled greenhouse

Weather prevailed during transplanting to heading stage is given in Table 4.13.

4.5.4.1. Temperature (Tmax, Tmin, DTR, Tmean)

Transplanting to heading stage of Jyothi experienced a maximum temperature of 38 °C and minimum temperature of 20.1 °C. Highest maximum temperature was experienced during January 1st planting and lowest maximum temperature during June 30th planting. Highest diurnal range of temperature of 17.9 °C was experienced in January 1st planting and lowest diurnal temperature range of 9.7 °C was experienced during June 30th planting. Mean temperature experienced during crop growth period ranged from 26.6 °C to 29.1 °C.

4.5.4.2. Relative humidity (RH1, RH2 and RHmean)

Forenoon relative humidity, afternoon relative humidity and mean relative humidity were showing a decreasing trend from June 30th planting towards January 1st planting. Forenoon relative humidity experienced was highest (95.2%) in June 30th planting and lowest (93.4 %) in October 1st and October 30th planting. Highest afternoon relative humidity (85.5 %) was experienced in second date of planting and lowest (57.3 %) in fifth date of planting. Mean relative humidity ranged from 75.4 % to 90.3 %.

4.5.4.3. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature experienced was found to be highest (35.8 °C) in January 1st planting and lowest (34.1 °C) in June 30th planting. Highest canopy air temperature depression (-1.1 °C) was observed during October 1st planting and lowest (-1.4 °C) during June 30th planting.

4.5.4.4. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (223.3 µmol $m^{-2} s^{-1}$) in January 1st planting and lowest (98.8 µmol $m^{-2} s^{-1}$) in June 1st planting from transplanting to heading stage.

4.5.5. Weather during transplanting to 50% flowering stage under climate controlled greenhouse

Weather prevailed during transplanting to 50% flowering stage under climate controlled greenhouse were given in Table 4.14.

4.5.5.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature was experienced during January 1st planting and lowest maximum temperature during June 30th planting from transplanting to 50% flowering stage. Crop under climate controlled greenhouse experienced a highest maximum temperature of 38.2 °C and lowest maximum temperature of 31.5 °C. Minimum temperature observed was highest (22.5 °C) during June 1st planting and lowest (20.2 °C) during January 1st planting. Highest diurnal range of temperature of 18 °C was experienced in January 1st planting and lowest diurnal temperature range of 9.7 °C was experienced during June 30th planting. Mean temperature experienced during transplanting to 50% flowering stage ranges from 26.6 °C to 29.2 °C.

4.5.5.2. Relative humidity (RH1, RH2 and RHmean)

Highest forenoon relative humidity (95.1 %) experienced was in June 30th planting and lowest (93.3 %) in October 30th planting. Afternoon relative humidity was found to be highest (85.6 %) in June 30th planting and lowest (57.8 %) in January 1st planting. Mean relative humidity ranges from 75.6 % to 90.3 %. Forenoon relative humidity, afternoon relative humidity and mean relative humidity showed a decreasing trend from June 30th planting towards January 1st planting.

4.5.5.3. Canopy temperature and canopy air temperature depression (CT and CATD)

Canopy temperature was found to be highest (35.9 °C) in January 1st planting and lowest (34 °C) in June 30th planting. Highest canopy air temperature depression (-1.1 °C) was observed during January 1st planting and lowest (-1.3 °C) during June 30th planting.

Table 4.14. Weather during transplanting to 50% flowering stage under climate controlled greenhouse

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	32.9	31.5	35.0	35.3	38.2
Tmin (˚C)	22.5	21.8	21.9	21.8	20.2
DTR (˚C)	10.4	9.7	13.1	13.5	18.0
Tmean (˚C)	27.7	26.6	28.5	28.5	29.2
RH 1 (%)	94.5	95.1	93.5	93.3	93.5
RH 2 (%)	84.7	85.6	64.6	57.9	57.8
RH mean(%)	89.6	90.3	79.0	75.6	75.7
CT (°C)	34.2	34.0	34.5	34.4	35.9
CATD (°C)	-1.2	-1.3	-1.2	-1.2	-1.1
APAR (µmol m^{-2} s^{-1})	116.5	132.7	141.0	189.8	235.2

Table 4.15. Weather during transplanting to physiological maturity under climate controlled greenhouse

Weather parameters	Date of planting				
	D1	D2	D3	D4	D5
Tmax (°C)	32.3	32.0	35.2	35.9	38.6
Tmin (˚C)	22.2	22.0	21.8	21.2	20.9
DTR (˚C)	10.2	10.0	13.4	14.7	17.6
Tmean (˚C)	27.2	27.0	28.5	28.6	29.8
RH 1 (%)	94.7	95.1	93.3	93.2	93.5
RH 2 (%)	85.2	85.7	62.5	55.6	59.5
RH mean(%)	90.0	90.4	77.9	74.4	76.5
CT (°C)	33.8	34.1	34.6	35.1	36.5
CATD (°C)	-1.0	-1.2	-1.3	-1.1	-1.0
APAR (µmol m^{-2} s^{-1})	133.7	147.6	163.3	229.5	264.8

D1- June 1^{st} D2-June 30^{th} D3-October 1^{st} D4-October 30^{th} D5-January 1^{st}

4.5.5.4. Absorbed photosynthetically active radiation (APAR)

Highest APAR (235.2 µmol $m^{-2} s^{-1}$) was recorded during January 1st planting and lowest (116.5 µmol $m^{-2} s^{-1}$) in June 1st planting from transplanting to 50% flowering stage.

4.5.6. Weather during transplanting to physiological maturity stage under climate controlled greenhouse

Weather prevailed during transplanting to physiological maturity stage under climate controlled greenhouse is given in Table 4.15.

4.5.6.1. Temperature (Tmax, Tmin, DTR, Tmean)

The highest maximum temperature during transplanting to physiological maturity stage was 38.6 °C and lowest maximum temperature was 32 °C for variety Jyothi under climate controlled greenhouse. Highest minimum temperature (22.2 °C) was experienced for June 1st planting and lowest minimum temperature (20.9 °C) during January 1st planting. The mean temperature ranged from 27 °C to 29.8 °C, which was highest during January 1st planting and lowest during June 30th planting. Diurnal temperature range showed an increasing trend from June 30th planting towards January 1st planting.

4.5.6.2. Relative humidity (RH1, RH2 and RHmean)

Forenoon relative humidity showed a decreasing trend from June 1st planting towards January 1st planting. The maximum forenoon relative humidity was found to be 95.1 % for June 30th planting and minimum of 93.2 % for October 30th planting. The maximum afternoon relative humidity was found 85.7 % for June 30th planting and minimum of 55.6 % for October 30th planting. The mean relative humidity ranged from 74.4 % to 90.4 % with maximum during June 30th planting and minimum during October 30th planting.

4.5.6.3. Canopy temperature and canopy air temperature depression (CT and CATD)

Highest canopy temperature (36.5 °C) was experienced during January 1st planting and lowest (33.8 °C) in June 1st planting. Canopy air temperature depression observed was highest (-1.0 °C) during June 1st and January 1st planting and lowest (-1.3 °C) during October 1st planting.

4.5.6.4. Absorbed photosynthetically active radiation (APAR)

Absorbed photosynthetically active radiation was found to be highest (264.8 µmol m^{-2} s^{-1}) in January 1st planting and lowest (133.7 µmol m^{-2} s^{-1}) in June 1st planting from transplanting to physiological maturity stage.

4.6. STATISTICAL ANALYSIS OF PLANT CHARACTERS

Statistical analysis were performed for biometric observations such as plant height, leaf area index, number of tillers at weekly intervals, dry matter accumulation at harvest, grain yield, straw yield, number of panicles per unit area, number of spikelet per panicle, number of filled grains per panicle and thousand grain weight. The analysis of variance was carried out for above mentioned characters and results are depicted in appendix II.

4.6.1. Plant height

From analysis, it was found that there was no significant difference observed between dates of planting for plant height during all weekly intervals. Among all the five dates of plantings, October 1st planting was found to be superior and June 30th planting was found to be inferior compared to all other dates of planting. At 14th week after planting, October 1st and October 30th planting were on par with respect to height. Effect of dates of planting on plant height recorded at weekly interval is represented in the Table 4.16 (a).

Effect of growing conditions on plant height recorded at weekly intervals was found to be significant. A comparison was done between two growing conditions *i.e* open condition and climate controlled greenhouse with respect to plant height at weekly intervals and result were displayed in Table 4.16 (b). It was found that variety grown under climate controlled greenhouse recorded highest plant height when compared to plants grown under open condition.

4.6.2. Leaf area index (LAI)

Effect of dates of planting on leaf area index was found to be significant up to 8 weeks after planting. At first week LAI recorded during June 30th planting was on par with October 1st, October 30th and January 1st planting. At second week leaf area index recorded during June 30th planting was on par with all other dates of planting except with June 1st planting. At 3rd week after planting LAI recorded during October 1st planting was on par with October 30th planting. LAI recorded during June 1st planting was on par with October 1st and October 30th planting. LAI recorded during June 1st planting was on par with October 30th and January 1st planting at 5th and 6th weeks after planting. LAI recorded during June 1st planting was on par with January 1st planting at 6th week and 7th week. Interaction between dates of planting and growing conditions was found to be significant at 2nd week, 4th week, 5th week and 6th week. Effect of growing conditions on leaf area index was found to be significant during all weeks except for 3rd and 5th and 6th week. Leaf area index recorded inside climate controlled green house was higher than open condition. Effect of dates of planting on leaf area index recorded at weekly interval is represented in the Table 4.16 (c). Effects of growing conditions on leaf area index recorded at weekly intervals were displayed in 4.16 (d).

4.6.3. Number of tillers per unit area

Effect of dates of planting on number of tillers was found to be significant during all weeks except 1st week, 3rd week, 12th week, 13th week and 14th week. Maximum number of tillers was recorded during 1st week after planting. At 2nd week the number of tillers recorded during June 30th planting was on par with October 1st, October 30th and June 30th. From 4th week to 9th week maximum number of tillers was recorded during October 30th planting. During 10th week and 13th week number of tillers recorded during October 30th planting was on par with June 1st and June 30th planting. At 11th week number of tillers recorded during June 30th planting was on par with October 30th and January 1st planting. Interaction between dates of planting and growing conditions was found to be significant. Effect of growing condition on number of tillers per unit area was found to be significant during 6th week, 7th week, 8th week and 10th week to 14th week. Number of tillers per unit area was more under climate controlled green house compared to open conditions. Effect of dates of planting on number of tillers recorded at weekly interval is represented in the Table 4.16 (e). Effects of growing conditions on number of tillers recorded at weekly intervals were displayed in 4.16 (f).

Table 4.16 (a). Effect of date of planting on plant height (cm) at weekly intervals

Date of planting	Week 1			Week 2			Week 3			Week 4			Week 5		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	15.9	17.7	16.8	28.2	25.1	26.6^{d}	37.5	39.3	38.4^{bc}	42.7	51.7	47.2^{b}	49.4	56.1	52.8^{b}
D2	16.0	18.5	17.3	27.1	27.1	27.1^{cd}	30.8	36.8	33.8^{c}	33.2	43.5	38.3^{c}	35.8	50.7	43.3^{c}
D3	16.3	18.0	17.2	32.7	30.8	31.7^{a}	42.0	49.1	45.6^{a}	50.1	61.9	56.0^{a}	52.2	66.7	59.4^{a}
D4	15.0	17.3	16.2	30.1	32.0	31.1^{ab}	39.7	42.9	41.3^{ab}	48.0	50.2	49.1^{b}	52.7	60.1	56.4^{ab}
D5	16.7	17.7	17.2	28.0	30.2	29.1^{bc}	37.6	41.0	39.3^{b}	45.7	54.4	50.1^{b}	48.8	60.3	54.6^{b}
CD	NS		NS	NS		1.88	NS		4.09	NS		4.06	NS		3.90

Date of planting	Week 6			Week 7			Week 8			Week 9			Week 10		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	53.8	63.1	58.4^{a}	54.3	65.0	59.6^{ab}	56.1	66.4	61.3^{bc}	61.8	73.4	67.6^{a}	61.9	78.9	70.4^{a}
D2	44.0	56.6	50.3^{b}	48.0	61.4	54.7^{b}	48.9	63.9	56.4^{c}	50.3	66.4	58.4^{b}	51.9	69.2	60.6^{b}
D3	54.4	69.8	62.1^{a}	56.1	72.1	64.1^{a}	58.3	74.7	66.5^{a}	60.8	76.2	68.5^{a}	63.2	78.8	71.0^{a}
D4	56.8	65.3	61.0^{a}	59.2	67.4	63.3^{a}	62.6	70.1	66.3^{ab}	64.7	72.6	68.6^{a}	68.0	75.9	71.9^{a}
D5	52.0	67.1	59.6^{a}	54.7	71.2	62.9^{a}	57.6	75.0	66.3^{ab}	60.0	78.6	69.3^{a}	62.2	81.1	71.7^{a}
CD	NS		4.25	NS		4.39	NS		4.38	NS		5.04	NS		4.56

Table 4.16 (a). Effect of date of planting on plant height (cm) at weekly intervals (Contd.)

Date of planting	Week 11			Week 12			Week 13			Week 14		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	64.2	84.2	74.2^{a}	67.2	87.1	77.2^{a}	67.4	89.6	78.5^{a}	67.7	90.3	79.0^{b}
D2	53.2	71.6	62.4^{b}	54.9	72.9	63.9^{b}	56.2	74.4	65.3^{b}	57.2	75.3	66.3^{c}
D3	64.7	81.8	73.3^{a}	66.9	84.7	75.8^{a}	69.0	86.4	77.7^{a}	70.1	88.4	79.3^{ab}
D4	71.1	77.9	74.5^{a}	73.2	81.1	77.2^{a}	74.9	84.4	79.7^{a}	76.2	90.3	83.3^{a}
D5	64.7	83.4	74.1^{a}	66.4	85.9	76.2^{a}	67.7	87.9	77.8^{a}	68.4	89.4	78.9^{b}
CD	NS		4.55	NS		4.11	NS		3.73	NS		3.50

Table 4.16 (b). Comparison between two growing conditions with respect to plant height (cm) at weekly intervals

Growing conditions	Plant height													
	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
O	16.0^{b}	29.2	37.5^{b}	43.9^{b}	47.8^{b}	52.2^{b}	54.5^{b}	56.7^{b}	59.5^{b}	61.5^{b}	63.6^{b}	65.7^{b}	67.0^{b}	67.9^{b}
GH	17.8^{a}	29.0	41.8^{a}	52.3^{a}	58.8^{a}	64.4^{a}	67.4^{a}	70.0^{a}	73.4^{a}	76.8^{a}	79.8^{a}	82.3^{a}	84.6^{a}	86.8^{a}
CD	0.90	NS	2.59	2.57	2.47	2.69	2.78	2.77	3.19	2.88	2.88	2.60	2.36	2.21

Table 4.16 (c). Effect of date of planting on leaf area index at weekly intervals

Date of planting	Week 1			Week 2			Week 3			Week 4			Week 5		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	0.05	0.09	0.07^{b}	0.11^{c}	0.42^{a}	0.26^{b}	0.46	0.53	0.49^{bc}	0.88^{b}	0.96^{ab}	0.92^{ab}	1.82^{ab}	1.94^{a}	1.88^{a}
D2	0.06	0.13	0.10^{a}	0.27^{ab}	0.31^{b}	0.29^{ab}	0.38	0.52	0.45^{c}	0.68^{b}	0.70^{b}	0.69^{c}	0.91^{c}	1.06^{c}	0.98^{c}
D3	0.05	0.14	0.10^{a}	0.35^{a}	0.37^{ab}	0.36^{a}	0.47	0.78	0.63^{ab}	0.77^{b}	1.07^{ab}	0.92^{ab}	1.35^{b}	1.35^{b}	1.35^{b}
D4	0.07	0.16	0.11^{a}	0.26^{ab}	0.42^{a}	0.34^{ab}	0.57	0.82	0.69^{a}	1.05^{ab}	1.14^{a}	1.09^{a}	2.09^{a}	1.30^{b}	1.70^{a}
D5	0.05	0.17	0.11^{a}	0.22^{b}	0.36^{ab}	0.29^{ab}	0.33	0.46	0.40^{c}	0.73^{b}	0.90^{ab}	0.82^{bc}	1.63^{b}	1.91^{a}	1.77^{a}
CD	NS		0.02	0.11		0.08	NS		0.38	0.25		0.18	0.36		0.26

Date of planting	Week 6			Week 7			Week 8			Week 9			Week 10		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	2.08^{b}	2.42^{ab}	2.25^{a}	2.38	3.50	2.94^{a}	2.76	3.59	3.17^{a}	3.30	3.99	3.64	3.30	3.99	3.64
D2	1.15^{d}	1.20^{c}	1.18^{c}	1.43	1.68	1.55^{d}	2.27	2.56	2.41^{b}	3.26	4.00	3.63	3.26	4.00	3.63
D3	1.71^{b}	1.50^{c}	1.61^{b}	2.12	2.06	2.09^{c}	2.26	2.37	2.31^{b}	3.07	3.92	3.50	3.07	3.92	3.50
D4	2.51^{a}	1.57^{c}	2.04^{a}	2.72	2.11	2.41^{bc}	2.91	2.37	2.64^{b}	3.15	3.96	3.55	3.15	3.96	3.55
D5	1.85^{b}	2.28^{a}	2.07^{a}	2.13	3.14	2.64^{ab}	2.43	3.17	2.80^{ab}	3.25	3.73	3.49	3.25	3.73	3.49
CD	0.41		0.29	NS		1.14	NS		0.43	NS		NS	NS		NS

Table 4.16 (c). Effect of date of planting on leaf area index at weekly intervals (Contd.)

Date of planting	Week 11			Week 12			Week 13			Week 14		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	3.53	4.37	3.95	3.69	4.72	4.21	3.20	4.41	3.80	2.73	4.23	3.48
D2	3.18	4.21	3.70	3.52	4.26	3.89	3.51	4.26	3.88	3.19	3.66	3.42
D3	3.67	4.34	4.01	3.54	4.32	3.93	3.48	4.26	3.87	3.36	4.03	3.69
D4	3.86	4.45	4.15	3.87	4.40	4.14	3.52	4.19	3.86	3.31	4.10	3.70
D5	3.59	4.05	3.82	3.46	4.28	3.87	3.35	3.97	3.66	3.12	3.82	3.47
CD	NS		NS	NS		NS	NS		NS	NS		NS

Table 4.16 (d). Comparison between two growing conditions with respect to leaf area index at weekly intervals

Growing conditions	Leaf area index													
	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
O	0.06^{b}	0.24^{b}	0.44	0.82^{b}	1.56	1.9	2.2^{b}	2.5^{b}	3.2^{b}	3.2^{b}	3.6^{b}	3.6^{b}	3.4^{b}	3.1^{b}
GH	0.14^{a}	0.37^{a}	0.62	0.96^{a}	1.51	1.8	2.5^{a}	2.8^{a}	3.9^{a}	3.9^{a}	4.3^{a}	4.4^{a}	4.2^{a}	4.0^{a}
CD	0.01	0.05	NS	0.11	NS	NS	0.72	0.27	0.24	0.24	0.21	0.45	0.42	0.37

Table 4.16 (e). Effect of date of planting on number of tillers at weekly interval

Date of planting	Week 1			Week 2			Week 3			Week 4			Week 5		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	2	2	2.00	2.0^{b}	2.00^{b}	2.00^{b}	2.1	3.4	2.78	2.8	3.6^{ab}	3.17^{b}	3.0^{b}	4.2^{a}	3.61^{b}
D2	2	2	2.00	2.3^{b}	2.60^{a}	2.44^{a}	2.8	2.6	2.67	3.0^{b}	3.0^{b}	3.00^{b}	3.3^{b}	3.3^{b}	3.33^{b}
D3	2	2	2.00	2.0^{b}	2.30^{ab}	2.17^{ab}	2.7	2.6	2.61	2.9^{b}	3.2^{b}	3.06^{b}	3.1^{b}	3.6^{b}	3.33^{b}
D4	2	2	2.00	2.7^{a}	2.1^{b}	2.39^{a}	3.0	3.0	3.00	3.9^{a}	3.8^{a}	3.83^{a}	4.3^{a}	4.4^{a}	4.39^{a}
D5	2	2	2.00	2.0^{b}	2.4^{a}	2.22^{ab}	3.0	2.7	2.83	3.2^{b}	3.1^{b}	3.17^{b}	3.7^{a}	3.6^{b}	3.61^{b}
CD	NS		NS	0.38		0.27	NS		NS	0.69		0.49	0.76		0.54

Date of planting	Week 6			Week 7			Week 8			Week 9			Week 10		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	3.3^{b}	4.4^{a}	3.89^{b}	3.7^{b}	4.1^{b}	3.89^{b}	4.0	4.6^{b}	4.28^{b}	4.4	4.9^{b}	4.67^{b}	4.6	5.1^{b}	4.83^{ab}
D2	3.7^{a}	3.8^{b}	3.72^{b}	4.0^{a}	4.0^{b}	4.00^{b}	4.2	4.6^{b}	4.39^{b}	4.7	4.7^{b}	4.67^{b}	5.0	5.0^{b}	5.00^{ab}
D3	3.4^{b}	3.8^{b}	3.61^{b}	3.7^{b}	4.0^{b}	3.83^{b}	4.0	4.1^{b}	4.06^{b}	4.4	4.3^{b}	4.39^{b}	4.6	4.6^{b}	4.56^{b}
D4	4.4^{a}	5.3^{a}	4.89^{a}	4.7^{a}	6.1^{a}	5.39^{a}	4.7	6.1^{a}	5.39^{a}	4.7	6.1^{a}	5.39^{a}	4.7	6.1^{a}	5.39^{a}
D5	3.8^{a}	4.1^{b}	3.94^{b}	4.0^{a}	4.4^{b}	4.22^{b}	4.3	4.6^{b}	4.44^{b}	4.6	4.6^{b}	4.56^{b}	4.7	4.7^{b}	4.67^{b}
CD	0.88		0.62	0.85		0.60	0.92		0.65	0.84		0.60	0.7		0.49

Table 4.16 (e). Effect of date of planting on number of tillers at weekly interval (Contd.)

Date of planting	Week 11			Week 12			Week 13			Week 14		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	4.7	5.2^{b}	4.94^{b}	4.9	5.6	5.22	5.1	5.6^{b}	5.33^{ab}	5.3	5.7	5.50
D2	5.2	5.3^{b}	5.28^{ab}	5.4	5.7	5.56	5.4	5.7^{b}	5.56^{ab}	5.6	5.9	5.72
D3	4.9	4.6^{b}	4.72^{b}	4.9	5.2	5.06	5.1	5.3^{b}	5.22^{b}	5.2	6.3	5.78
D4	5.0	6.1^{a}	5.56^{a}	5.0	6.3	5.67	5.1	6.4^{a}	5.78^{a}	5.0	6.4	5.72
D5	4.9	5.1^{b}	5.00^{ab}	5.0	5.2	5.11	5.1	5.3^{b}	5.22^{b}	5.2	5.3	5.28
CD	0.71		0.50	NS		NS	0.64		0.45	NS		NS

Table 4.16 (f). Comparison between two growing conditions with respect to number of tillers at weekly intervals

Growing conditions	Plant height													
	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
O	2.00	2.20	2.71	3.16	3.49	3.7^{b}	4.0^{b}	4.2^{b}	4.6	4.7^{b}	4.9^{b}	5.0^{b}	5.2^{b}	5.3^{b}
GH	2.00	2.29	2.84	3.33	3.82	4.3^{a}	4.5^{a}	4.8^{a}	4.9	5.1^{a}	5.3^{a}	5.6^{a}	5.7^{a}	5.9^{a}
CD	NS	NS	NS	NS	NS	0.39	0.38	0.41	NS	0.31	0.32	0.34	0.28	0.34

4.7. STATISTICAL ANALYSIS OF YIELD AND YIELD ATTRIBUTES

Analysis of variance (ANOVA) was performed for yield and yield attributes and the results are represented Appendix II. Effect of dates of planting, growing conditions and their interactions were found to be significant (Table 4.16 (g)).

Table 4.16 (h) provides mean values of yield and yield attributes of variety Jyothi grown under open condition and climate controlled greenhouse on different dates of planting. When the interactions between dates of planting and different growing conditions were significant, comparison was made between dates of planting for different growing conditions separately.

4.7.1. Grain yield

Grain yield recorded for variety Jyothi under two growing conditions during five dates of planting was depicted in Table 4.16 (g). As per the ANOVA, October 30th planting showed significantly higher yield. June 1st, June 30th, October 1st and January 1st planting were on par. Interaction between dates of planting and growing condition was significant with respect to grain yield. In climate controlled green house also maximum yield was recorded during October 30th planting. Significant difference was observed between different growing conditions. Yield recorded was maximum under open conditions.

4.7.2. Number of panicles per unit area

Effect of dates of planting on number of panicles per unit area was found to be non significant. Interaction between dates of planting and growing conditions was also found to be non significant.

4.7.3. Number of spikelet per panicle

Planting dates had significant influence on number of spikelet per panicle. Numbers of spikelet per panicle at different planting dates for both the growing conditions were depicted in Table 4.16 (g). Number of spikelet per panicle recorded during October 1st planting was on par with October 30th planting. Interactions between dates of planting and growing conditions were found to be significant. In open condition and climate controlled green houses number of spikelet recorded during October 1st planting was on par with October 30th planting.

Comparison between different growing conditions for number of spikelet per panicle was done and is presented in Table 4.16 (h). Effect of growing condition on number of spikelet was found to be non significant.

4.7.4. Number of filled grains per panicle

Comparison between different growing conditions for number of filled grains per panicle was done and is presented in Table 4.16 (h). Number of filled grains per panicle was significantly influenced by planting dates. Numbers of filled grains per panicle at different planting dates for both the growing conditions were depicted in Table 4.16 (g). October 1st and October 30th planting were on par and that recorded during June 1st, June 30th and January 1st plantings were on par. Number of filled grains per panicle for different growing conditions did not show any significant difference with respect to different dates of planting. With respect to growing conditions, number of spikelet per panicle was found to be non-significant.

4.7.5. Straw yield

Straw yield was significantly influenced by dates of planting and growing conditions. Under open condition and climate controlled greenhouse, no significant difference in straw yield was observed with respect to different planting dates. Comparison between different planting dates for straw yield is shown in Table 4.16 (g).

Table 4.16 (g). Effect of date of planting on yield and yield attributes

Date of planting	Grain yield (kg/ha)			Number of panicles per unit area			Number of spikelet per panicle		
	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	5345.2^{b}	2380.9^{d}	3863.0^{b}	260.6	223.3	241.9	62.1^{b}	54.3^{c}	58.2^{b}
D2	6150.0^{ab}	2576.8^{d}	4199.0^{b}	282.9	230.8	256.8	64.6^{bc}	60.3^{bc}	62.4^{b}
D3	5686.9^{b}	1934.8^{d}	3810.8^{b}	290.3	238.2	264.3	84.9^{a}	69.1^{b}	77.0^{a}
D4	7038.8^{a}	4083.3^{c}	5360.7^{a}	297.8	215.9	256.8	87.8^{a}	81.9^{ab}	84.8^{a}
D5	4131.0^{c}	2760.7^{d}	3445.9^{b}	275.7	184.0	229.8	62.8^{bc}	62.1^{bc}	62.4^{b}
CD	1064.1		475.9	NS		NS	14.1		10

Date of planting	Number of filled grains per panicle			Straw yield			Dry matter accumulation at harvest		
	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	42.9^{b}	15.2^{c}	29.0^{b}	3131.6^{c}	3630.6^{bc}	3381.1^{b}	8476.8^{b}	6011.4^{c}	7244.1^{b}
D2	43.9^{b}	20.1^{c}	32.0^{b}	2756.5^{d}	3425.3^{bc}	3090.9^{c}	8906.6^{b}	6002.2^{c}	7454.4^{b}
D3	70.6^{a}	45.6^{b}	58.1^{a}	2703.5^{d}	3666.0^{b}	3184.7^{bc}	8390.3^{b}	5600.8^{c}	6995.6^{b}
D4	72.9^{a}	59.1^{ab}	66.0^{a}	3375.8^{c}	4012.7^{a}	3694.3^{ab}	10414.6^{a}	8096.0^{b}	9255.3^{a}
D5	47.3^{b}	39.1^{b}	43.2^{b}	2776.8^{d}	3640.6^{b}	3208.7^{bc}	6907.8^{c}	6401.3^{c}	6654.6^{b}
CD	17.1		12.1	256.0		181.03	1312.1		586.8

Table 4.16 (h). Effect of growing condition on yield and yield attributes

Growing conditions	Grain yield	Number of panicles per unit area	Number of spikelets per panicle	Number of filled grains per panicle	Straw yield	Dry matter accumulation at harvest
O	5670.4^{a}	281.4^{a}	72.4^{a}	55.5^{a}	2948.8^{b}	8619.2^{a}
GH	2747.3^{b}	218.4^{b}	65.6^{b}	35.8^{b}	3675.0^{a}	6422.3^{b}
CD	475.9	20.9	6.3	7.6	114.5	586.8

October 30st planting has higher straw yield. October 1st and January 1st planting were on par with both June 1st planting. June 30th planting was on par with October 1st planting.

4.7.6. Dry matter accumulation at harvest

Effect of dates of planting on dry matter accumulation at harvest was found to be significant. Maximum dry matter accumulation was recorded during October 30th planting and dry matter accumulation recorded during all other plantings were on par with each other. Interaction between dates of planting and growing conditions were found to be significant with respect to dry matter production. In both open condition and climate controlled green houses maximum dry matter accumulation was recorded during October 30th planting. Dry matter accumulation at harvest for different growing conditions did not show any significant differences.

4.8. STATISTICAL ANALYSIS OF YIELD PHYSICAL AND COOKING QUALITY PARAMETERS

Physical and cooking quality parameters like milling percentage and head rice recovery were evaluated. The analyses of variance were carried out for physical and cooking quality parameters were done and represented in Table 4.16 (i).

4.8.1. Milling percentage

Milling percentage was significantly influenced by planting dates in all the date of planting. Milling percentage for different planting dates for both the growing conditions were depicted in Table 4.16 (i). June 1st planting showed highest milling percentage and January 1st planting showed lowest milling percentage. Milling percentage for different growing conditions did not show any significant difference with respect to different dates of planting.

4.8.2. Head rice recovery

Comparison between head rice recovery recorded during different dates of planting and growing conditions were done. Effect of dates of planting on head rice recovery was found to be significant irrespective of growing conditions. Among the five dates of planting head rice recovery during June 1st planting was higher. Head rice recovery was lower during January 1st planting. Head rice recovery for different growing conditions did not show any significant difference with respect to different dates of planting.

Table 4.16(i). Effect of date of planting on milling percentage and head rice recovery

Date of planting	Milling percentage			Head rice recovery percentage		
	O	GH	Mean	O	GH	Mean
D1	76.4^{a}	68.9^{a}	72.7^{a}	52.0^{a}	47.9^{a}	50.0^{a}
D2	71.6^{b}	64.1^{b}	67.8^{b}	49.7^{b}	47.3^{a}	48.5^{b}
D3	67.3^{c}	62.0^{c}	64.7^{c}	47.1^{c}	44.6^{b}	45.8^{c}
D4	65.0^{d}	57.4^{d}	61.2^{d}	44.1^{d}	41.5^{c}	42.8^{d}
D5	62.6^{e}	55.3^{e}	59.0^{e}	40.9^{e}	38.3^{d}	39.6^{e}
CD	0.43		0.31	1.16		0.82

Table 4.16(j). Effect of date of planting on starch and amylose content

Date of planting	Starch			Amylose		
	O	GH	Mean	O	GH	Mean
D1	65.25^{a}	64.57^{b}	64.9^{a}	22.04^{a}	20.4^{d}	21.2^{a}
D2	56.47^{c}	52.2^{e}	54.3^{b}	21.67^{b}	20.28^{de}	21.0^{a}
D3	54.22^{d}	48.37^{g}	51.3^{c}	21.52^{bc}	20^{e}	20.8^{a}
D4	54^{d}	47.25^{h}	50.6^{d}	21.28^{c}	19.56^{f}	20.4^{b}
D5	49.27^{f}	44.55^{i}	46.9^{e}	19.6^{f}	19.24^{g}	19.4^{c}
CD	0.42		0.30	0.27		0.19

Table 4.16(k). Effect of date of planting on protein and fat content

Date of planting	Protein			Fat		
	O	GH	Mean	O	GH	Mean
D1	2.78^{a}	2.66^{b}	2.7^{a}	3.00^{a}	2.58^{b}	2.8^{a}
D2	2.62^{bc}	2.49^{d}	2.6^{b}	2.58^{b}	2.33^{c}	2.5^{b}
D3	2.57^{c}	2.32^{e}	2.4^{c}	2.26^{c}	2.08^{d}	2.2^{c}
D4	2.3^{e}	2.26^{f}	2.3^{d}	1.88^{e}	1.62^{f}	1.8^{d}
D5	2.25^{f}	1.99^{g}	2.1^{e}	1.66^{f}	1.62^{f}	1.6^{e}
CD	0.05		0.04	0.17		0.12

Table 4.16 (l). Effect of date of planting on mineral content

Date of planting	Calcium			Iron			Zinc			Phosphorus		
	O	GH	Mean	O	GH	Mean	O	GH	Mean	O	GH	Mean
D1	18.4^{a}	15.4^{b}	16.9^{a}	2.03^{a}	1.77^{b}	1.9^{a}	19.5^{a}	16.9^{c}	18.2^{a}	207.6^{a}	193.2^{b}	200.4^{a}
D2	14.4^{bc}	13.4^{b}	13.9^{b}	1.94^{ab}	1.3^{c}	1.6^{b}	17.7^{b}	16.8^{c}	17.3^{b}	188.0^{c}	146.8^{e}	167.4^{b}
D3	14^{c}	13.2^{c}	13.6^{c}	1.86^{ab}	1.11^{cd}	1.5b^{c}	15.7^{d}	12.9^{e}	14.3^{c}	152.0^{d}	122.4^{f}	137.2^{c}
D4	13.4^{c}	10.4^{d}	11.9^{d}	1.66^{b}	1.00^{d}	1.3^{c}	15.3^{d}	12.4^{e}	13.9^{d}	117.2^{g}	118.0^{h}	117.6^{d}
D5	10.7^{d}	9.8^{d}	10.3^{e}	1.11^{cd}	0.9^{d}	1.0^{d}	12.3^{e}	11.2^{f}	11.8^{e}	110.0^{j}	109.2^{i}	109.6^{e}
CD	1.12		0.79	0.22		0.15	0.37		0.26	0.54		0.38

Table 4.16 (m). Effect of growing conditions on grain quality and nutritional parameters

Growing conditions	Milling percentage	Head rice recovery	Starch	Amylose	Protein	Fat	Calcium	Iron	Zinc	Phosphorus
O	68.57^{a}	46.75^{a}	55.84^{a}	11.22^{a}	2.504^{a}	2.276^{a}	14.18^{a}	1.72^{a}	16.1^{a}	154.96^{a}
GH	61.55^{b}	43.92^{b}	51.39^{b}	9.90^{b}	2.344^{b}	2.046^{b}	12.44^{b}	1.216^{b}	14.04^{b}	137.92^{b}
CD	0.09	0.25	0.09	0.06	0.01	0.04	0.24	0.05	0.08	0.12

4.9. STATISTICAL ANALYSIS OF NUTRITIONAL QUALITY

Analysis of variance was carried out to evaluate effect of dates of planting and growing conditions on nutritional quality of rice. The results obtained from the analysis were explained below.

4.9.1. Starch content

Effect of dates of planting on starch content was found to be significant irrespective of variety. Starch content recorded during June 1^{st} planting was found to be higher and that recorded during January 1^{st} planting was lower. There was no significant difference between starch content in different growing conditions with respect to different dates of planting. Among the two growing conditions starch content recorded in open field condition was higher compared to climate controlled green houses.

4.9.2. Amylose content

Amylose content was found to be significantly influenced by dates of planting irrespective of growing conditions. Amylose content recorded during June 1^{st}, June 30^{th} and October 1^{st} plantings were on par. A minimum value of amylose content was recorded during January 1^{st} planting.

4.9.3. Protein content

Amount of protein content recorded during different dates of planting showed a significant difference irrespective of growing conditions. Protein content recorded during June 1^{st} planting was higher and that recorded during January 1^{st} planting was lower. The effect of controlled conditions with respect to date of planting was found to be non significant. The effect of growing conditions irrespective of dates of planting on protein content was found to be significant. Protein content recorded in open condition was higher than climate controlled green houses.

4.9.4. Fat content

Effect of dates of planting on fat content was found to be significant irrespective of growing conditions. The fat content recorded during June 1st planting was higher while during January 1st planting showed a lower value. The effect of controlled conditions with respect to date of planting was found to be non significant. Fat content was found to be significantly influenced by growing conditions irrespective of variety. Fat content recorded in open condition was higher compared to climate controlled green houses.

4.9.5. Mineral content

Analysis of variance was carried out on mineral content in rice, Effect of date of planting and effect of growing conditions were found to be significant for all minerals. Effect of growing conditions with respect to dates of planting was found to be non significant for all minerals.

4.9.5.1. Calcium content

Effect of date of planting irrespective of growing condition was found to be significant. Maximum calcium content was observed during June 1st planting and minimum calcium content was recorded during January first planting. Calcium content recorded in open field condition was higher than climate controlled green house condition.

4.9.5.2. Iron content

Iron content was significantly influenced by dates of planting irrespective of growing conditions. Maximum iron content was recorded during June 1st planting and minimum iron content was recorded during January 1st planting. Iron content recorded during October 1st and October 30th were on par with each other. Iron content recorded under open condition was more than climate controlled green house condition.

4.9.5.3. Zinc content

Effect of date of planting on zinc content was found to be significantly influenced by dates of planting irrespective of variety. Maximum zinc content was recorded during June 1st planting and minimum zinc content was recorded during January 1st planting. Zinc content recorded in open field condition was greater than climate controlled green house conditions.

4.9.5.4. Phosphorous content

Phosphorous content recorded was found to be significantly influenced by different dates of planting irrespective of growing conditions. Phosphorous content recorded during June 1st planting was higher and that recorded during January 1st planting was lower. Among the two growing conditions phosphorous content recorded in open field condition was greater than climate controlled green houses.

4.10. Gelatinization temperature index

Rice variety Jyothi grown under both open condition and climate controlled greenhouse were subjected to the alkali digestion test and were visually observed to evaluate the degree of disintegration in alkali. After the stipulated time of observation, no effect was observed among grins obtained from open condition and climate controlled greenhouse. The gelatinization temperature index of rice variety Jyothi grown under open condition and climate controlled greenhouse are presented in plate VIII.

4.11. CROP WEATHER RELATIONSHIPS

Correlation between weather and duration of different phenophases under open condition and climate controlled greenhouse for variety Jyothi were worked out. Correlation of yield and yield contributing factors with weather elements in open condition and climate controlled greenhouse were also worked out for different phenophases of crop growth.

4.11.1. Influence of weather parameter on crop duration

The correlation between weather elements and duration of different phenological stages under open condition and under climate controlled greenhouse were presented in Table 4.17 (a) and 4.17 (b) respectively.

4.11.1.1. Transplanting to active tillering

Under open condition canopy temperature had a significant positive correlation on duration from transplanting to active tillering stage. Whereas, maximum temperature and canopy air temperature depression had a significant negative correlation.

During transplanting to active tillering stage afternoon relative humidity influenced positively under climate controlled greenhouse. Whereas, maximum temperature and soil temperature influenced negatively.

4.11.1.2. Active tillering to panicle initiation

Rainfall and number of rainy days had significant positive correlation with duration from active tillering to panicle initiation under open condition. Maximum temperature, bright sunshine hours, evaporation rate, absorbed PAR and canopy air temperature depression had significant negative effect.

Under climate controlled greenhouse duration from active tillering to panicle initiation had significant positive influence by soil temperature. Minimum temperature, afternoon relative humidity and canopy temperature had significant negative effect.

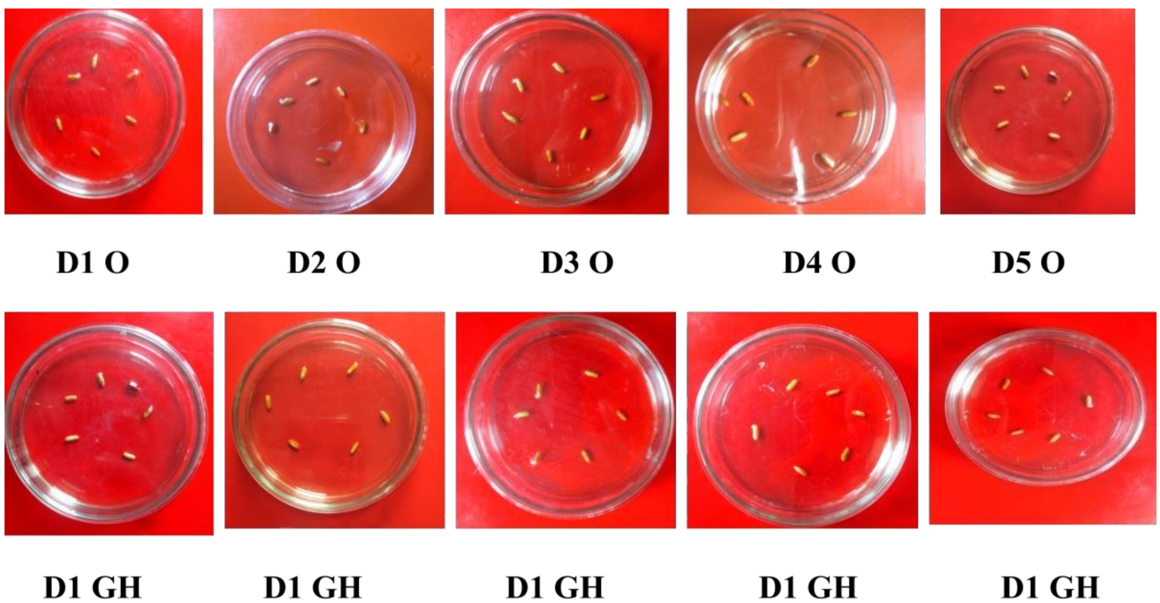


Plate VIII. Gelatinization temperature index of rice variety Jyothi grown under open condition and climate controlled greenhouse

4.11.1.3. Panicle initiation to booting

Weather variables like rainfall, rainy days and absorbed PAR had significant positive correlation on duration from panicle initiation to booting period in Jyothi under open condition.

No significant correlation was found between weather variables and duration from panicle initiation to booting period in Jyothi under climate controlled greenhouse.

4.11.1.4. Booting to heading

Minimum temperature had significant positive correlation with duration from booting to heading stage under open condition.

Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity had a significant positive effect on duration from booting to heading. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature influenced negatively.

4.11.1.5. Heading to 50% flowering

The duration from heading to 50% flowering of rice variety Jyothi under open condition showed significant positive correlation with forenoon relative humidity, afternoon relative humidity, rainfall and rainy days under open condition. The weather variables like maximum temperature, soil temperature, bright sunshine hours and canopy air temperature depression showed significant negative correlation.

The duration from heading to 50% flowering of rice variety Jyothi under climate controlled greenhouse showed positive correlation with weather variables like minimum

Table 4.17 (a). Correlation between phenophase duration and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH 2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.626*	0.126	0.396	0.375	0.12	0.163	-0.471	-0.374	0.105	0.022	0.545*	-0.721**
P2	-0.532*	-0.176	-0.102	0.473	0.897**	0.858**	-0.425	-0.876**	-0.812**	-0.759**	0.31	-0.846**
P3	-0.246	0.016	0.304	0.346	0.608*	0.698**	-0.314	-0.461	0.37	0.634*	0.132	-0.258
P4	-0.292	0.911**	0.138	0.099	-0.434	-0.164	-0.342	0.073	-0.003	-0.398	-0.416	0.449
P5	-0.789**	-0.191	0.611*	0.911**	0.995**	0.765**	-0.805**	-0.937**	0.182	0.051	-0.24	-0.575*
P6	0.750**	-0.524*	-0.485	-0.808**	-0.656**	-0.673**	0.752**	0.806**	0.914**	0.432	0.790**	0.512

Table 4.17 (b). Correlation between phenophase duration and weather variables under climate controlled greenhouse

Crop stage	Tmax	Tmin	RH1	RH 2	ST	APAR	CT	CATD
P1	-0.620*	0.473	0.469	0.833**	-0.700**	-0.434	-0.034	0.344
P2	0.436	-0.786**	-0.408	-0.709**	0.529*	0.207	-0.800**	0.407
P3	0.223	-0.241	0.169	-0.327	0.279	0.123	0.233	0.139
P4	-0.940**	0.090	0.674**	0.735**	-0.890**	-0.856**	-0.953**	0.082
P5	-0.360	0.828**	0.857**	0.289	-0.431	0.026	-0.676**	0.210
P6	0.504	-0.483	-0.389	-0.476	0.510*	0.635*	0.582*	0.203

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4- Booting to heading
P5- Heading to 50% flowering
P6- 50% flowering to physiological maturity

temperature and forenoon relative humidity and negative correlation with canopy temperature.

4.11.1.6. 50% flowering to physiological maturity

Under open condition, weather variables like maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature had significant positive correlation, whereas, minimum temperature, afternoon relative humidity, rainfall and rainy days had significant negative correlation with duration from 50% flowering to physiological maturity.

Soil temperature, absorbed PAR and canopy temperature had significant positive correlation with duration from 50% flowering to physiological maturity under climate controlled greenhouse.

4.11.2. Influence of weather parameter on grain yield

The correlation between weather elements and grain yield are under open condition and climate controlled greenhouse were presented in Table 4.18(a) and 4.18(b) respectively.

4.11.2.1. Transplanting to active tillering

Canopy air temperature depression showed a significant negative correlation with grain yield from transplanting to active tillering stage under open condition.

Absorbed PAR showed a significant positive correlation and afternoon relative humidity showed a negative correlation with grain yield under climate controlled greenhouse from transplanting to active tillering stage.

4.11.2.2. Active tillering to panicle initiation

Under open condition, canopy temperature showed a significant positive correlation grain yield during active tillering to panicle initiation.

No weather variables showed significant correlation with grain yield from active tillering to panicle initiation under climate controlled greenhouse.

4.11.2.3. Panicle initiation to booting

Evaporation rate and canopy temperature exhibited a significant negative correlation with grain yield from panicle initiation to booting period in Jyothi under open condition.

Under climate controlled greenhouse, correlation was not exhibited by weather variables with grain yield from active tillering to panicle initiation stage.

4.11.2.4. Booting to heading

Grain yield showed significant negative correlation with evaporation rate from booting to heading in rice variety Jyothi under open condition.

No weather variables showed significant correlation with grain yield from heading to 50% flowering under climate controlled greenhouse.

4.11.2.5. Heading to 50% flowering

Under open condition and climate controlled greenhouse no weather variables showed correlation with grain yield from heading to 50% flowering.

4.11.2.6. 50% flowering to physiological maturity

Minimum temperature showed a significant negative correlation with grain yield from 50% flowering to physiological maturity under open condition and climate controlled greenhouse.

Table 4.18(a). Correlation between grain yield and weather variables under open condition

Growth stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.429	0.377	0.472	0.456	0.197	0.26	-0.368	-0.36	-0.381	-0.185	0.456	-0.548*
P2	-0.482	0.483	-0.009	0.404	0.090	0.103	-0.425	-0.235	-0.405	-0.480	0.718**	-0.148
P3	-0.426	0.401	0.295	0.307	0.115	0.057	-0.375	-0.262	-0.566*	-0.159	-.592*	-0.067
P4	-0.447	0.121	-0.096	0.347	0.165	0.119	-0.416	-0.287	-0.519*	0.152	-0.454	0.384
P5	-0.247	-0.317	-0.477	0.065	-0.098	-0.023	-0.237	-0.05	-0.116	-0.034	-0.333	0.291
P6	-0.253	-0.577*	-0.134	-0.023	-0.086	-0.033	-0.249	0.090	0.090	-0.333	-0.143	-0.215

Table 4.18(b). Correlation between grain yield and weather variables under climate controlled greenhouse

Crop stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	0.014	-0.260	-0.136	-0.528*	0.143	0.575*	-0.444	0.246
P2	0.434	0.473	-0.107	-0.256	0.382	0.402	0.398	0.082
P3	0.141	-0.177	-0.099	-0.262	0.171	0.320	-0.119	-0.125
P4	0.232	0.026	-0.427	-0.368	0.309	0.376	0.216	-0.366
P5	0.277	-0.172	-0.388	-0.347	0.382	0.143	0.476	-0.074
P6	0.357	-0.552*	-0.301	-0.397	0.371	0.549	0.423	0.318

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4- Booting to heading
P5- Heading to 50% flowering
P6- 50% flowering to physiological maturity

4.11.3. Influence of weather parameter on straw yield

The correlation between weather elements and straw yield under open condition and climate controlled greenhouse were presented in Table 4.19(a) and 4.19(b) respectively.

4.11.3.1. Transplanting to active tillering

Straw yield showed significant positive correlation with canopy temperature during transplanting to active tillering stage under open condition.

Afternoon relative humidity was negatively correlated with straw yield during transplanting to active tillering stage under climate controlled greenhouse.

4.11.3.2. Active tillering to panicle initiation

Under open condition, canopy air temperature depression exhibited a positive correlation with straw yield from active tillering to panicle initiation stage. Whereas, rainfall and rainy days showed significant negative correlation with straw yield.

Maximum temperature and soil temperature exhibited significant positive correlation with straw yield from active tillering to panicle initiation stage under climate controlled greenhouse. Whereas, forenoon relative humidity and afternoon relative humidity were influenced negatively.

4.11.3.3. Panicle initiation to booting

No weather variables showed significant correlation with straw yield from panicle initiation to booting period in Jyothi under open condition.

Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity exhibited negative correlation with straw yield from panicle initiation to booting.

Table 4.19 (a). Correlation between straw yield and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	0.069	0.282	0.103	0.048	-0.371	-0.252	-0.025	-0.164	-0.507	0.230	0.761**	0.105
P2	0.000	0.446	-0.21	0.022	-0.529*	-0.533*	-0.067	0.343	0.284	0.188	0.409	0.569*
P3	-0.242	0.058	-0.031	0.055	-0.148	0.007	-0.267	-0.019	0.089	-0.257	-0.273	-0.099
P4	-0.046	0.499	-0.321	-0.066	-0.273	-0.21	-0.077	0.192	-0.047	0.201	-0.363	0.853**
P5	-0.017	-0.365	-0.51	-0.025	0.198	-0.281	-0.027	-0.038	0.517*	0.657**	0.162	0.582*
P6	-0.114	-0.669**	0.085	-0.038	0.238	0.144	-0.117	-0.022	0.098	-0.070	-0.155	-0.412

Table 4.19 (b). Correlation between straw yield and weather variables under climate controlled greenhouse

Crop stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	0.383	-0.116	-0.467	-0.517*	0.450	0.124	0.154	-0.360
P2	0.558*	0.503	-0.591*	-0.524*	0.551*	0.013	0.389	0.372
P3	0.312	-0.077	-0.602*	-0.616*	0.370	0.317	-0.348	0.407
P4	0.424	0.378	-0.356	-0.663**	0.492	0.457	0.396	-0.725**
P5	0.340	0.240	-0.241	-0.659**	0.457	0.439	0.400	-0.368
P6	0.381	-0.781**	-0.633*	-0.690**	0.463	0.548*	0.333	-0.033

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

4.11.3.4. Booting to heading

Under open condition, canopy air temperature depression exhibited significant positive correlation with straw yield from booting to heading period.

Afternoon relative humidity and canopy air temperature depression was negatively correlated with straw yield from booting to heading period under climate controlled greenhouse.

4.11.3.5. Heading to 50% flowering

Straw yield showed significant positive correlation with evaporation rate, absorbed PAR and canopy air temperature depression from heading to 50% flowering in rice variety Jyothi under open condition.

Under climate controlled greenhouse, straw yield showed significant negative correlation with afternoon relative humidity from heading to 50% flowering in rice variety Jyothi.

4.11.3.6. 50% flowering to physiological maturity

Minimum temperature showed significant negative correlation with straw yield from 50% flowering to physiological maturity under open condition.

Under climate controlled greenhouse, absorbed PAR showed significant positive correlation with straw yield from 50% flowering to physiological maturity. Weather variables like minimum temperature, forenoon relative humidity and afternoon relative humidity had significant negative correlation with straw yield.

4.11.4. Influence of weather parameter on dry matter accumulation at harvest

The correlation between weather elements and dry matter accumulation at harvest under open condition and climate controlled greenhouse were presented in Table 4.20(a) and 4.20(b) respectively.

4.11.4.1. Transplanting to active tillering

During transplanting to active tillering stage, canopy temperature showed significant positive correlation with dry matter accumulation at harvest under open condition.

Under climate controlled greenhouse from transplanting to active tillering stage, afternoon relative humidity correlated negatively with dry matter accumulation at harvest.

4.11.4.2. Active tillering to panicle initiation

Minimum temperature and canopy temperature had significant positive effect on dry matter accumulation at harvest from active tillering to panicle initiation under open condition.

Under climate controlled greenhouse, minimum temperature had significant positive effect on dry matter accumulation at harvest from active tillering to panicle initiation.

4.11.4.3. Panicle initiation to booting

Under open condition, canopy temperature had negative correlation on dry matter accumulation at harvest during panicle initiation to booting period in Jyothi.

No weather variables showed significant correlation with dry matter accumulation at harvest during panicle initiation to booting period in Jyothi under climate controlled greenhouse.

4.11.4.4. Booting to heading

Canopy air temperature depression had significant positive correlation with dry matter accumulation at harvest from booting to heading stage in open condition.

Table 4.20 (a). Correlation between dry matter accumulation at harvest and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.378	0.405	0.454	0.428	0.101	0.184	-0.342	-0.364	-0.457	-0.120	0.580*	-0.479
P2	-0.441	0.537*	-0.053	0.375	-0.031	-0.02	-0.403	-0.141	-0.309	-0.399	0.744**	-0.014
P3	-0.441	0.379	0.263	0.292	0.073	0.053	-0.400	-0.243	-0.499	-0.200	-0.599*	-0.082
P4	-0.419	0.217	-0.157	0.303	0.092	0.063	-0.397	-0.221	-0.484	0.182	-0.493	0.534*
P5	-0.229	-0.368	-0.545*	0.054	-0.048	-0.081	-0.222	-0.054	0.005	0.109	-0.270	0.390
P6	-0.256	-0.670**	-0.105	-0.029	-0.028	0.000	-0.253	0.077	0.103	-0.32	-0.163	-0.285

Table 4.20 (b). Correlation between dry matter accumulation at harvest and weather variables under climate controlled greenhouse

Crop stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	0.100	-0.252	-0.224	-0.575*	0.227	0.526	-0.349	0.131
P2	0.503	0.524*	-0.228	-0.342	0.457	0.350	0.434	0.156
P3	0.193	-0.171	-0.223	-0.368	0.233	0.350	-0.183	-0.015
P4	0.298	0.109	-0.451	-0.470	0.380	0.430	0.277	-0.483
P5	0.318	-0.094	-0.390	-0.451	0.435	0.224	0.503	-0.149
P6	0.396	-0.657**	-0.406	-0.501	0.427	0.600*	0.443	0.267

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

Under climate controlled greenhouse, no weather variables showed significant correlation with dry matter accumulation at harvest from booting to heading stage.

4.11.4.5. Heading to 50% flowering

Under open condition, dry matter accumulation at harvest showed significant negative correlation with forenoon relative humidity.

The dry matter accumulation at harvest showed no significant correlation with weather variables under climate controlled greenhouse.

4.11.4.6. 50% flowering to physiological maturity

Minimum temperature had significant negative correlation with dry matter accumulation at harvest from 50% flowering to physiological maturity under open condition.

Under climate controlled greenhouse, absorbed PAR showed significant positive correlation with dry matter accumulation at harvest from 50% flowering to physiological maturity. Whereas, minimum temperature had significant negative correlation with dry matter accumulation at harvest from 50% flowering to physiological maturity.

4.11.5. Influence of weather parameter on number of panicles per unit area

The correlation between weather elements and number of panicles per unit area under open condition and climate controlled greenhouse were presented in Table 4.21(a) and 4.21(b) respectively.

4.11.5.1. Transplanting to active tillering

Under open condition and climate controlled greenhouse, no weather variable showed significant correlation with number of panicles per unit area from transplanting to active tillering stage.

Table 4.21(a). Correlation between number of panicles per unit area and weather variables under open condition

Growth stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.047	-0.15	-0.011	-0.003	-0.059	-0.476	0.101	0.171	-0.145	-0.476	0.306	-0.487
P2	-0.092	-0.103	-0.331	-0.018	-0.031	-0.476	0.020	-0.106	-0.424	-0.298	0.407	-0.386
P3	0.124	-0.028	-0.156	-0.186	-0.234	-0.476	0.185	0.215	-0.247	-0.210	-0.086	0.012
P4	0.02	-0.155	-0.382	-0.084	-0.051	-0.476	0.073	0.068	-0.077	-0.24	0.120	0.011
P5	0.226	-0.073	-0.492	-0.375	-0.51	-0.476	0.239	0.402	0.289	-0.091	-0.088	0.368
P6	0.232	-0.39	-0.493	-0.434	-0.501	-0.476	0.238	0.486	0.443	-0.155	0.305	0.332

Table 4.21(b). Correlation between number of panicles per unit area and weather variables under climate controlled greenhouse

Crop stage	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.350	0.496	-0.024	0.476	-0.365	-0.464	0.157	-0.001
P2	-0.478	0.153	0.188	0.276	-0.453	-0.340	0.357	0.203
P3	-0.448	0.487	0.130	0.129	-0.403	-0.486	-0.457	-0.174
P4	-0.343	0.416	0.236	0.165	-0.306	-0.335	-0.400	-0.207
P5	-0.525*	0.393	0.153	0.152	-0.494	-0.418	-0.489	-0.176
P6	-0.379	-0.169	0.026	0.125	-0.326	-0.447	-0.426	-0.266

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

4.11.5.2. Active tillering to panicle initiation

No weather variable had significant correlation with number of panicles per unit area from active tillering to panicle initiation under both the growing conditions.

4.11.5.3. Panicle initiation to booting

No weather variable exhibited significant correlation with number of panicles per unit area from panicle initiation to booting period in Jyothi under open condition as well as climate controlled greenhouse.

4.11.5.4. Booting to heading

No weather variables had significant correlation with number of panicles per unit area from booting to heading in rice variety Jyothi under open condition and greenhouse.

4.11.5.5. Heading to 50% flowering

Under open condition, no weather variables had significant correlation with number of panicles per unit area from heading to 50% flowering. Whereas, under climate controlled greenhouse, number of panicles per unit area had significant negatively influenced by maximum temperature.

4.11.5.6. 50% flowering to physiological maturity

Weather variables didn’t show any significant correlation with number of panicles per unit area from 50% flowering to physiological maturity under both the growing conditions.

4.11.6. Influence of weather parameter on number of spikelet per panicle

The correlation between weather elements and number of spikelet per panicle under open condition and climate controlled greenhouse were presented in Table 4.22(a) and 4.22(b) respectively.

4.11.6.1. Transplanting to active tillering

Number of spikelet per panicle showed significant negative correlation with absorbed PAR and evaporation rate during transplanting to active tillering stage under open condition.

Forenoon relative humidity had significant negative correlation with number of spikelet per panicle from transplanting to active tillering stage under climate controlled greenhouse.

4.11.6.2. Active tillering to panicle initiation

Weather variable, canopy temperature exhibited a significant positive correlation and forenoon relative humidity and evaporation rate exhibited a significant negative correlation with number of spikelet per panicle from active tillering to panicle initiation stage under open condition.

Under climate controlled greenhouse, canopy air temperature depression exhibited a significant positive correlation and afternoon relative humidity exhibited significant negative correlation with number of spikelet per panicle from active tillering to panicle initiation stage.

4.11.6.3. Panicle initiation to booting

Absorbed PAR had significant negative correlation with number of spikelet per panicle from panicle initiation to booting period in Jyothi under open condition.

Under climate controlled greenhouse, afternoon relative humidity showed significant negative correlation with number of spikelet per panicle from panicle initiation to booting.

Table 4.22 (a). Correlation between number of spikelet per panicle and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	0.071	0.030	0.057	0.060	-0.076	-0.059	0.172	0.177	-0.510*	-0.647**	0.438	-0.454
P2	-0.214	-0.028	-0.549*	0.126	0.116	0.070	-0.124	-0.251	-0.533*	-0.385	0.618*	-0.335
P3	0.110	0.140	-0.113	-0.156	-0.459	-0.462	0.152	0.287	-0.307	-0.606*	-0.200	0.360
P4	-0.007	0.218	-0.491	-0.155	-0.356	-0.425	0.032	0.212	-0.033	-0.475	0.023	0.264
P5	0.18	-0.477	-0.713**	-0.404	-0.479	-0.342	0.189	0.468	0.140	-0.055	-0.278	0.487
P6	0.105	-0.672**	-0.648**	-0.46	-0.432	-0.492	0.109	0.476	0.394	-0.500	0.118	0.230

Table 4.22 (b). Correlation between number of spikelet per panicle and weather variables under climate controlled greenhouse

Crop stage	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	0.211	-0.186	-0.725**	-0.479	0.364	0.122	-0.098	-0.112
P2	0.365	0.237	-0.261	-0.598*	0.398	0.289	0.381	0.720**
P3	0.250	-0.145	-0.262	-0.720**	0.362	0.328	-0.340	0.136
P4	0.504	0.602*	-0.665**	-0.765**	0.606*	0.607*	0.408	-0.805**
P5	0.186	0.046	-0.636*	-0.760**	0.350	0.170	0.414	-0.714**
P6	0.526*	-0.697**	-0.809**	-0.808**	0.615*	0.544*	0.470	-0.385

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering P3- Panicle initiation to booting P5- Heading to 50% flowering

P2- Active tillering to panicle initiation P4- Booting to heading P6- 50% flowering to physiological maturity

4.11.6.4. Booting to heading

Under open condition, no weather variables showed significant correlation with number of spikelet per panicle from booting to heading period.

Minimum temperature, soil temperature and absorbed PAR exhibited significant positive correlation and forenoon relative humidity, afternoon relative humidity and canopy air temperature depression showed significant negative correlation with number of spikelets per panicle from booting to heading period under climate controlled greenhouse.

4.11.6.5. Heading to 50% flowering

Number of spikelets` per panicle showed significant negative correlation with forenoon relative humidity from heading to 50% flowering in rice variety Jyothi under open condition.

Under climate controlled greenhouse, number of spikelets per panicle showed significant negative correlation with forenoon relative humidity, afternoon relative humidity and canopy air temperature depression from heading to 50% flowering in rice variety Jyothi.

4.11.6.6. 50% flowering to physiological maturity

Minimum temperature and forenoon relative humidity had significant negative correlation with number of spikelets per panicle from 50% flowering to physiological maturity under open condition.

Under climate controlled greenhouse, maximum temperature, soil temperature and absorbed PAR showed significant positive correlation with number of spikelets per panicle from 50% flowering to physiological maturity. Whereas, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant negative correlated.

4.11.7. Influence of weather parameter on number of filled grains per panicle

The correlation between weather elements and number of filled grains per panicle under open condition and climate controlled greenhouse were presented in Table 4.23(a) and 4.23(b) respectively.

4.11.7.1. Transplanting to active tillering

During transplanting to active tillering stage, evaporation rate and absorbed PAR showed significant negative correlation with number of filled grains per panicle under open condition.

Under climate controlled greenhouse from transplanting to active tillering stage, maximum temperature and soil temperature showed significant positive correlation with number of filled grains per panicle. Whereas forenoon relative humidity and afternoon relative humidity exhibited significant negative correlation with number of filled grains per panicle from active tillering to panicle initiation under climate controlled greenhouse.

4.11.7.2. Active tillering to panicle initiation

Under open condition, canopy temperature had significant positive effect on number of filled grains per panicle from active tillering to panicle initiation. Forenoon relative humidity had significant negative correlation with number of filled grains per panicle from active tillering to panicle initiation.

Maximum temperature, soil temperature and canopy air temperature depression had significant positive effect on number of filled grains per panicle from active tillering to panicle initiation under climate controlled greenhouse afternoon relative humidity had significant negative correlation with number of filled grains per panicle from active tillering to panicle initiation.

4.11.7.3. Panicle initiation to booting

Absorbed PAR had significant negative correlation with number of filled grains per panicle during panicle initiation to booting period in Jyothi under open condition.

Under climate controlled greenhouse, maximum temperature, soil temperature and absorbed PAR had significant positive correlation on number of filled grains per panicle during panicle initiation to booting period in Jyothi. Afternoon relative humidity showed significant negative correlation with number of filled grains per panicle from panicle initiation to booting stage.

4.11.7.4. Booting to heading

No weather variables showed significant correlation with number of filled grains per panicle from booting to heading stage under open condition.

Under climate controlled greenhouse maximum temperature, minimum temperature, soil temperature, absorbed PAR and canopy temperature showed significant positively correlation with number of filled grains per panicle from booting to heading stage. Whereas, forenoon relative humidity, afternoon relative humidity and canopy air temperature depression had significant negatively correlation with number of filled grains per panicle.

4.11.7.5. Heading to 50% flowering

Number of filled grains per panicle under open condition showed significant negative correlation with minimum temperature and forenoon relative humidity under open condition.

Under climate controlled greenhouse, number of filled grains per panicle showed significant negative correlation with forenoon relative humidity, afternoon relative humidity and canopy air temperature depression. Soil temperature and canopy temperature and had significant positive correlation with number of filled grains per panicle from heading to 50% flowering.

Table 4.23 (a). Correlation between number of filled grains per panicle and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	0.168	0.087	0.027	0.024	-0.124	-0.094	0.208	0.167	-0.577*	-0.532*	0.405	-0.255
P2	-0.162	-0.006	-0.538*	0.117	0.063	0.010	-0.117	-0.203	-0.360	-0.260	0.518*	-0.164
P3	0.108	0.142	-0.103	-0.138	-0.477	-0.393	0.123	0.283	-0.144	-0.652**	-0.158	0.439
P4	0.032	0.371	-0.441	-0.199	-0.447	-0.451	0.049	0.28	0.064	-0.474	-0.004	0.347
P5	0.143	-0.548*	-0.633*	-0.331	-0.321	-0.286	0.146	0.391	0.309	0.034	-0.248	0.441
P6	0.040	-0.632*	-0.543*	-0.362	-0.266	-0.365	0.043	0.344	0.275	-0.510	0.005	0.118

Table 4.23 (b). Correlation between number of filled grains per panicle and weather variables under climate controlled greenhouse

Crop stage	Tmax	Tmin	RHI	RH 2	ST	APAR	CT	CATD
P1	0.525*	-0.413	-0.866**	-0.678**	0.662**	0.152	0.042	-0.322
P2	0.597*	0.026	-0.471	-0.842**	0.649*	0.350	0.095	0.763**
P3	0.555*	-0.394	-0.443	-0.912**	0.656**	0.580*	-0.123	0.402
P4	0.767**	0.519*	-0.783**	-0.940**	0.838**	0.817**	0.690**	-0.771**
P5	0.419	-0.058	-0.698**	-0.937**	0.602*	0.458	0.616*	-0.774**
P6	0.743**	-0.576*	-0.938**	-0.957**	0.825**	0.733**	0.662*	-0.473

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering　P3- Panicle initiation to booting　P5- Heading to 50% flowering

P2- Active tillering to panicle initiation　P4- Booting to heading　P6- 50% flowering to physiological maturity

4.7.11.6. 50% flowering to physiological maturity

Under open condition, minimum temperature and forenoon relative humidity had significant negative correlation with number of filled grains per panicle from 50% flowering to physiological maturity.

Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant positive correlation with number of filled grains per panicle from 50% flowering to physiological maturity under climate controlled greenhouse. Whereas, number of filled grains per panicle had significant negative correlation with minimum temperature, forenoon relative humidity and afternoon relative humidity.

4.7.12. Influence of weather parameter on thousand grain weight

The correlation between weather elements and thousand grain weight under open condition and climate controlled greenhouse were presented in Table 4.24(a) and 4.24(b) respectively.

4.1.12.1. Transplanting to active tillering

Under open condition, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and rainy days showed significant positive correlation with thousand grain weight from transplanting to active tillering stage. Whereas, thousand grain weight showed a significant negative correlation with maximum temperature, soil temperature and bright sunshine hours.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity were positively correlated. Whereas, thousand grain weight showed a negative correlation with maximum temperature and soil temperature.

4.7.12.2. Active tillering to panicle initiation

Under open condition, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant positive correlation with thousand grain weight from active tillering to panicle initiation. Whereas, maximum temperature and soil temperature had significant negative correlation

Maximum temperature and soil temperature were negatively correlated with thousand grain weight under climate controlled greenhouse. Afternoon relative humidity had significant positive correlation.

4.7.12.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days showed significant positive correlation and maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature showed significant negative correlation with thousand grain weight from panicle initiation to booting period in Jyothi under open condition.

Minimum temperature and afternoon relative humidity showed significant positive correlation and maximum temperature, soil temperature and absorbed PAR showed significant negative correlation with thousand grain weight under climate controlled greenhouse.

4.7.12.4. Booting to heading

Under open condition, forenoon relative humidity, afternoon relative humidity, amount of rainfall, rainy days and absorbed PAR showed significant positive correlation with thousand grain weight from booting to heading in rice variety Jyothi. Maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature showed significant negative correlation with thousand grain weight during booting to heading stage.

Table 4.24 (a). Correlation between thousand grain weight and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.805**	0.828**	0.873**	0.864**	0.748**	0.812**	-0.909**	-0.929**	-0.167	0.424	-0.231	-0.198
P2	-0.757**	0.840**	0.788**	0.803**	0.430	0.487	-0.818**	-0.477	-0.054	-0.482	0.322	0.073
P3	-0.912**	0.791**	0.902**	0.926**	0.820**	0.872**	-0.912**	-0.926**	-0.515*	0.302	-0.799**	-0.113
P4	-0.884**	0.175	0.784**	0.896**	0.678**	0.828**	-0.905**	-0.837**	-0.801**	0.648**	-0.872**	0.134
P5	-0.912**	-0.203	0.387	0.881**	0.668**	0.798**	-0.910**	-0.862**	-0.281	-0.339	-0.578*	-0.553*
P6	-0.865**	0.105	0.652**	0.831**	0.643**	0.768**	-0.863**	-0.758**	-0.753**	-0.278	-0.758**	-0.784**

Table 4.24 (b). Correlation between thousand grain weight and weather variables under climate controlled greenhouse

Crop stage	Tmax	Tmin	RHI	RH 2	ST	APAR	CT	CATD
P1	-0.694**	0.671**	0.516*	0.794**	-0.765**	-0.408	-0.006	0.299
P2	-0.777**	0.184	0.510	0.767**	-0.797**	-0.435	0.337	-0.283
P3	-0.765**	0.667**	0.442	0.677**	-0.781**	-0.772**	-0.352	-0.490
P4	-0.780**	0.052	0.629*	0.709**	-0.776**	-0.770**	-0.791**	0.259
P5	-0.751**	0.338	0.493	0.699**	-0.796**	-0.695**	-0.768**	0.317
P6	-0.765**	0.142	0.586*	0.677**	-0.769**	-0.798**	-0.739**	0.107

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P3- Panicle initiation to booting

P5- Heading to 50% flowering

P2- Active tillering to panicle initiation

P4- Booting to heading

P6- 50% flowering to physiological maturity

Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity had significant positive correlation with thousand grain weight. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation with thousand grain weight.

4.7.12.5. Heading to 50% flowering

Under open condition, thousand grain weight showed a significant positive correlation with afternoon relative humidity, amount of rainfall and rainy days. Whereas, maximum temperature, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression showed a significant negative correlation.

Under climate controlled greenhouse, thousand grain weight showed a significant positive correlation with afternoon relative humidity. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed a significant negative correlation.

4.7.12.6. 50% flowering to physiological maturity

Under open condition, thousand grain weight had significant positive correlation with forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days. Weather variables like maximum temperature, canopy temperature, soil temperature, bright sunshine hours, evaporation rate and canopy air temperature depression showed a significant negative correlation with thousand grain weight from 50% flowering to physiological maturity.

Thousand grain weight had significant positive correlation with forenoon relative humidity and afternoon relative humidity under climate controlled greenhouse. Weather variables like maximum temperature, soil temperature, absorbed PAR and canopy temperature showed a significant negative correlation.

4.7.13. Influence of weather parameter on milling percentage

The correlation between weather elements and milling percentage content are presented in Table 4.25(a) and 4.25(b).

4.7.13.1. Transplanting to active tillering

During transplanting to active tillering stage, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall, number of rainy days and absorbed PAR showed significant positive correlation with milling percentage content under open condition. Whereas, maximum temperature, soil temperature and bright sunshine hours had significant negative correlation with miiling percentage.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity showed positive correlation with milling percentage. Whereas, maximum temperature, soil temperature and absorbed PAR were negatively correlated with milling percentage.

4.7.13.2. Active tillering to panicle initiation

Under open condition, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant positive effect on milling percentage from active tillering to panicle initiation. Maximum temperature and soil temperature had significant negative correlation with milling percentage.

Afternoon relative humidity had significant positive effect on milling percentage under climate controlled greenhouse and maximum temperature, soil temperature and absorbed PAR had significant negative correlation with milling percentage from active tillering to panicle initiation.

4.7.13.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days had significant positive correlation on milling percentage during panicle initiation to booting period in Jyothi under open condition. Maximum temperature, soil temperature, bright sunshine hours and canopy temperature had significant negative correlation.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity had positive correlation on milling percentage. Maximum temperature, soil temperature and absorbed PAR showed significant negative correlation with milling percentage from panicle initiation to booting stage.

4.7.13.4. Booting to heading

Forenoon relative humidity, afternoon relative humidity, rainy days and absorbed PAR exhibited significant positive correlation with milling percentage from booting to heading stage under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature had significant negative correlation with milling percentage.

Under climate controlled greenhouse forenoon relative humidity and afternoon relative humidity had significant positive correlation. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation with milling percentage.

4.7.13.5. Heading to 50% flowering

Milling percentage under open condition showed significant positive correlation with forenoon relative humidity, afternoon relative humidity, amount rainfall and number of rainy days. Maximum temperature, soil temperature, bright sunshine hours, canopy

Table 4.25(a). Correlation between milling percentage and weather variables under open condition

Growth stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.610*	0.888**	0.790**	0.777**	0.679**	0.754**	-0.813**	-0.902**	-0.260	0.574*	-0.348	0.146
P2	-0.654**	0.814**	0.788**	0.773**	0.384	0.425	-0.786**	-0.425	0.215	-0.277	0.115	0.314
P3	-0.865**	0.781**	0.899**	0.928**	0.762**	0.960**	-0.911**	-0.899**	-0.222	0.208	-0.684**	0.065
P4	-0.787**	0.415	0.872**	0.794**	0.505	0.763**	-0.845**	-0.701**	-0.599*	0.590*	-0.864**	0.208
P5	-0.951**	-0.315	0.548*	0.982**	0.906**	0.901**	-0.959**	-0.963**	-0.008	-0.237	-0.541*	-0.666**
P6	-0.950**	0.217	0.794**	0.978**	0.895**	0.949**	-0.953**	-0.963**	-0.953**	-0.308	-0.931**	-0.923**

Table 4.25(b). Correlation between milling percentage and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.612*	0.893**	0.645**	0.932**	-0.765**	-0.641*	0.333	0.017
P2	-0.781**	0.382	0.264	0.867**	-0.812**	-0.804**	0.410	-0.429
P3	-0.825**	0.871**	0.170	0.746**	-0.864**	-0.932**	-0.507	-0.259
P4	-0.913**	0.061	0.945**	0.803**	-0.929**	-0.976**	-0.892**	0.226
P5	-0.793**	0.654**	0.856**	0.785**	-0.868**	-0.584*	-0.953**	0.468
P6	-0.986**	0.040	0.683**	0.772**	-0.972**	-0.951**	-0.989**	0.203

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

temperature and canopy air temperature depression were negatively correlated with milling percentage under open condition.

Under climate controlled greenhouse, milling percentage showed significant positive correlation with minimum temperature, forenoon relative humidity and afternoon relative humidity. Maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation.

4.7.13.6. 50% flowering to physiological maturity

Under open condition, forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days had significant positive correlation with milling percentage. Whereas, maximum temperature, evaporation rate, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression exhibited significant negative correlation.

Forenoon relative humidity and afternoon relative humidity had significant positive correlation under climate controlled greenhouse. Whereas, milling percentage showed significant negative correlation with maximum temperature, soil temperature, absorbed PAR and canopy temperature.

4.7.14. Influence of weather parameter on head rice recovery

The correlation between weather elements and head rice recovery under open condition and climate controlled greenhouse were presented in Table 4.26(a) and 4.26(b) respectively.

4.7.14.1. Transplanting to active tillering

Head rice recovery showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days during transplanting to active tillering stage under open condition. Whereas, maximum temperature, soil temperature and bright sunshine hours were correlated negatively with head rice recovery.

Under climate controlled greenhouse, minimum temperature, soil temperature and canopy air temperature depression were positively correlated with head rice recovery. Whereas, maximum temperature, forenoon relative humidity, afternoon relative humidity, canopy temperature and canopy air temperature depression were negatively correlated.

4.7.14.2. Active tillering to panicle initiation

Weather variable, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days exhibited a significant positive correlation and maximum temperature, soil temperature and bright sunshine hours exhibited a significant negative correlation with head rice recovery from active tillering to panicle initiation stage under open condition.

Under climate controlled greenhouse, afternoon relative humidity and canopy temperature exhibited a significant positive correlation and maximum temperature, soil temperature and absorbed PAR exhibited significant negative correlation.

4.7.14.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with head rice recovery from panicle initiation to booting period in Jyothi under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and canopy temperature showed significant negative correlation.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity had significant positive correlation with head rice recovery from panicle initiation to booting stage. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation.

4.7.14.4. Booting to heading

Under open condition, forenoon relative humidity, afternoon relative humidity, rainfall and rainy days showed significant positive correlation with head rice recovery

Table 4.26 (a). Correlation between head rice recovery and weather variables under open condition

	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.703**	0.919**	0.881**	0.877**	0.797**	0.862**	-0.858**	-0.916**	-0.320	0.377	-0.357	-0.061
P2	-0.797**	0.814**	0.744**	0.883**	0.549*	0.586*	-0.889**	-0.602*	-0.020	-0.486	0.276	0.102
P3	-0.886**	0.884**	0.957**	0.962**	0.744**	0.900**	-0.910**	-0.906**	-0.408	0.124	-0.784**	0.146
P4	-0.877**	0.377	0.850**	0.859**	0.538*	0.766**	-0.915**	-0.770**	-0.702**	0.494	-0.880**	0.143
P5	-0.978**	-0.391	0.450	0.942**	0.772**	0.913**	-0.980**	-0.894**	-0.117	-0.405	-0.703**	-0.663**
P6	-0.971**	0.136	0.642**	0.915**	0.762**	0.837**	-0.971**	-0.871**	-0.903**	-0.455	-0.920**	-0.846**

Table 4.26 (b). Correlation between head rice recovery and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.621*	0.940**	-0.736**	-0.742**	0.975**	0.471	-0.737**	0.975**
P2	-0.918**	0.350	0.467	0.884**	-0.936**	-0.679**	0.521*	-0.259
P3	-0.937**	0.911**	0.368	0.728**	-0.943**	-0.987**	-0.588*	-0.463
P4	-0.936**	0.210	0.809**	0.776**	-0.922**	-0.944**	-0.956**	0.142
P5	-0.935**	0.596*	0.666**	0.760**	-0.974**	-0.787**	-0.984**	0.305
P6	-0.963**	0.000	0.608*	0.728**	-0.939**	-0.980**	-0.961**	0.067

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

from booting to heading period. Whereas, maximum temperature, soil temperature, evaporation rate, bright sunshine hours and canopy temperature had significant negative correlation.Forenoon relative humidity and afternoon relative humidity were positively correlated and maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation.

4.7.14.5. Heading to 50% flowering

Head rice recovery showed significant positive correlation with afternoon relative humidity, rainfall and number of rainy days from heading to 50% flowering in rice variety Jyothi under open condition and maximum temperature, bright sunshine hours, soil temperature, canopy temperature and canopy air temperature depression had significant negative correlation.

Under climate controlled greenhouse, head rice recovery showed significant positive correlation with minimum temperature, forenoon relative humidity and afternoon relative. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation.

4.7.14.6. 50% flowering to physiological maturity

Forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days showed significant positive correlation with head rice recovery under open condition from 50% flowering to physiological maturity. Maximum temperature, soil temperature, bright sunshine hours, evaporation rate, canopy temperature and canopy air temperature depression had significant negative correlation with head rice recovery.

Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity had significant positively correlation. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negatively correlation.

4.7.15. Influence of weather parameter on starch content

The correlation between weather elements and starch content under open condition and climate controlled greenhouse were presented in Table 4.27(a) and 4.27(b) respectively.

4.7.15.1. Transplanting to active tillering

During transplanting to active tillering stage, minimum temperature, forenoon relative humidity, afternoon relative humidity, number of rainy days and absorbed PAR showed significant positive correlation with starch content under open condition. Whereas, soil temperature and bright sunshine hours had significant negative correlation with starch content.

Under climate controlled greenhouse from transplanting to active tillering stage, minimum temperature, forenoon relative humidity and afternoon relative humidity showed significant positive correlation with starch content. Whereas, soil temperature had significant negative correlation with starch content.

4.7.15.2. Active tillering to panicle initiation

Under open condition, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant positive effect on starch content from active tillering to panicle initiation. Maximum temperature and soil temperature had significant negative correlation with starch content.

Minimum temperature and afternoon relative humidity had significant positive effect on starch content under climate controlled greenhouse and maximum temperature, soil temperature, absorbed PAR and canopy air temperature depression had significant negative correlation.

4.7.15.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, number of rainy days and amount of rainfall had significant positive correlation on starch content during panicle initiation to booting period in Jyothi under open condition. Maximum temperature, soil temperature, bright sunshine hours and canopy temperature had significant negative correlation.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity had significant positive correlation on starch content during panicle initiation to booting period in Jyothi. Maximum temperature, soil temperature and absorbed PAR showed negative correlation.

4.7.15.4. Booting to heading

Minimum temperature, forenoon relative humidity, afternoon relative humidity and number of rainy days had significant positive correlation with starch content. Whereas, maximum temperature and canopy temperature had significant negative correlation.

Under climate controlled greenhouse forenoon relative humidity and afternoon relative humidity showed significant positive correlation. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation.

4.7.15.5. Heading to 50% flowering

Starch content under open condition showed significant positive correlation with afternoon relative humidity, number of rainy days and amount of rainfall. Maximum temperature, soil temperature and bright sunshine hours had significant negative correlation.

Table 4.27 (a): Correlation between starch content and weather variables under open condition

Crop stage	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.442	0.913**	0.717**	0.690**	0.494	0.598*	-0.683**	-0.829**	-0.469	0.564*	-0.139	0.261
P2	-0.581*	0.834**	0.600*	0.717**	0.223	0.246	-0.738**	-0.32	0.319	-0.165	0.185	0.489
P3	-0.812**	0.743**	0.801**	0.844**	0.576*	0.862**	-0.877**	-0.777**	-0.085	0.005	-0.663**	0.170
P4	-0.688**	0.640*	0.701**	0.643**	0.27	0.563*	-0.760**	-0.506	-0.469	0.497	-0.871**	0.460
P5	-0.870**	-0.492	0.365	0.888**	0.926**	0.764**	-0.884**	-0.876**	0.262	-0.023	-0.479	-0.464
P6	-0.925**	0.006	0.728**	0.896**	0.938**	0.924**	-0.929**	-0.922**	-0.893**	-0.38	-0.956**	-0.977**

Table 4.27 (b). Correlation between starch content and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.463	0.781**	0.773**	0.731**	-0.635*	-0.437	0.338	-0.049
P2	-0.521*	0.560*	0.058	0.817**	-0.587*	-0.798**	0.404	-0.647**
P3	-0.685**	0.774**	-0.028	0.744**	-0.757**	-0.787**	-0.428	-0.123
P4	-0.854**	-0.148	0.986**	0.774**	-0.883**	-0.928**	-0.789**	0.265
P5	-0.565*	0.631*	0.961**	0.762**	-0.655**	-0.348	-0.782**	0.681**
P6	-0.927**	-0.047	0.732**	0.755**	-0.928**	-0.771**	-0.902**	0.500

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

Under climate controlled greenhouse, starch content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity and canopy air temperature depression. Maximum temperature, soil temperature and canopy temperature showed significant negative correlation.

4.7.15.6. 50% flowering to physiological maturity

Under open condition, forenoon relative humidity, afternoon relative humidity, number of rainy days and amount of rainfall had significanrt positive correlation. Whereas, maximum temperature, evaporation rate, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression had significant negative correlation.

Forenoon relative humidity and afternoon relative humidity exhibited significant positively correlation with starch content under climate controlled greenhouse. Whereas, starch content had significant negative correlation with maximum temperature, soil temperature, absorbed PAR and canopy temperature.

4.7.16. Influence of weather parameter on amylose content

The correlation between weather elements and amylose content under open condition and climate controlled greenhouse were presented in Table 4.28(a) and 4.28(b) respectively.

4.7.16.1. Transplanting to active tillering

Amylose content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days during transplanting to active tillering stage under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and evaporation rate had significant negative correlation.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity showed significant positive correlation. Whereas, maximum temperature, soil temperature and absorbed PAR had significant negative correlation.

4.7.16.2. Active tillering to panicle initiation

Weather variables, minimum temperature, afternoon relative humidity, rainfall, number of rainy days and canopy temperature exhibited a significant positive correlation and maximum temperature, soil temperature, bright sunshine hours and absorbed PAR exhibited a significant negative correlation with amylose content from active tillering to panicle initiation stage under open condition.

Under climate controlled greenhouse, afternoon relative humidity exhibited a significant positive correlation and maximum temperature, soil temperature and absorbed PAR exhibited significant negative correlation.

4.7.16.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with amylose content from panicle initiation to booting stage in Jyothi under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature had significant negative correlation.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity showed significant positive correlation with amylose content from panicle initiation to booting. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation under climate controlled greenhouse.

Table 4.28 (a). Correlation between amylose content and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.733**	0.966**	0.958**	0.949**	0.742**	0.829**	-0.830**	-0.885**	-0.587*	0.091	-0.026	-0.350
P2	-0.931**	0.887**	0.489	0.961**	0.542*	0.564*	-0.973**	-0.683**	-0.291	-0.695**	0.669**	-0.032
P3	-0.901**	0.967**	0.918**	0.914**	0.555*	0.687**	-0.896**	-0.807**	-0.625*	-0.141	-0.957**	0.230
P4	-0.928**	0.471	0.576*	0.826**	0.408	0.584*	-0.943**	-0.705**	-0.796**	0.346	-0.937**	0.360
P5	-0.903**	-0.617*	0.024	0.746**	0.530*	0.704**	-0.900**	-0.679**	-0.069	-0.370	-0.819**	-0.342
P6	-0.928**	-0.283	0.341	0.678**	0.542*	0.601*	-0.926**	-0.617*	-0.667**	-.676**	-0.848**	-0.775**

Table 4.28 (b). Correlation between amylose content and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RHI	RH 2	ST	APAR	CT	CATD
P1	-0.707**	0.888**	0.541*	0.930**	-0.816**	-0.617*	0.207	0.133
P2	-0.844**	0.367	0.384	0.841**	-0.865**	-0.696**	0.494	-0.283
P3	-0.876**	0.878**	0.288	0.694**	-0.889**	-0.940**	-0.566*	-0.386
P4	-0.894**	0.182	0.813**	0.742**	-0.886**	-0.915**	-0.905**	0.135
P5	-0.867**	0.606*	0.691**	0.726**	-0.909**	-0.702**	-0.941**	0.326
P6	-0.934**	-0.016	0.591*	0.699**	-0.910**	-0.932**	-0.936**	0.098

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

4.7.16.4. Booting to heading

Under open condition, forenoon relative humidity, afternoon relative humidity and rainy days showed significant positive correlation with amylose content from booting to heading period. Whereas, maximum temperature, soil temperature, evaporation rate, bright sunshine hours and canopy temperature had significant negative correlation .

Forenoon relative humidity and afternoon relative humidity had significant positive correlation and maximum temperature, soil temperature, absorbed PAR and canopy temperature exhibited significant negative correlation.

4.7.16.5. Heading to 50% flowering

Amylose content showed significant positive correlation with afternoon relative humidity, rainfall and number of rainy days from heading to 50% flowering in rice variety Jyothi under open condition and maximum temperature, minimum temperature, bright sunshine hours, evaporation rate, soil temperature and canopy temperature showed significant negative correlation.

Under climate controlled greenhouse, amylose content showed significant positive correlation with minimum temperature, forenoon relative humidity and afternoon relative humidity. Maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation.

4.7.16.6. 50% flowering to physiological maturity

Afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with amylose content under open condition from 50% flowering to physiological maturity. Maximum temperature, soil temperature, bright sunshine hours, evaporation rate, absorbed PAR, canopy temperature and canopy air temperature depression showed significant negative correlation. Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity had significant positive correlation with amylose content. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation.

4.7.17. Influence of weather parameter on protein content

The correlation between weather elements and protein content under open condition and climate controlled greenhouse were presented in Table 4.29(a) and 4.29(b) respectively.

4.7.17.1. Transplanting to active tillering

During transplanting to active tillering stage, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days showed significant positive correlation with protein content under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and canopy temperature had significant negative correlation with protein content.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity showed significant positive correlation with protein content. Whereas, maximum temperature, soil temperature and absorbed PAR showed significant negative correlation.

4.7.17.2. Active tillering to panicle initiation

Under open condition, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive effect on protein content from active tillering to panicle initiation. Maximum temperature, soil temperature and bright sunshine hours had significant negative correlation.

Minimum temperature, afternoon relative humidity and canopy temperature had significant positive effect on protein content under climate controlled greenhouse and maximum temperature, soil temperature and absorbed PAR had significant negative correlation.

4.7.17.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days had significant positive correlation on protein content during panicle initiation to booting period in Jyothi under open condition. Maximum temperature, soil temperature, bright sunshine hours and canopy temperature showed significant negative correlation.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity had significant positive correlation. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation.

4.7.17.4. Booting to heading

Forenoon relative humidity, afternoon relative humidity and rainy days showed significant positive correlation with protein content from booting to heading stage under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature had significant negative correlation with protein content.

Under climate controlled greenhouse forenoon relative humidity and afternoon relative humidity had significant positive correlation with protein content. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation.

4.7.17.5. Heading to 50% flowering

Protein content under open condition showed significant positive correlation with afternoon relative humidity, amount rainfall and rainy days. Maximum temperature, soil temperature, bright sunshine hours, canopy temperature, absorbed PAR and canopy air temperature depression showed significant negative correlation.

Table 4.29 (a). Correlation between protein content and weather variables under open condition

Crop Stages	Tmax	Tmin	RHI	RH 2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.597*	0.864**	0.798**	0.804**	0.812**	0.857**	-0.767**	-0.827**	-0.291	0.338	-0.527*	0.048
P2	-0.741**	0.682**	0.722**	0.848**	0.630*	0.656**	-0.844**	-0.651**	0.008	-0.444	0.132	0.070
P3	-0.777**	0.852**	0.925**	0.910**	0.688**	0.877**	-0.815**	-0.839**	-0.298	0.079	-0.665**	0.277
P4	-0.795**	0.395	0.895**	0.785**	0.467	0.722**	-0.840**	-0.705**	-0.577*	0.372	-0.773**	0.018
P5	-0.944**	-0.349	0.528	0.926**	0.745**	0.964**	-0.948**	-0.849**	-0.209	-0.580*	-0.745**	-0.775**
P6	-0.952**	0.271	0.621*	0.929**	0.777**	0.830**	-0.952**	-0.901**	-0.961**	-0.482	-0.934**	-0.783**

Table 4.29 (b). Correlation between protein content and weather variables under climate controlled greenhouse

Crop stages	Tmax	Tmin	RHI	RH 2	ST	APAR	CT	CATD
P1	-0.734	0.942**	0.619*	0.906**	-0.847**	-0.566*	0.199	0.136
P2	-0.796**	0.561*	0.323	0.886**	-0.838**	-0.748**	0.629*	-0.366
P3	-0.921**	0.947**	0.216	0.728**	-0.939**	-0.971**	-0.654**	-0.385
P4	-0.952**	0.162	0.875**	0.759**	-0.934**	-0.961**	-0.952**	0.084
P5	-0.863**	0.680**	0.768**	0.745**	-0.898**	-0.681**	-0.941**	0.414
P6	-0.986**	-0.155	0.622*	0.708**	-0.957**	-0.912**	-0.973**	0.245

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

Under climate controlled greenhouse, protein content showed significant positive correlation with minimum temperature, forenoon relative humidity and afternoon relative humidity. Maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant positive correlation.

4.7.17.6. 50% flowering to physiological maturity

Under open condition, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days showed significant positive correlation with protein content from 50% flowering to physiological maturity. Whereas, maximum temperature, soil temperature, evaporation rate, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression had significant negative correlation.

Forenoon relative humidity and afternoon relative humidity had positively correlated with protein content under climate controlled greenhouse. Whereas, protein content showed significant negative correlation with maximum temperature, soil temperature, absorbed PAR and canopy temperature.

4.7.18. Influence of weather parameter on fat content

The correlation between weather elements and fat content under open condition and climate controlled greenhouse were presented in Table 4.30(a) and 4.30(b) respectively.

4.7.18.1. Transplanting to active tillering

Fat content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days during transplanting to active tillering stage under open condition. Whereas, maximum temperature, soil temperature and bright sunshine hours had significant negative correlation with fat content.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant positive correlation with fat content. Whereas, maximum temperature, soil temperature and absorbed PAR showed significant negative correlation.

4.7.18.2. Active tillering to panicle initiation

Weather variables, minimum temperature, forenoon relative humidity, afternoon relative humidity and number of rainy days exhibited a significant positive correlation and maximum temperature, bright sunshine hours and soil temperature exhibited a significant negative correlation with fat content from active tillering to panicle initiation stage under open condition.

Under climate controlled greenhouse, afternoon relative humidity exhibited a significant positive correlation and maximum temperature, soil temperature and absorbed PAR exhibited significant negative correlation.

4.7.18.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with fat content from panicle initiation to booting period in Jyothi under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and canopy temperature showed significant negative correlation.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity exhibited significant positive correlation with fat content. Maximum temperature, soil temperature and absorbed PAR showed significant negative correlation.

4.7.18.4. Booting to heading

Under open condition, forenoon relative humidity, afternoon relative humidity, rainy days and absorbed PAR showed significant positive correlation with fat content from booting to heading period. Whereas, maximum temperature, soil temperature, evaporation rate, bright sunshine hours and canopy temperature had significant negative correlation.

Table 4.30 (a). Correlation between fat content and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.629*	0.898**	0.818**	0.811**	0.749**	0.814**	-0.818**	-0.895**	-0.280	0.482	-0.413	0.089
P2	-0.711**	0.785**	0.775**	0.824**	0.491	0.527*	-0.830**	-0.527*	0.121	-0.363	0.143	0.212
P3	-0.854**	0.829**	0.929**	0.942**	0.750**	0.941**	-0.895**	-0.896**	-0.275	0.161	-0.702**	0.143
P4	-0.815**	0.408	0.891**	0.813**	0.508	0.764**	-0.866**	-0.724**	-0.616*	0.519*	-0.851**	0.140
P5	-0.969**	-0.354	0.550*	0.978**	0.863**	0.938**	-0.975**	-0.940**	-0.047	-0.343	-0.628*	-0.713**
P6	-0.968**	0.228	0.732**	0.970**	0.853**	0.911**	-0.970**	-0.946**	-0.964**	-0.386	-0.945**	-0.882**

Table 4.30 (b). Correlation between fat content and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.636*	0.822**	0.676**	0.946**	-0.785**	-0.597*	0.257	0.100
P2	-0.823**	0.232	0.371	0.890**	-0.848**	-0.716**	0.285	-0.461
P3	-0.808**	0.796**	0.289	0.801**	-0.855**	-0.902**	-0.379	-0.327
P4	-0.909**	-0.025	0.918**	0.861**	-0.937**	-0.970**	-0.885**	0.359
P5	-0.786**	0.529*	0.812**	0.844**	-0.877**	-0.623*	-0.938**	0.495
P6	-0.963**	0.205	0.746**	0.839**	-0.968**	-0.969**	-0.955**	0.187

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

Forenoon relative humidity and afternoon relative humidity showed significant positive correlation and maximum temperature, soil temperature, absorbed PAR and canopy temperature had significant negative correlation.

4.7.18.5. Heading to 50% flowering

Fat content showed significant positive correlation with forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days from heading to 50% flowering in rice variety Jyothi under open condition and maximum temperature, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression had significant negative correlation.

Under climate controlled greenhouse, fat content showed significant positive correlation with minimum temperature, forenoon relative humidity and afternoon relative humidity from heading to 50% flowering. Maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation.

4.7.18.6. 50% flowering to physiological maturity

Forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with fat content under open condition from 50% flowering to physiological maturity. Maximum temperature, soil temperature, bright sunshine hours, evaporation rate, canopy temperature and canopy air temperature depression had significant negative correlation with fat content.

Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity had significant positive correlation with fat content. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature showed significant negative correlation.

4.7.19. Influence of weather parameter on Calcium content

The correlation between weather elements and calcium content under open condition and climate controlled greenhouse were presented in Table 4.31(a) and 4.31(b) respectively.

4.7.19.1. Transplanting to active tillering

During transplanting to active tillering stage, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days showed significant positive correlation with calcium content under open condition. Whereas, soil temperature, bright sunshine hours and evaporation rate correlated negatively with calcium content.

Under climate controlled greenhouse from transplanting to active tillering stage, minimum temperature, forenoon relative humidity and afternoon relative humidity were showed positive correlation with calcium content. Whereas, maximum temperature, soil temperature and absorbed PAR were negatively correlated with calcium content from active tillering to panicle initiation under climate controlled greenhouse.

4.7.19.2. Active tillering to panicle initiation

Under open condition, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant positive effect on calcium content from active tillering to panicle initiation. Maximum temperature and soil temperature had significant negative correlation with calcium content from active tillering to panicle initiation.

Calcium content from active tillering to panicle initiation under climate controlled greenhouse had positive correlation with afternoon relative humidity negative correlation with maximum temperature, soil temperature and absorbed PAR from active tillering to panicle initiation.

4.7.19.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, number of rainy days and amount of rainfall had significant positive correlation on calcium content during panicle initiation to booting period in Jyothi under open condition. Maximum temperature, soil temperature, bright sunshine hours and canopy temperature were negatively correlated.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity had positive correlation on calcium content during panicle initiation to booting period in Jyothi. Maximum temperature, soil temperature and absorbed PAR showed negative correlation with calcium content from panicle initiation to booting stage.

4.7.19.4. Booting to heading

Minimum temperature, forenoon relative humidity, afternoon relative humidity and number of rainy days were positively correlated with calcium content from booting to heading stage under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and canopy temperature were correlated negatively with calcium content.

Under climate controlled greenhouse forenoon relative humidity and afternoon relative humidity were positively correlated with calcium content from booting to heading stage. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated with calcium content.

4.7.19.5. Heading to 50% flowering

Calcium content under open condition showed significant positive correlation with afternoon relative humidity amount rainfall and number of rainy days. Maximum temperature, soil temperature, bright sunshine hours and canopy temperature were negatively correlated with calcium content under open condition.

Table 4.31(a). Correlation between calcium content and weather variables under open condition

Crop Stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.469	0.951**	0.769**	0.747**	0.554*	0.656**	-0.694**	-0.834**	-0.548*	0.447	-0.141	0.172
P2	-0.666**	0.838**	0.555*	0.791**	0.320	0.337	-0.808**	-0.431	0.200	-0.277	0.281	0.391
P3	-0.822**	0.817**	0.838**	0.866**	0.541*	0.827**	-0.879**	-0.773**	-0.167	-0.088	-0.722**	0.263
P4	-0.734**	0.671**	0.685**	0.666**	0.250	0.541*	-0.799**	-0.521*	-0.506	0.415	-0.888**	0.451
P5	-0.893**	-0.581*	0.301	0.871**	0.869**	0.777**	-0.904**	-0.838**	0.248	-0.109	-0.586*	-0.460
P6	-0.955**	-0.058	0.637*	0.868**	0.887**	0.872**	-0.958**	-0.885**	-0.884**	-0.499	-0.981**	-0.953**

Table 4.31(b). Correlation between calcium content and weather variables under climate controlled greenhouse

Crop stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.565*	0.885**	0.558*	0.948**	-0.720**	-0.721**	0.398	-0.047
P2	-0.799**	0.287	0.249	0.813**	-0.813**	-0.817**	0.349	-0.340
P3	-0.789**	0.852**	0.157	0.684**	-0.820**	-0.920**	-0.497	-0.208
P4	-0.862**	0.125	0.913**	0.756**	-0.882**	-0.940**	-0.850**	0.201
P5	-0.797**	0.663**	0.822**	0.735**	-0.871**	-0.571*	-0.964**	0.376
P6	-0.955**	0.078	0.621*	0.728**	-0.934**	-0.963**	-0.979**	0.077

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

Under climate controlled greenhouse, starch content showed significant positive correlation with minimum temperature, forenoon relative humidity and afternoon relative humidity. Maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated with calcium content from heading to 50% flowering.

4.7.19.6. 50% flowering to physiological maturity

Under open condition, forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days were positively correlated with calcium content from 50% flowering to physiological maturity. Whereas, maximum temperature, evaporation rate, soil temperature, bright sunshine hours, evaporation rate, canopy temperature and canopy air temperature depression were correlated negatively.

Forenoon relative humidity and afternoon relative humidity were positively correlated with calcium content from 50% flowering to physiological maturity under climate controlled greenhouse. Whereas, calcium content was negatively correlated with maximum temperature, soil temperature, absorbed PAR and canopy temperature.

4.7.20. Influence of weather parameter on Iron content

The correlation between weather elements and Iron content under open condition and climate controlled greenhouse were presented in Table 4.32(a) and 4.32(b) respectively.

4.7.20.1. Transplanting to active tillering

Iron content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days during transplanting to active tillering stage under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and evaporation rate were correlated negatively with iron content.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity were positively correlated with iron content from transplanting to active tillering stage. Whereas, soil temperature was negatively correlated.

4.7.20.2. Active tillering to panicle initiation

Weather variable, minimum temperature, afternoon relative humidity, rainfall, number of rainy days and canopy temperature exhibited a significant positive correlation and maximum temperature, soil temperature, bright sunshine hours and absorbed PAR exhibited a negative correlation with iron content from active tillering to panicle initiation stage under open condition.

Under climate controlled greenhouse, afternoon relative humidity exhibited a positive correlation and maximum temperature, soil temperature, absorbed PAR and canopy air temperature depression exhibited negative correlation with iron content from active tillering to panicle initiation stage.

4.7.20.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with iron content from panicle initiation to booting period in Jyothi under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature were correlated negatively.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity were positively correlated with iron content from panicle initiation to booting stage. Maximum temperature, soil temperature and absorbed PAR showed significant negative correlation with iron content from panicle initiation to booting stage under climate controlled greenhouse.

Table 4.32 (a). Correlation between Iron content and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.704**	0.929**	0.931**	0.929**	0.775**	0.847**	-0.790**	-0.833**	-0.571*	0.013	-0.112	-0.360
P2	-0.932**	0.808**	0.462	0.960**	0.622*	0.638*	-0.965**	-0.747**	-0.347	-0.727**	0.636*	-0.116
P3	-0.841**	0.965**	0.905**	0.885**	0.519*	0.648**	-0.835**	-0.766**	-0.623*	-0.176	-0.913**	0.304
P4	-0.902**	0.450	0.584*	0.801**	0.386	0.560*	-0.914**	-0.688**	-0.759**	0.258	-0.873**	0.267
P5	-0.882**	-0.622*	0.052	0.719**	0.483	0.722**	-0.878**	-0.636*	-0.094	-0.457	-0.860**	-0.394
P6	-0.907**	-0.233	0.282	0.654**	0.496	0.552*	-0.904**	-0.591*	-0.667**	-0.715**	-0.833**	-0.705**

Table 4.32 (b). Correlation between Iron content and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.477	0.744**	0.730**	0.729**	-0.635*	-0.429	0.294	-0.008
P2	-0.546*	0.478	0.117	0.796**	-0.604*	-0.736**	0.362	-0.596*
P3	-0.675**	0.736**	0.037	0.728**	-0.740**	-0.766**	-0.391	-0.163
P4	-0.826**	-0.133	0.926**	0.759**	-0.853**	-0.892**	-0.770**	0.280
P5	-0.573*	0.571*	0.888**	0.748**	-0.659**	-0.382	-0.766**	0.628*
P6	-0.888**	0.004	0.709**	0.741**	-0.892**	-0.765**	-0.864**	0.436

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

4.7.20.4. Booting to heading

Under open condition, forenoon relative humidity, afternoon relative humidity and rainy days were showed significant positive correlation with iron content from booting to heading period. Whereas, maximum temperature, soil temperature, bright sunshine hours evaporation rate and canopy temperature were correlated negatively.

Forenoon relative humidity and afternoon relative humidity were positively correlated and maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated with iron content from booting to heading period under climate controlled greenhouse.

4.7.20.5. Heading to 50% flowering

Iron content showed significant positive correlation with afternoon relative humidity and number of rainy days from heading to 50% flowering in rice variety Jyothi under open condition and maximum temperature, minimum temperature, soil temperature, bright sunshine hours and canopy temperature were negatively correlated.

Under climate controlled greenhouse, iron content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity and canopy air temperature depression from heading to 50% flowering in rice variety Jyothi. Maximum temperature, soil temperature and canopy temperature were negatively correlated.

4.7.20.6. 50% flowering to physiological maturity

Afternoon relative humidity and number of rainy days were correlated positively with iron content under open condition from 50% flowering to physiological maturity. Maximum temperature, soil temperature, bright sunshine hours, evaporation rate, absorbed PAR, canopy temperature and canopy air temperature depression were negatively correlated with iron content from 50% flowering to physiological maturity under open condition.

Under climate controlled greenhouse, forenoon relative humidity and afternoon relative humidity were positively correlated with iron content from 50% flowering to physiological maturity. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated.

4.7.21. Influence of weather parameter on Zinc content

The correlation between weather elements and zinc content under open condition and climate controlled greenhouse were presented in Table 4.33(a) and 4.33(b) respectively.

4.7.21.1. Transplanting to active tillering

During transplanting to active tillering stage, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days showed significant positive correlation with zinc content under open condition. Whereas, maximum temperature, soil temperature and bright sunshine hours correlated negatively with zinc content.

Under climate controlled greenhouse from transplanting to active tillering stage, minimum temperature, forenoon relative humidity and afternoon relative humidity were showed positive correlation with zinc content. Whereas, maximum temperature and soil temperature were negatively correlated with zinc content from active tillering to panicle initiation under climate controlled greenhouse.

4.7.21.2. Active tillering to panicle initiation

Under open condition, minimum temperature, forenoon relative humidity and afternoon relative humidity had significant positive effect on zinc content from active tillering to panicle initiation. Maximum temperature and soil temperature had significant negative correlation with zinc content from active tillering to panicle initiation.

Forenoon relative humidity and afternoon relative humidity had positive significant effect on zinc content from active tillering to panicle initiation under climate controlled greenhouse and maximum temperature, soil temperature and canopy air temperature depression were negatively correlated with zinc content from active tillering to panicle initiation.

4.7.21.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and number of rainy days had significant positive correlation on zinc content during panicle initiation to booting period in Jyothi under open condition. Maximum temperature, soil temperature, bright sunshine hours and canopy temperature were negatively correlated.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity had positive correlation on zinc content during panicle initiation to booting period in Jyothi. Maximum temperature, soil temperature, absorbed PAR and canopy air temperature depression showed negative correlation with zinc content from panicle initiation to booting stage.

4.7.21.4. Booting to heading

Forenoon relative humidity, afternoon relative humidity, number of rainy days and absorbed PAR were positively correlated with zinc content from booting to heading stage under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours, evaporation rate and canopy temperature were correlated negatively with zinc content.

Under climate controlled greenhouse forenoon relative humidity and afternoon relative humidity were positively correlated with zinc content from booting to heading

Table 4.33 (a). Correlation between zinc content and weather variables under open condition

Crop stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.704**	0.964**	0.900**	0.883**	0.709**	0.799**	-0.873**	-0.955**	-0.397	0.445	-0.179	-0.052
P2	-0.786**	0.914**	0.714**	0.872**	0.412	0.452	-0.889**	-0.502	0.046	-0.438	0.361	0.227
P3	-0.943**	0.878**	0.942**	0.969**	0.731**	0.903**	-0.970**	-0.917**	-0.400	0.106	-0.841**	0.077
P4	-0.886**	0.448	0.777**	0.852**	0.507	0.736**	-0.929**	-0.742**	-0.727**	0.570*	-0.957**	0.322
P5	-0.972**	-0.431	0.340	0.932**	0.805**	0.838**	-0.976**	-0.903**	-0.033	-0.250	-0.642**	-0.526*
P6	-0.979**	-0.003	0.672**	0.900**	0.801**	0.864**	-0.980**	-0.864**	-0.863**	-0.433	-0.928**	-0.928**

Table 4.33 (b). Correlation between zinc content and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.846**	0.776**	0.788**	0.890**	-0.941**	-0.337	-0.081	0.419
P2	-0.847**	0.356	0.583*	0.990**	-0.901**	-0.508	0.437	-0.541*
P3	-0.918**	0.787**	0.503	0.915**	-0.963**	-0.902**	-0.378	-0.612*
P4	-0.992**	-0.110	0.826**	0.930**	-0.993**	-0.971**	-0.975**	0.399
P5	-0.828**	0.371	0.684**	0.924**	-0.896**	-0.781**	-0.869**	0.582*
P6	-0.950**	0.148	0.827**	0.895**	-0.973**	-0.909**	-0.883**	0.376

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

stage. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated with zinc content.

4.7.21.5. Heading to 50% flowering

Zinc content under open condition showed significant positive correlation with afternoon relative humidity, amount rainfall and rainy days. Maximum temperature, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression were negatively correlated with zinc content under open condition.

Under climate controlled greenhouse, zinc content showed significant positive correlation with forenoon relative humidity, afternoon relative humidity and canopy air temperature depression. Maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated with zinc content from heading to 50% flowering.

4.7.21.6. 50% flowering to physiological maturity

Under open condition, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days were positively correlated with zinc content from 50% flowering to physiological maturity. Whereas, maximum temperature, soil temperature, bright sunshine hours, evaporation rate, canopy temperature and canopy air temperature depression were correlated negatively.

Forenoon relative humidity and afternoon relative humidity were positively correlated with zinc content from 50% flowering to physiological maturity under climate controlled greenhouse. Whereas, zinc content was negatively correlated with maximum temperature, soil temperature, absorbed PAR and canopy temperature.

4.7.22. Influence of weather parameter on phosphorus content

The correlation between weather elements and phosphorus content under open condition and climate controlled greenhouse were presented in Table 4.34(a) and 4.34 (b) respectively.

4.7.22.1. Transplanting to active tillering

Phosphorus content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity, amount of rainfall and rainy days during transplanting to active tillering stage under open condition. Whereas, maximum temperature, soil temperature and bright sunshine hours were correlated negatively with phosphorus content.

Under climate controlled greenhouse, minimum temperature, forenoon relative humidity and afternoon relative humidity were positively correlated with fat content from transplanting to active tillering stage. Whereas, maximum temperature and soil temperature were negatively correlated.

4.7.22.2. Active tillering to panicle initiation

Weather variable, minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days exhibited a significant positive correlation and maximum temperature, bright sunshine hours and soil temperature exhibited a negative correlation with phosphorus content from active tillering to panicle initiation stage under open condition.

Under climate controlled greenhouse, minimum temperature and afternoon relative humidity exhibited a positive correlation and maximum temperature, soil temperature, absorbed PAR and canopy air temperature depression exhibited negative correlation with phosphorus content from active tillering to panicle initiation stage.

4.7.22.3. Panicle initiation to booting

Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days had significant positive correlation with phosphorus content from panicle initiation to booting period in Jyothi under open condition. Whereas, maximum temperature, soil temperature, bright sunshine hours and canopy temperature were correlated negatively. Under climate controlled greenhouse, minimum temperature and afternoon relative humidity were positively correlated with phosphorus content from panicle initiation to booting stage. Maximum temperature, soil temperature and absorbed PAR showed significant negative correlation with phosphorus content from panicle initiation to booting stage under climate controlled greenhouse.

4.7.22.4. Booting to heading

Under open condition, forenoon relative humidity, afternoon relative humidity, amount of rainfall, rainy days and absorbed PAR were showed significant positive correlation with phosphorus content from booting to heading period. Whereas, maximum temperature, soil temperature, evaporation rate, bright sunshine hours and canopy temperature were correlated negatively.

Forenoon relative humidity and afternoon relative humidity were positively correlated and maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated with phosphorus content from booting to heading period under climate controlled greenhouse.

4.7.22.5. Heading to 50% flowering

Phosphorus content showed significant positive correlation with forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days from heading to

Table 4.34 (a). Correlation between phosphorus content and weather variables under open condition

Crop Stages	Tmax	Tmin	RH1	RH2	Rain	RD	ST	BSS	Evp	APAR	CT	CATD
P1	-0.683**	0.842**	0.810**	0.809**	0.796**	0.845**	-0.850**	-0.897**	-0.144	0.502	-0.498	0.052
P2	-0.698**	0.745**	0.852**	0.801**	0.524*	0.571*	-0.804**	-0.529*	0.097	-0.374	0.078	0.144
P3	-0.846**	0.797**	0.933**	0.943**	0.825**	0.964**	-0.879**	-0.925**	-0.312	0.282	-0.671**	0.058
P4	-0.822**	0.271	0.946**	0.852**	0.612*	0.841**	-0.866**	-0.791**	-0.649**	0.570*	-0.812**	0.014
P5	-0.967**	-0.228	0.636*	0.992**	0.836**	0.966**	-0.970**	-0.958**	-0.176	-0.412	-0.606*	-0.786**
P6	-0.936**	0.340	0.762**	0.981**	0.813**	0.904**	-0.937**	-0.940**	-0.958**	-0.302	-0.889**	-0.829**

Table 4.34 (b). Correlation between phosphorus content and weather variables under climate controlled greenhouse

Growth stages	Tmax	Tmin	RH1	RH2	ST	APAR	CT	CATD
P1	-0.524*	0.767**	0.819**	0.754**	-0.689**	-0.396	0.261	0.038
P2	-0.565*	0.522*	0.146	0.865**	-0.634*	-0.747**	0.383	-0.682**
P3	-0.717**	0.763**	0.064	0.805**	-0.793**	-0.799**	-0.385	-0.206
P4	-0.889**	-0.195	0.983**	0.831**	-0.919**	-0.951**	-0.824**	0.335
P5	-0.591*	0.568*	0.942**	0.821**	-0.686**	-0.407	-0.791**	0.716**
P6	-0.941**	0.018	0.789**	0.813**	-0.952**	-0.795**	-0.901**	0.525*

*-significant at 5% level **- significant at 1% level

P1- Transplanting to active tillering

P2- Active tillering to panicle initiation

P3- Panicle initiation to booting

P4- Booting to heading

P5- Heading to 50% flowering

P6- 50% flowering to physiological maturity

50% flowering in rice variety Jyothi under open condition and maximum temperature, soil temperature, bright sunshine hours, canopy temperature and canopy air temperature depression were negatively correlated.

Under climate controlled greenhouse, phosphorus content showed significant positive correlation with minimum temperature, forenoon relative humidity, afternoon relative humidity and canopy air temperature depression from heading to 50% flowering in rice variety Jyothi. Maximum temperature, soil temperature and canopy temperature were negatively correlated.

4.7.22.6. 50% flowering to physiological maturity

Forenoon relative humidity, afternoon relative humidity, rainfall and number of rainy days were correlated positively with phosphorus content under open condition from 50% flowering to physiological maturity. Maximum temperature, soil temperature, bright sunshine hours, evaporation rate, canopy temperature and canopy air temperature depression were negatively correlated with phosphorus content from 50% flowering to physiological maturity under open condition.

Under climate controlled greenhouse, forenoon relative humidity, afternoon relative humidity and canopy air temperature depression were positively correlated with phosphorus content from 50% flowering to physiological maturity. Whereas, maximum temperature, soil temperature, absorbed PAR and canopy temperature were negatively correlated.

4.8. Results of DSSAT-CERES simulation

The CERES-Rice model was calibrated based on experimental data collected during 2019-2020 rice crop season. The genetic coefficient generated for Jyothi at the Department of Agricultural Meteorology during previous experiment was used to simulate the yield.

Table 4.35. Genetic coefficients used in DSSAT-CERES-Rice model

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Jyothi	553	22.3	415	11.6	43	0.245	1.1	1.15	82

4.8.1. Simulated v/s observed grain yield

In variety Jyothi, observed grain yield of rice varied from 4131 kg ha^{-1} (D5) to 7039 kg ha^{-1} (D4) for different planting dates under open condition. The model underestimated the grain yield in D4 planting, while it was overestimated in D1, D2, D3 and D5 plantings. Error percent of CERES-Rice simulated grain yields from those corresponding observed ones during the crop season is presented in Table 4.36.

Table 4.36. Observed and predicted grain yield (kg ha^{-1}) of rice with their percentage error

Planting dates	Grain yield(kg ha^{-1})		Error %
	Observed	Simulated	
D1	5345.0	5932.0	11.0
D2	6150.0	6231.0	1.3
D3	5687.0	5809.0	2.1
D4	7039.0	5919.0	-15.9
D5	4131.0	5340.0	29.3
Average	5670.4	5846.2	5.6

Error percentage = [(Simulated-observed)/observed]*100

4.8.2. Simulated V/s observed phenological development

Accurate simulation of phasic development of crop is necessary to get precise simulation of crop growth and yield. Evaluation of phasic development is first step in any study for the assessment of performance of a crop simulation model. The duration of various phenological events were analyzed and the results are presented below.

4.8.2.1. Days to panicle initiation

Model simulated and field observed duration of panicle initiation and their error percentage are presented in Table 4.37. The results showed that observed duration of panicle initiation varied from 29 (D1, D5) to 32 days (D2, D3) in Jyothi under. While days to panicle initiation simulated by model ranges from 27 (D5) to 33 days (D2). Days to panicle initiation was underestimated by model in D3, D4 and D5 date of planting, whereas it is overestimated in D1 and D2 planting.

Table 4.37. Observed and predicted panicle initiation days for variety Jyothi under open condition with their percentage error

Planting dates	Panicle Initiation day		Error %
	Observed	Simulated	
D1	29	32	10.3
D2	32	33	3.1
D3	32	29	-9.4
D4	30	29	-3.3
D5	29	27	-6.9
Average	30.4	30.0	-1.2

Error percentage = [(Simulated-observed)/observed]*100

4.8.2.2. Days to anthesis

Error percentage in the models between observed and simulated duration of anthesis for variety Jyothi presented in Table 4.38. Observed duration of anthesis varied from 64 (D4) to 71 days (D1) in Jyothi under open condition. While days to anthesis simulated by model ranged from 65 (D3) to 70 days (D2). Days to anthesis was underestimated by model in D1 and D3 date of planting, whereas it is overestimated in D4 and D5 planting. Model simulated days to anthesis for D2 planting accurately.

Table 4.38. Observed and predicted anthesis days for variety Jyothi under open condition with their percentage error

Planting dates	Anthesis day		Error %
	Observed	Simulated	
D1	71	68	-4.2
D2	70	70	0.0
D3	68	65	-4.4
D4	64	66	3.1
D5	65	66	1.5
Average	67.6	67.0	-0.8

Error percentage = [(Simulated-observed)/observed]*100

4.8.2.3. Days to maturity

Observed duration of rice variety Jyothi for attaining maturity varied from 93 (D3) to 100 days (D1) for different planting dates under open condition. The model overestimated days to maturity in all dates of planting. Error percent of CERES-Rice simulated value from those corresponding observed ones during the crop season is presented in Table 4.39.

Table 4.39. Observed and predicted days to maturity for variety Jyothi under open condition with their percentage error

Planting dates	Maturity day		Error %
	Observed	Simulated	
D1	100	103	3.0
D2	99	104	5.1
D3	93	101	8.6
D4	97	103	6.2
D5	96	103	7.3
Average	97.0	102.8	6.0

Error percentage = [(Simulated-observed)/observed]*100

4.8.3. Model performance

Root Mean Square Error (RMSE), d-stat index, and Mean Absolute Percentage Error (MAPE) for variety Jyothi is given in Table 4.40.

Table 4.40. RMSE, d-stat index and MAPE for variety Jyothi

Variable	Observed	Simulated	RMSE	d-Stat	MAPE
Anthesis day	67.6	67	2.145	0.748	2.7
Grain yield (kg/ha)	5670.4	5846.2	785.124	0.592	11.9
Panicle initiation day	30.4	30	2.191	0.612	6.6
Maturity day	97	102.8	6.05	0.412	6.0

4.9. Climate change scenarios

Future vulnerability to climate change caused by greenhouse gas emission can be analysed using climate change scenarios. Projected climate change data in the year 2030, 2050 and 2080 under two representative concentration pathways (RCP 4.5 and RCP 8.5) were taken from ECHAM model and Marksim DSSAT weather file generator.

4.9.1. Comparison of predicted data to observed data

A study conducted by Venkat *et al.* (2017) in the Department of Agricultural Meteorology, Kerala Agricultural University showed that GFDL-CM3 model is best suited for central zone of Kerala.

4.9.2. Future climate data of Pattambi station during the crop period

Weather data for different dates of planting under RCP 4.5 and RCP 8.5 scenarios in the year 2019, 2030, 2050 and 2080 were displayed in Table 4.41.

Table 4.41. Baseline (2019) and projected mean solar radiation, maximum, minimum temperature and rainfall at Pattambi during crop growth period

Date of planting	Weather parameter	2019	RCP 4.5			RCP 8.5		
			2030	2050	2080	2030	2050	2080
D1	SRAD	17.5	14.4	14.1	15.2	14.1	14.4	15.0
	Tmax	30.2	30.7	31.2	32.2	30.6	31.4	32.3
	Tmin	21.6	25.1	25.6	26.3	25.1	25.7	27.3
	Rainfall	2293.8	2359.9	2515.7	2198.6	2529.4	2491.3	2270.0
D2	SRAD	17.5	16.6	16.6	17.5	16.6	17.0	16.9
	Tmax	30.2	30.5	30.8	31.7	30.3	31.1	31.8
	Tmin	21.5	24.7	25.2	25.9	24.7	25.3	26.9
	Rainfall	2064.9	1697.9	1723.8	1412.8	1753.9	1665.7	1503.3
D3	SRAD	17.4	18.4	18.3	18.2	18.7	18.4	17.9
	Tmax	32.1	32.6	33.0	33.9	32.4	33.2	33.7
	Tmin	20.9	24.4	24.9	25.7	24.4	25.2	26.6
	Rainfall	509.7	337.5	412.0	425.2	352.1	419.3	456.9
D4	SRAD	18.2	19.6	19.4	19.4	19.6	19.2	18.6
	Tmax	32.8	32.1	32.4	33.4	31.7	32.3	33.1
	Tmin	20.2	23.1	23.6	24.3	23.0	23.8	25.5
	Rainfall	78.6	66.6	106.5	131.7	84.6	115.2	193.0
D5	SRAD	21.5	21.9	21.2	21.5	21.6	21.0	20.1
	Tmax	35.3	33.5	34.0	35.1	33.1	33.8	34.5
	Tmin	20.4	24.2	24.7	25.3	23.9	24.8	26.8
	Rainfall	37.0	28.3	34.8	32.2	24.7	31.4	29.8

4.10. Impact of climate change on selected rice varieties under RCP 4.5 and RCP 8.5 scenarios

The study was conducted to identify the yield and growth changes of selected variety Jyothi cultivated at Pattambi under the global climate change scenarios Representative Concentration Pathway (RCP) 4.5 and 8.5. The Decision Support System for Agro technology Transfer (DSSAT) software was used to forecast the rice yield in 2030s, 2050s and 2080s.

4.10.1. Impact on panicle initiation

Days taken for panicle initiation for base line period (2019) and projected periods 2030s, 2050s and 2080s under RCP 4.5 and RCP 8.5 scenarios for rice variety Jyothi was presented below. A comparison between baseline and projected duration for panicle initiation are presented in Table 4.42 and 4.43.

4.10.1.1. RCP 4.5 scenario

The result showed that in the baseline year 2019, duration for panicle initiation varied from 27 (D5) to 33 (D2) days in Jyothi. Days taken for panicle initiation simulated during projected period 2030 under RCP 4.5 ranges from 27 (D5) to 32 days (D2). During projected period 2050, under RCP 4.5, days to panicle initiation ranges from 26 (D5) to 31 days (D1 and D2). Whereas in the projected period 2080 under RCP 4.5 Duration for panicle initiation ranges from 26 (D5) to 31 days (D1).

4.10.1.2. RCP 8.5 scenario

During projected period 2030, under RCP 8.5, days to panicle initiation ranges from 27 (D5) to 32 days (D2). Days taken for panicle initiation simulated during projected period 2050 under RCP 8.5 ranges from 26 (D5) to 31 days (D1 and D2). Whereas in the projected period 2080 under RCP 8.5 Duration for panicle initiation ranges from 25 (D5) to 34 days (D1).

Table 4.42. Baseline and projected days to panicle initiation under RCP 4.5

Panicle initiation							
Date of planting	2019	RCP 4.5					
		2030		2050		2080	
		Simulated	Days (Error %)	Simulated	Days (Error %)	Simulated	Days (Error %)
D1	32	31	-1(-3.1%)	31	-1(-3.1%)	31	-1(-3.2%)
D2	33	32	-1(-3.0%)	31	-2(-6.1%)	30	-3(-10.0%)
D3	29	27	-2(-6.9%)	27	-2(-6.9%)	27	-2(-7.4%)
D4	29	28	-1(-3.4%)	27	-2(-6.9%)	27	-2(-7.4%)
D5	27	27	0(0.0%)	26	-1(-3.7%)	26	-1(-3.8%)

Table 4.43. Baseline and projected days to panicle initiation under RCP 8.5

Panicle initiation							
Date of planting	2019	RCP 8.5					
		2030		2050		2080	
		Simulated	Days (Error %)	Simulated	Days (Error %)	Simulated	Days (Error %)
D1	32	31	-1(-3.1%)	31	-1(-3.1%)	34	2(6.3%)
D2	33	32	-1(-3.0%)	31	-2(-6.1%)	29	-4(-12.1%)
D3	29	27	-2(-6.9%)	27	-2(-6.9%)	28	-1(-3.4%)
D4	29	28	-1(-3.4%)	27	-2(-6.9%)	27	-2(-6.9%)
D5	27	27	0(0.0%)	26	-1(-3.7%)	25	-2(-7.4%)

4.10.2. Impact on days to anthesis

Days taken for anthesis for base line period (2019) and projected periods 2030s, 2050s and 2080s under RCP 4.5 and RCP 8.5 scenarios for rice variety Jyothi was presented below.

Table 4.44. Baseline and projected days to anthesis under RCP 4.5

Anthesis							
Date of planting	2019	RCP 4.5					
		2030		2050		2080	
		Simulated	Days (Error %)	Simulated	Days (Error %)	Simulated	Days (Error %)
D1	68	65	-3(-4.4%)	64	-4(-5.9%)	64	-4(-5.9%)
D2	70	66	-4(-5.7%)	64	-6(-8.6%)	64	-6(-8.6%)
D3	65	62	-3(-4.6%)	61	-4(-6.2%)	61	-4(-6.2%)
D4	66	64	-2(-3.0%)	63	-3(-4.5%)	63	-3(-4.5%)
D5	66	63	-3(-4.5%)	62	-4(-6.1%)	62	-4(-6.1%)

Table 4.45. Baseline and projected days to anthesis under RCP 8.5

Anthesis							
Date of planting	2019	RCP 8.5					
		2030		2050		2080	
		Simulated	Days (Error %)	Simulated	Days (Error %)	Simulated	Days (Error %)
D1	68	65	-3(-4.4%)	64	-4(-5.9%)	66	-2(-2.9%)
D2	70	66	-4(-5.7%)	65	-5(-7.1%)	63	-7(-10.0%)
D3	65	62	-3(-4.6%)	61	-4(-6.2%)	62	-3(-4.6%)
D4	66	64	-2(-3.0%)	63	-3(-4.5%)	62	-4(-6.1%)
D5	66	63	-3(-4.5%)	61	-5(-7.6%)	60	-6(-9.1%)

4.10.2.1. RCP 4.5 scenario

Baseline and projected duration for anthesis were compared and presented in Table 4.44. The result showed that in the baseline year 2019, duration for anthesis varied from 65 (D3) to 70 (D2) days in Jyothi. Days taken for anthesis simulated during projected period 2030 under RCP 4.5 ranges from 62 (D3) to 66 days (D2). During projected period 2050, under RCP 4.5, days to anthesis ranges from 61 (D3) to 64 days

(D1 and D2). Whereas in the projected period 2080 under RCP 4.5 Duration for anthesis ranges from 61 (D3) to 64 days (D1 and D2).

4.10.2.2. RCP 8.5 scenario

The result showed that during projected period 2030, under RCP 8.5, days to anthesis ranges from 62 (D3) to 66 days (D2). Days taken for anthesis simulated during projected period 2050 under RCP 8.5 ranges from 61 (D3 and D5) to 65 days (D2). Whereas in the projected period 2080 under RCP 8.5 Duration for anthesis ranges from 60 (D5) to 66 days (D1). Baseline and projected duration for anthesis under RCP 8.5 were compared and presented in Table 4.45.

4.10.3. Days to physiological maturity

The days to physiological maturity for base line period (2019) and projected periods 2030s, 2050s and 2080s under RCP 4.5 and RCP 8.5 scenarios for rice variety Jyothi was presented below.

4.10.3.1. RCP 4.5 scenario

A comparison between baseline and projected duration for physiological maturity are presented in Table 4.46. The result showed that in the baseline year 2019, duration for physiological maturity varied from 101 (D3) to 104 (D2) days in Jyothi. Days taken for physiological maturity simulated during projected period 2030 under RCP 4.5 ranges from 97 (D1, D3 and D5) to 98 days (D2 and D4). During projected period 2050, under RCP 4.5, days to physiological maturity ranges from 95 (D3 and D4) to 97 days (D1 and D2). Whereas in the projected period 2080 under RCP 4.5 Duration for panicle initiation ranges from 95 (D3) to 98 days (D5).

4.10.3.2. RCP 8.5 scenario

During projected period 2030, under RCP 8.5, days to physiological maturity ranges from 97 (D5) to 99 days (D2). Days taken for physiological maturity simulated during projected period 2050 under RCP 8.5 ranges from 95 (D3 and D4) to 97 days (D1 and D2). Whereas in the projected period 2080 under RCP 8.5, duration for physiological maturity ranges from 93 (D2) to 99 days (D1).

Table 4.46. Baseline and projected days to physiological maturity under RCP 4.5

Physiological maturity							
Date of planting	2019	RCP 4.5					
		2030		2050		2080	
		Simulated	Days (Error %)	Simulated	Days (Error %)	Simulated	Days (Error %)
D1	103	97	-6(-5.8%)	97	-6(-5.8%)	97	-6(-5.8%)
D2	104	98	-6(-5.8%)	97	-7(-6.7%)	96	-8(-7.7%)
D3	101	97	-4(-4.0%)	95	-6(-5.9%)	95	-6(-5.9%)
D4	103	98	-5(-4.9%)	95	-8(-7.8%)	96	-7(-6.8%)
D5	103	97	-6(-5.8%)	96	-7(-6.8%)	98	-5(-4.9%)

Table 4.47. Baseline and projected days to physiological maturity under RCP 8.5

Physiological maturity							
Date of planting	2019	RCP 8.5					
		2030		2050		2080	
		Simulated	Days (Error %)	Simulated	Days (Error %)	Simulated	Days (Error %)
D1	103	98	-5(-4.9%)	97	-6(-5.8%)	99	-4(-3.9%)
D2	104	99	-5(-4.8%)	97	-7(-6.7%)	93	-11(-10.6%)
D3	101	98	-3(-3.0%)	95	-6(-5.9%)	95	-6(-5.9%)
D4	103	98	-5(-4.9%)	95	-8(-7.8%)	94	-9(-8.7%)
D5	103	97	-6(-5.8%	96	-7(-6.8%)	95	-8(-7.8%)

4.10.4. Impact on grain yield

Impact of climate change on grain yield under baseline period (2019) and projected periods 2030s, 2050s and 2080s under RCP 4.5 and RCP 8.5 scenarios for selected rice variety Jyothi are presented in Table 4.48 and 4.49 respectively.

4.10.4.1. RCP 4.5 scenario

In variety Jyothi, grain yield in baseline period varied from 5340 (D1) to 6231 kg ha^{-1} (D2) for different planting dates. The grain yield simulated for projected period 2030 under RCP 4.5 scenario ranges from 3558 (D1) to 6160 kg ha^{-1} (D3). While, in the projected year 2050 grain yield ranges from 3299 (D1) to 5741 kg ha^{-1} (D3). During projected period 2080 under RCP 4.5, grain yield ranges between 3079 (D4) to 5570 kg ha^{-1} (D3).

4.10.4.2. RCP 8.5 scenario

The grain yield simulated during projected period 2030 under RCP 8.5 ranges between 3429 (D1) to 6340 kg ha^{-1} (D3). Grain yield simulated during projected period 2050 under RCP 8.5 ranges from 3260 (D1) to 5706 kg ha^{-1} (D3). Whereas, in the projected period 2080 under RCP 8.5, grain yield ranges from 3097 (D2) to 5601 kg ha^{-1} (D1).

Table 4.48. Baseline and projected grain yield under RCP 4.5

Grain yield (kg ha^{-1})							
Date of planting	2019	RCP 4.5					
		2030		2050		2080	
		Simulated	Yield (Error %)	Simulated	Yield (Error %)	Simulated	Yield (Error %)
D1	5932	3558	-40.0	3299	-44.4	3337	-43.7
D2	6231	5525	-11.3	5046	-19.0	3986	-36.0
D3	5809	6160	6.0	5741	-1.2	5570	-4.1
D4	5919	4412	-25.5	3709	-37.3	3079	-48.0
D5	5340	5445	2.0	4908	-8.1	3844	-28.0

Table 4.49. Baseline and projected grain yield under RCP 8.5

Grain yield (kg ha^{-1})							
Date of planting	2019	RCP 8.5					
		2030		2050		2080	
		Simulated	Yield (Error %)	Simulated	Yield (Error %)	Simulated	Yield (Error %)
D1	5932	3429	-42.2	3260	-45.0	3196	-46.1
D2	6231	5529	-11.3	4634	-25.6	3097	-50.3
D3	5809	6340	9.1	5706	-1.8	5601	-3.6
D4	5919	4352	-26.5	3509	-40.7	3135	-47.0
D5	5340	5492	2.8	4807	-10.0	3596	-32.7

Discussion

5. DISCUSSION

The study was conducted to assess the impact of climate change on production and nutritional qualities of rice in variety Jyothi.

5.1. EFFECT OF WEATHER ON GROWTH AND DEVELOPMENT OF RICE

5.1.1. Grain yield

Grain yield was significantly affected by planting dates in both the growing conditions in variety Jyothi. In both conditions, October 1st planting gave higher yield compared to other dates of planting. Number of panicles per unit area, number of spikelets per panicle and number of filled grains per panicle contributed to the high yield. The variation in grain yield is due to the negative effect of minimum temperature on grain yield. The results were in good agreement with Baker *et al*. (1992) and Morita *et al*. (2004). Baker *et al*. (1992) observed a yield reduction of about 7–8% in rice for each 1 °C increase in night time minimum temperature from 21 to 27 °C. Morita *et al*. (2004) reported that in rice, high minimum temperature (22/34 °C, day/night) were more harmful to grain weight compared to high day temperatures (34/22 °C) and control conditions (22/22 °C) at optimum temperature.

Table 5.1. Correlation coefficient between minimum temperature and grain yield from 50% flowering to physiological maturity

Grain yield	Tmin
O	-0.577*
GH	-0.552*

5.1.2. Thousand grain weight

In variety Jyothi, maximum temperature and soil temperature influenced thousand grain weight negatively under both the growing conditions. These results were supported by the study of Yi-Chien Wua *et al.* (2016), Nyang'Au *et al*. (2014), Long (1991) and Makino *et al*. (1994).

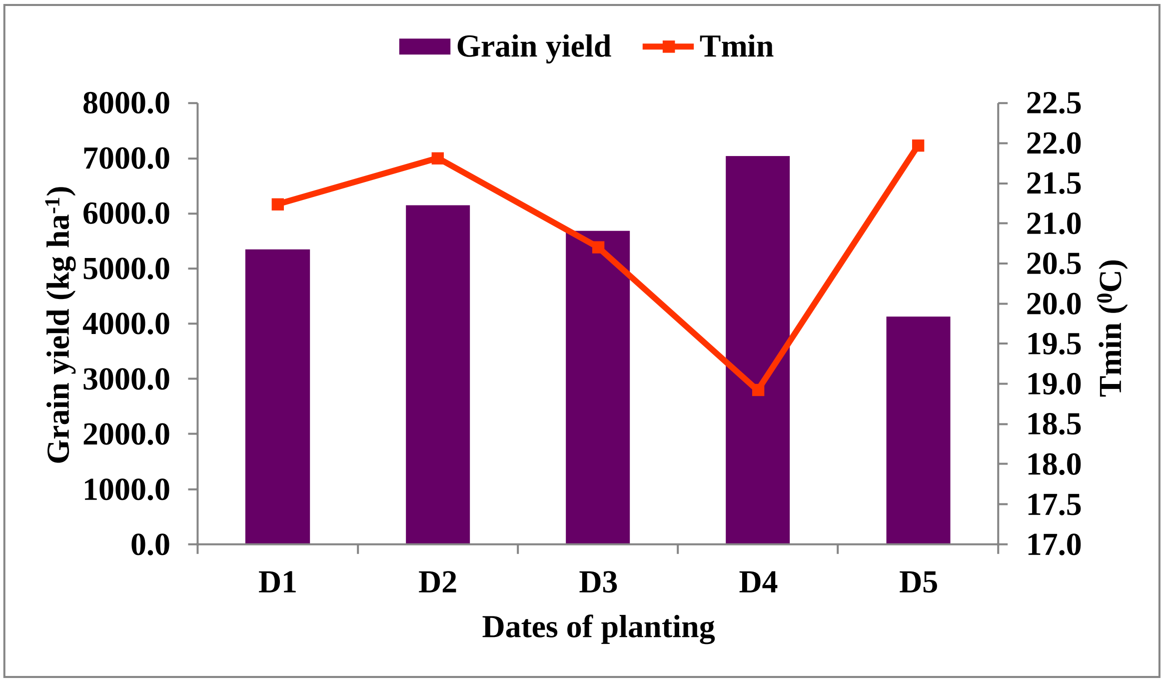


Fig. 5.1. (a) Effect of minimum temperature on grain yield in Jyothi under open condition from 50% flowering to physiological maturity

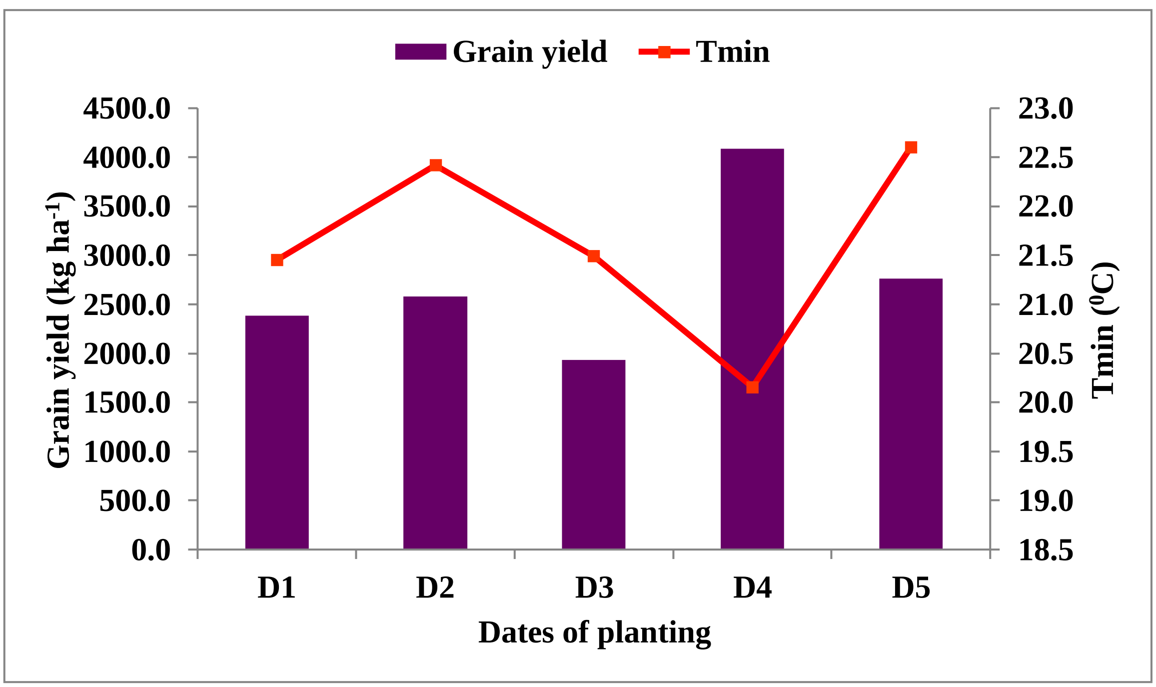


Fig. 5.1. (b) Effect of minimum temperature on grain yield in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

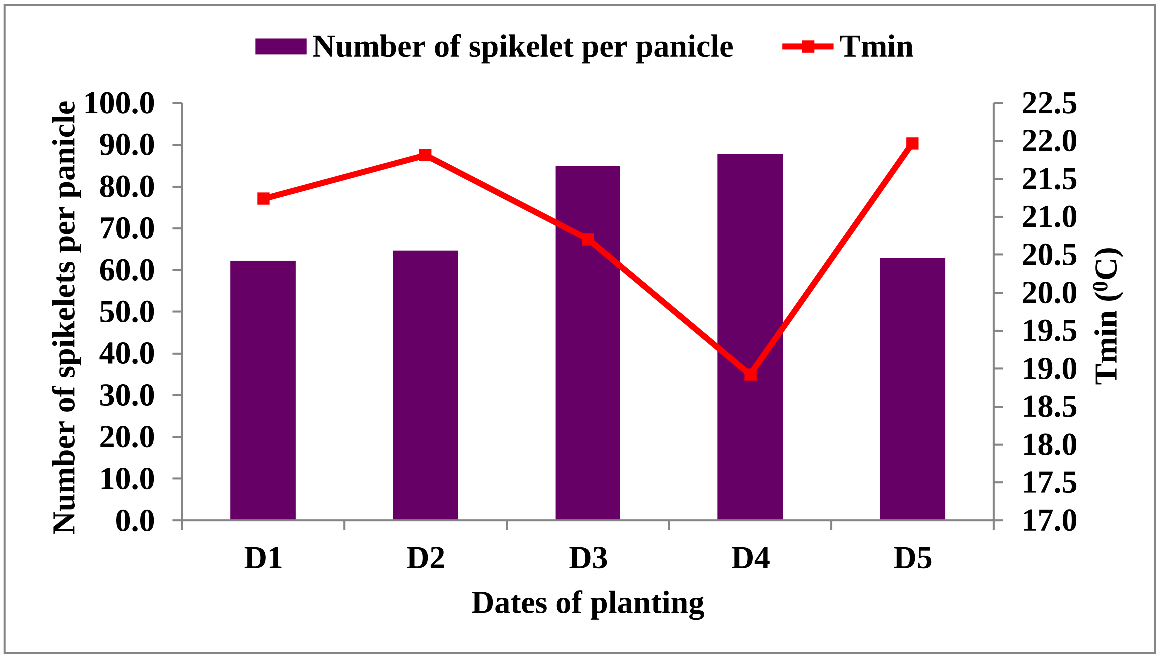


Fig. 5.2. (a) Effect of minimum temperature on number of spikelets per panicle in Jyothi under open condition from 50% flowering to physiological maturity

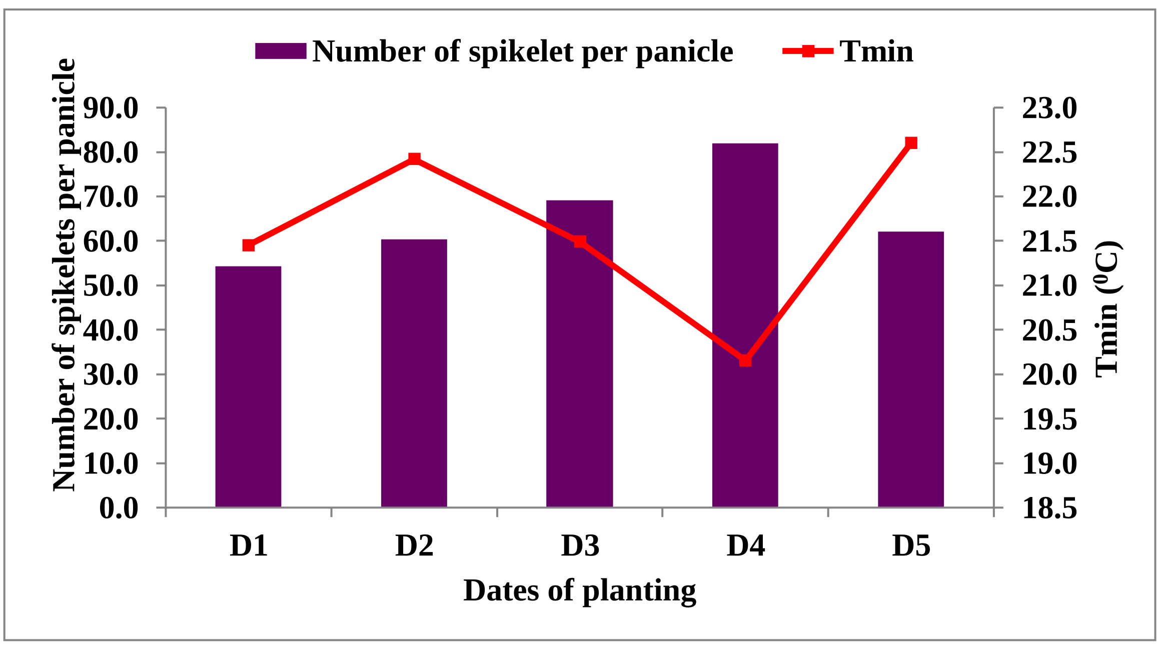


Fig. 5.2. (b) Effect of minimum temperature on number of spikelets per panicle in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

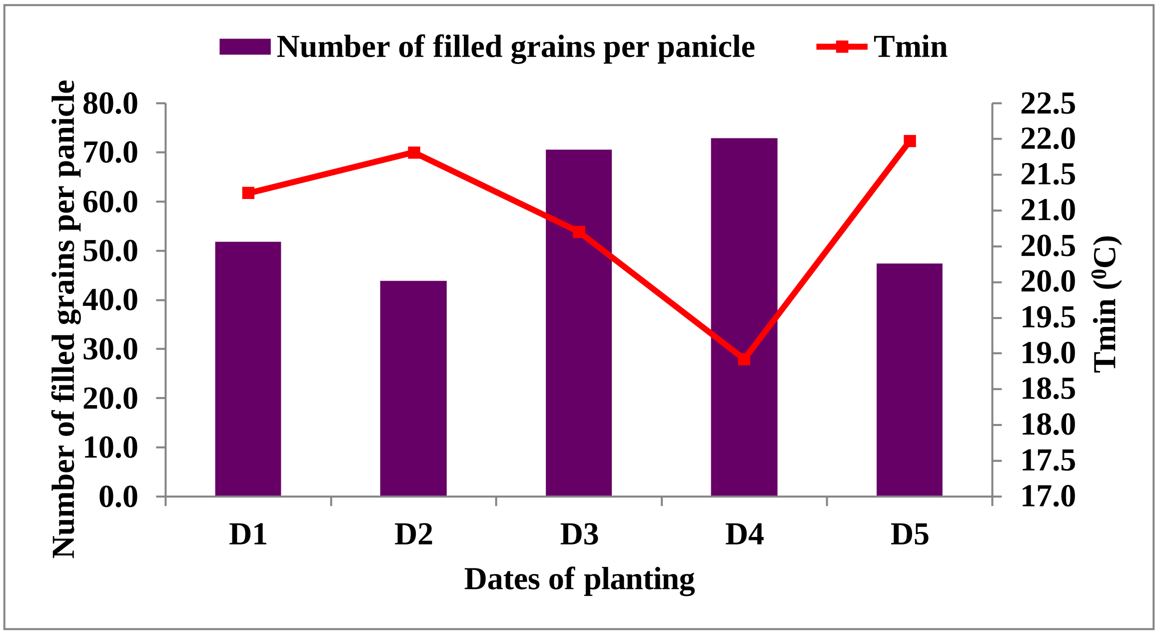


Fig. 5.3. (a) Effect of minimum temperature on number of filled grains per panicle in Jyothi under open condition from 50% flowering to physiological maturity

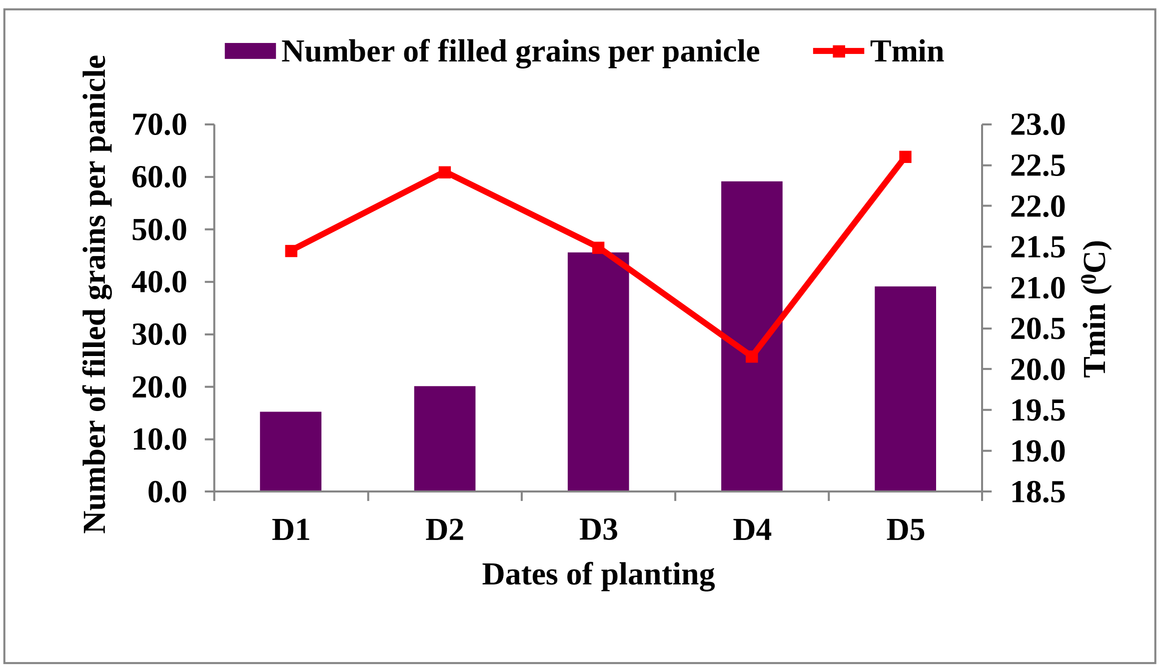


Fig. 5.3. (b) Effect of minimum temperature on number of filled grains per panicle in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

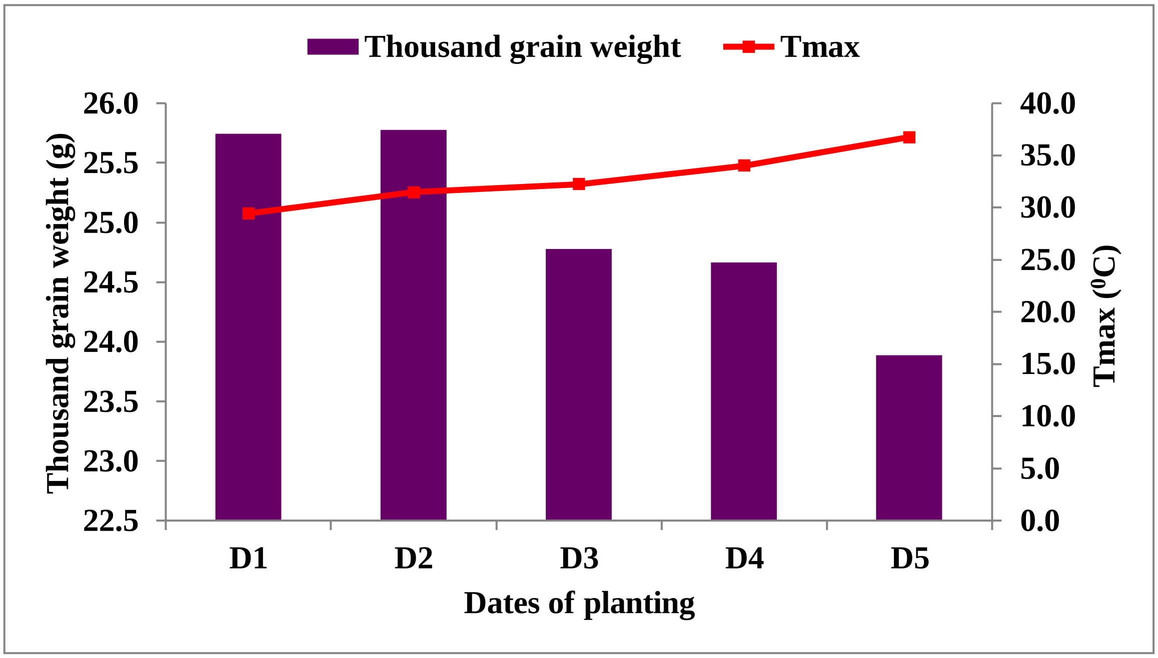


Fig. 5.4. (a) Effect of maximum temperature on thousand grain weight in Jyothi under open condition from 50% flowering to physiological maturity

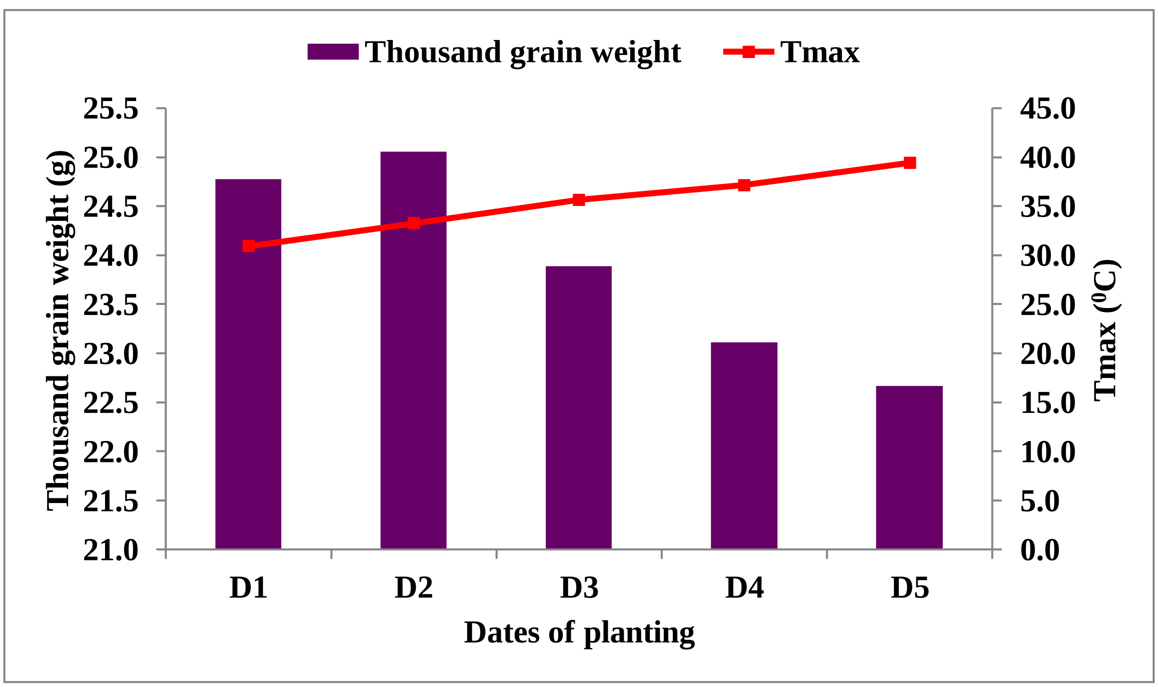


Fig. 5.4. (b) Effect of maximum temperature on thousand grain weight in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

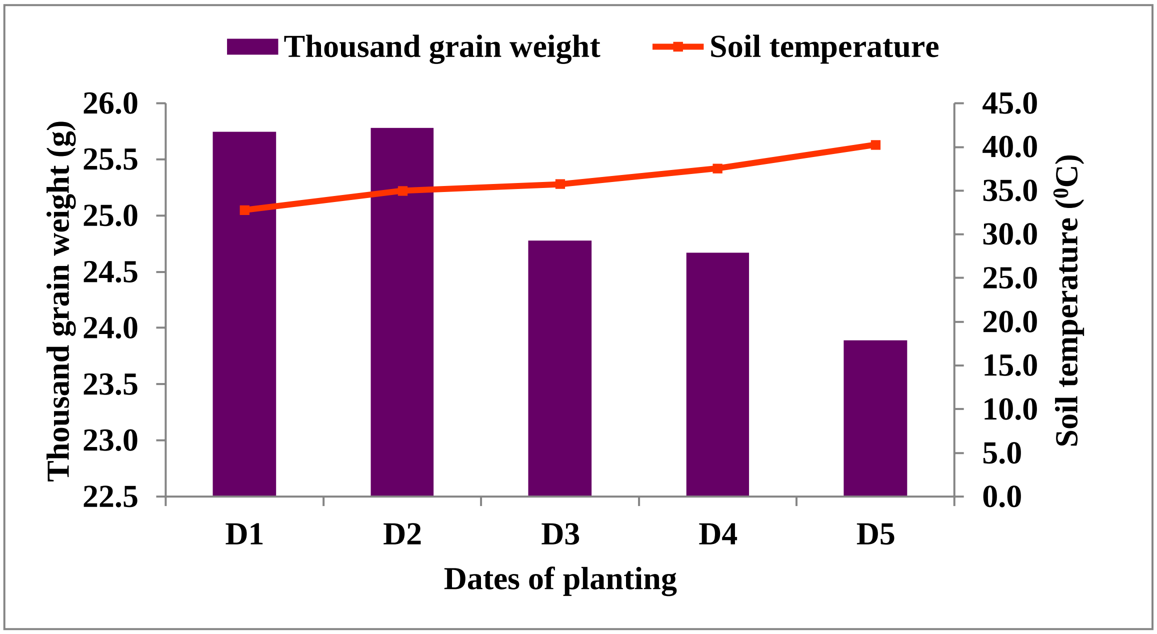


Fig. 5.5. (a) Effect of soil temperature on thousand grain weight in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

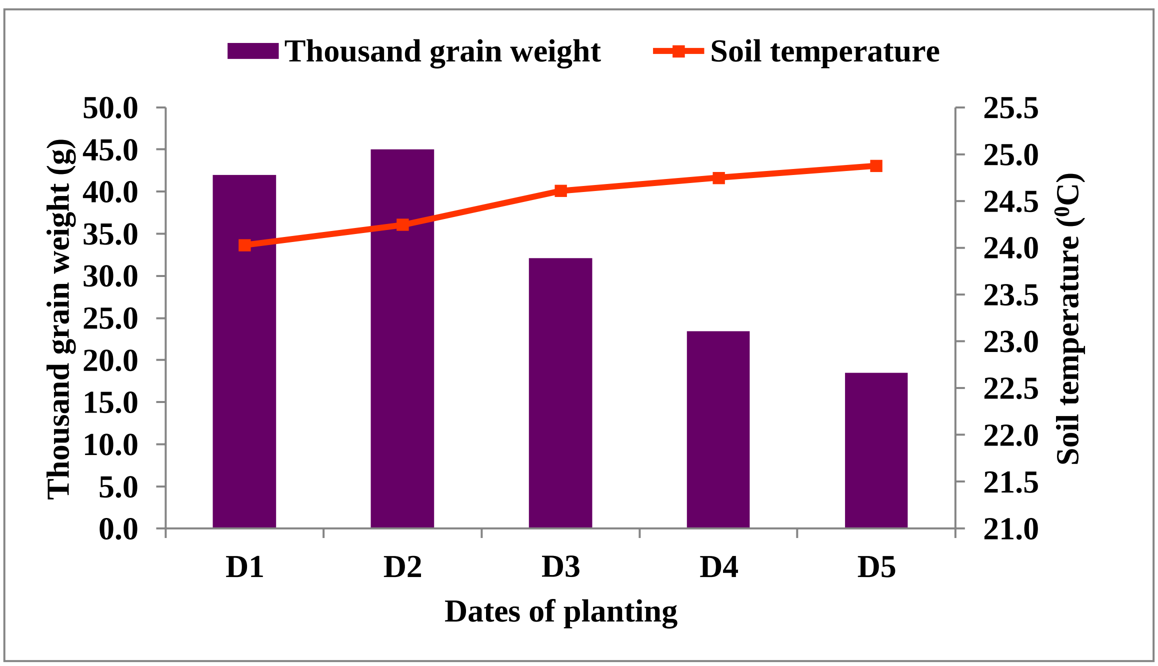


Fig. 5.5. (b) Effect of soil temperature on thousand grain weight in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

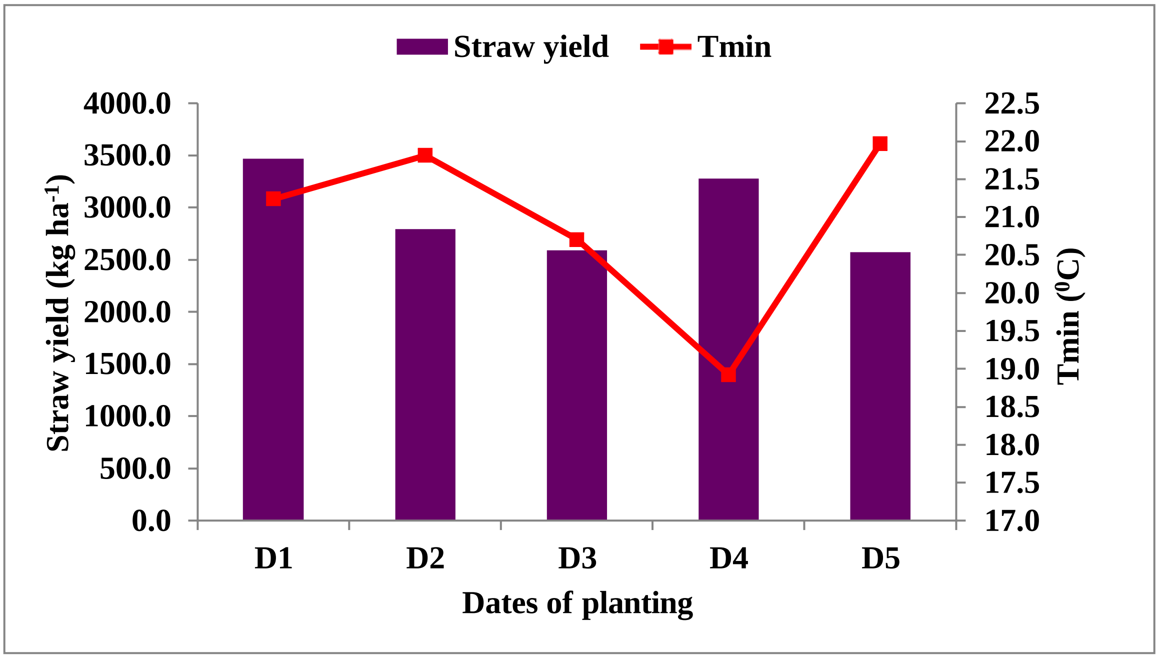


Fig. 5.6. (a) Effect of minimum temperature on straw yield in Jyothi under open condition from 50% flowering to physiological maturity

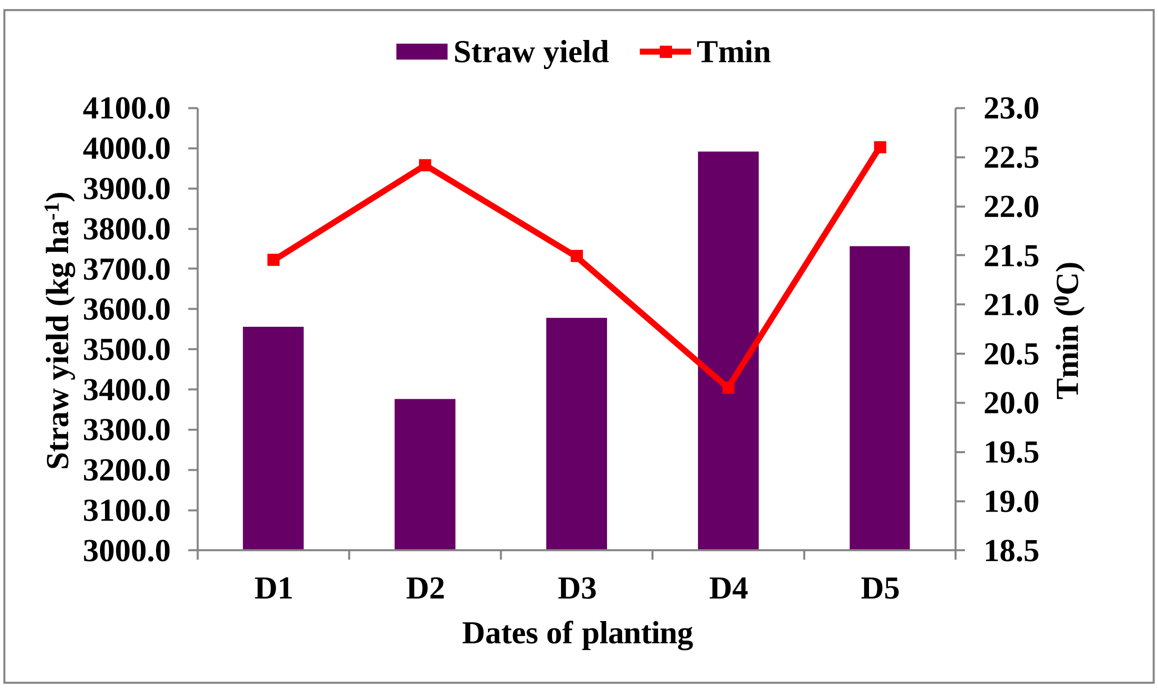


Fig. 5.6. (b) Effect of minimum temperature on straw yield in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

Yi-Chien Wua *et al*. (2016) observed that when temperature of H15 was raised 1 °C above the thresholds, grain weight decreased by about 2–6%. Perfect grain ratio and chalky grain ratio decreased and increased, respectively, when the temperature of H15 was raised above the thresholds. High (daytime/nighttime temperatures were 32.8/31 °C) temperature promote respiration (Long, 1991) and limit photosynthesis (Makino *et al*., 1994), which would lead to decreased sink, and cause a lower thousand grains weight. Nyang'Au *et al*. (2014) evaluated the effects of change in weather conditions on the yields of Basmati 370 and IR 2793-80-1 cultivated under System of Rice Intensification (SRI) in Mwea and Western Kenya irrigation schemes through sensitivity analysis using the CERES-Rice model v 4.5 of the DSSAT modeling system and they observed that an increase of both maximum and minimum temperatures affects Basmati 370 and IR 2793-80-1 grain yield under SRI.

5.1.3. Straw yield

Date of planting had significant influence on straw yield in Jyothi under open condition and climate controlled greenhouse. October 30th planted crop received low minimum temperature compared to other planting and this reduction in minimum temperature increased straw yield in variety Jyothi under both growing conditions. This was in conformity with Mathauda *et al.* (2000). He reported that an average temperature rise of 1°C is expected around the year 2020 and this will reduce the crop duration by three days over the normal and it will have negative effect on yield contributing characters of the crop. This will lead to reduction in biomass, maximum LAI and straw yield in the tune of 3.6, 2.4 and 2.2 per cent respectively.

Table 5.2. Correlation coefficient between minimum temperature and straw yield from 50% flowering to physiological maturity

Straw yield	Tmin
O	-0.669**
GH	-0.781**

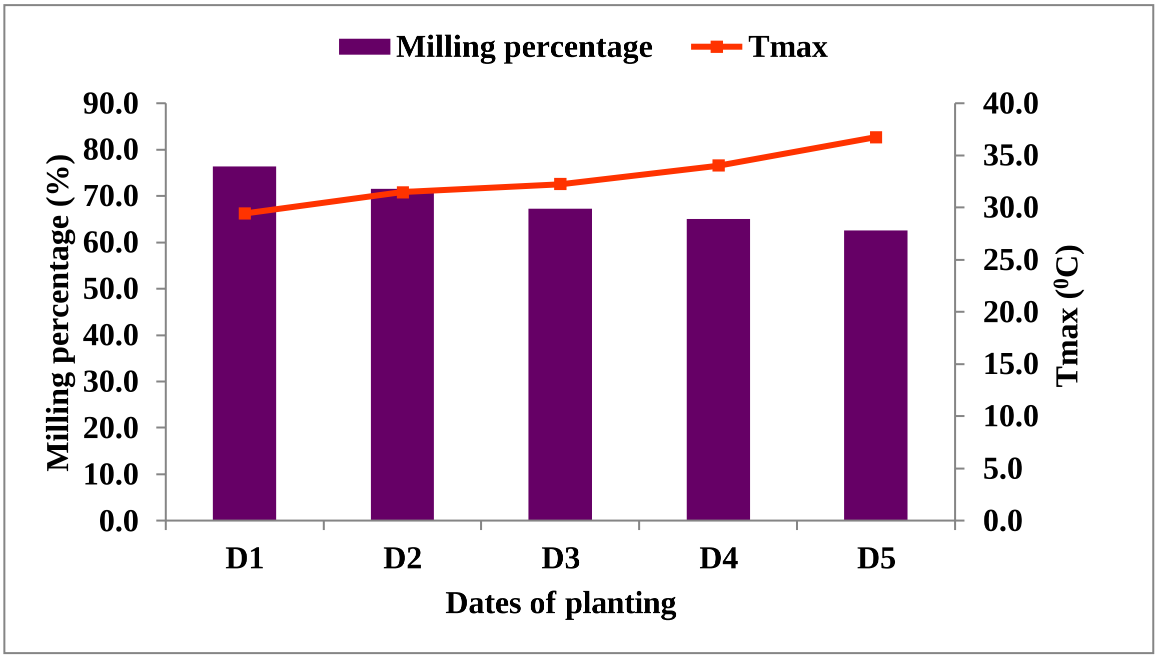


Fig. 5.7. (a) Effect of maximum temperature on milling percentage in Jyothi under open condition from 50% flowering to physiological maturity

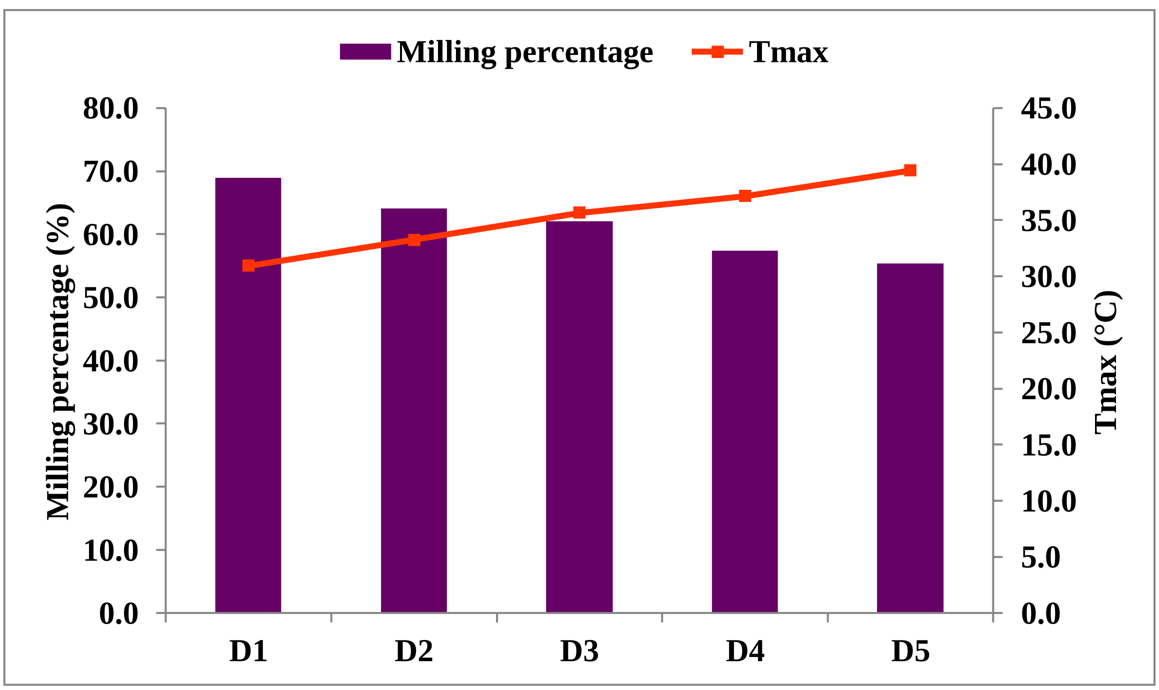


Fig. 5.7. (b) Effect of maximum temperature on milling percentage in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

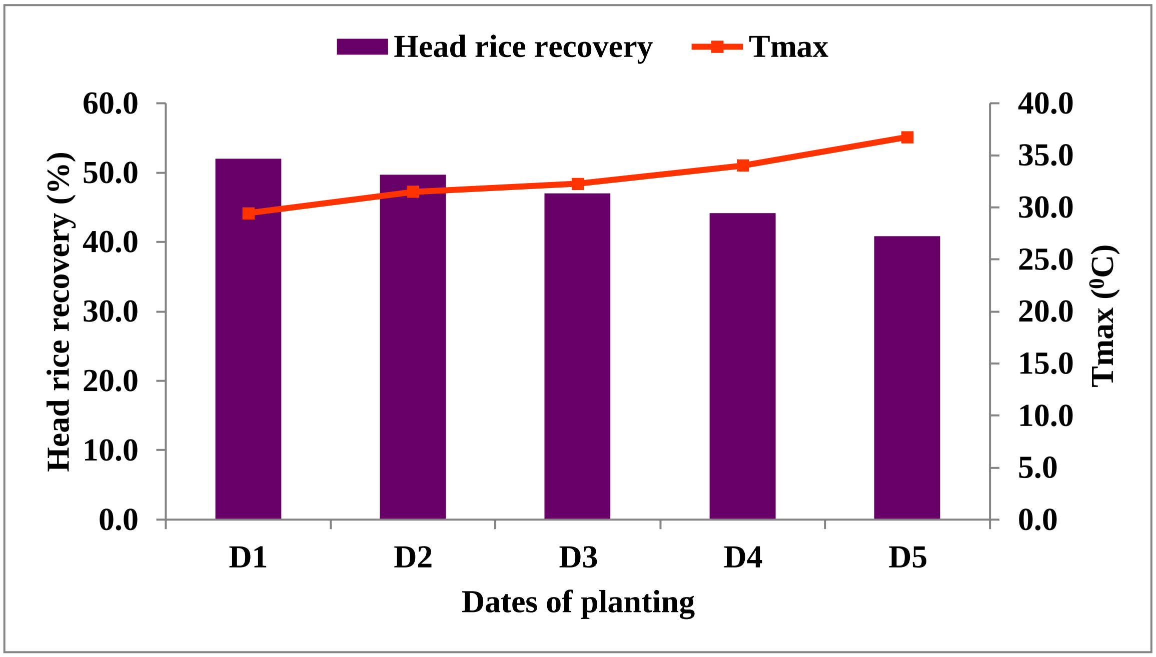


Fig. 5.8. (a) Effect of maximum temperature on head rice recovery in Jyothi under open condition from 50% flowering to physiological maturity

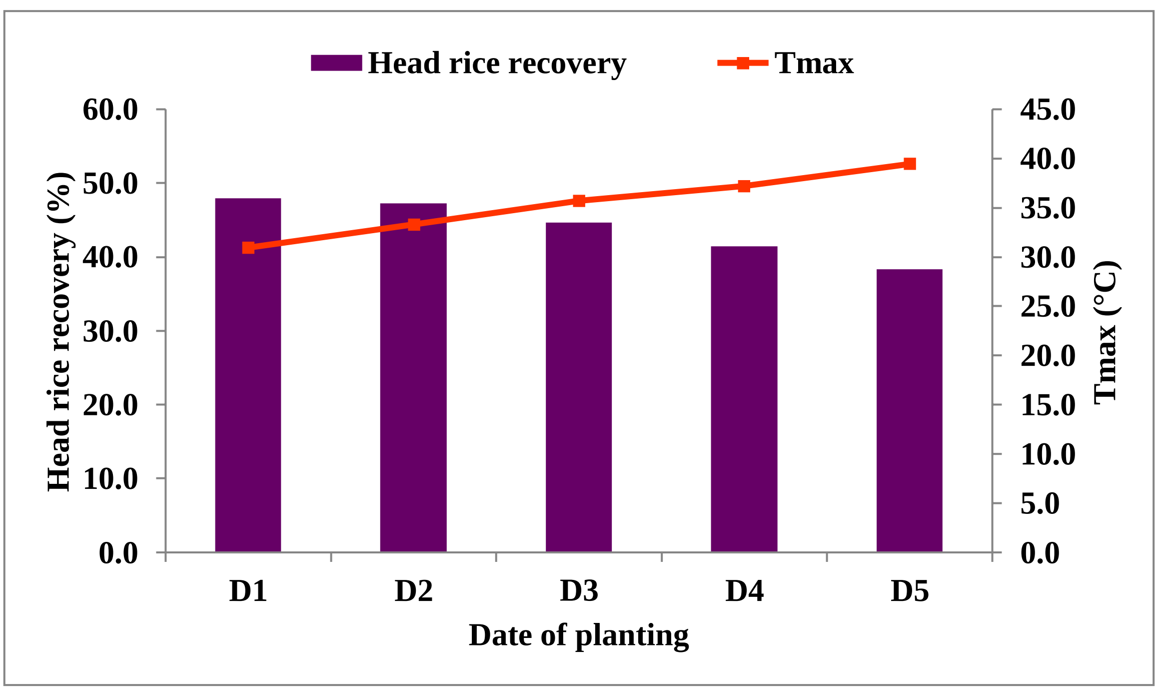


Fig. 5.8. (b) Effect of maximum temperature on head rice recovery in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

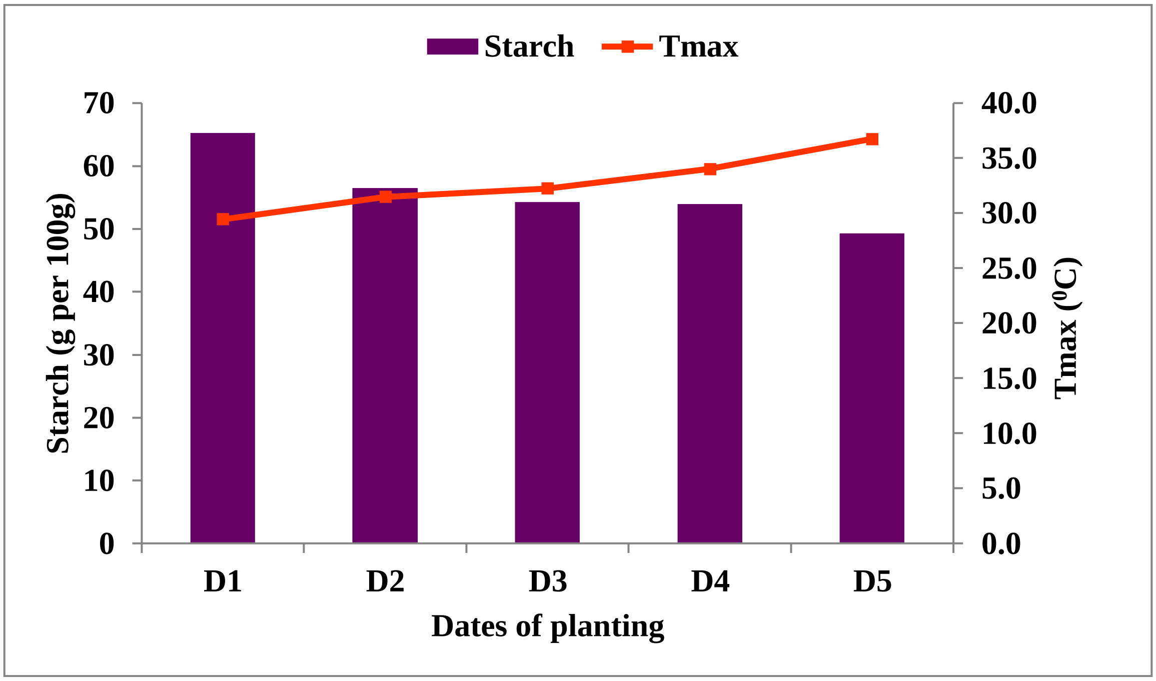


Fig. 5.9. (a) Effect of maximum temperature on starch content in Jyothi under open condition from 50% flowering to physiological maturity

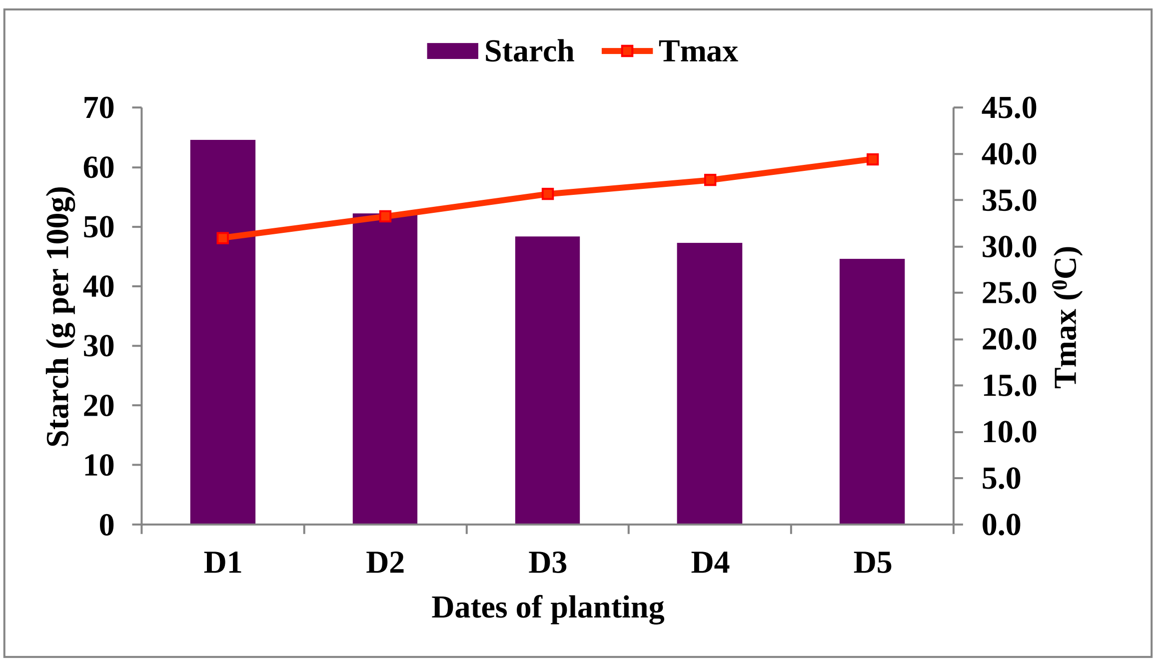


Fig. 5.9. (b) Effect of maximum temperature on starch content in Jyothi under climate controlled greenhouse from 50% flowering to physiological maturity

5.1.4. Starch content

Rice variety Jyothi under both growing conditions is significantly affected by maximum temperature. Early transplanted crop recorded high starch content compared to other plantings. Under both the growing conditions, maximum temperature showed a negative influence on starch content. The results were supported by the study of Ito *et al*. (2009), Umemoto and Terashima (2002), Jin *et al*. (2005) and Ahmed *et al*. (2014). Extreme high day temperatures during the grain-filling period may reduce starch synthesis in the grains especially under N-deficient conditions (Ito *et al*., 2009). In rice under high-temperature stress, high chalkiness and poor edible quality are closely related with starch synthesis in endosperm during grain filling (Umemoto and Terashima (2002); Jin *et al*. (2005)). Ahmed *et al*. (2014) reported that high temperature treatment during grain filling had a considerable influence on starch component in hulled rice endosperm. Starch content per milligram of hulled rice at maturity on an equal dry weight basis at 22 and 32 ˚C was 16.5 (77.2%) and 14.9 (74.1%) respectively – 3.1% lower at 32 ˚C than that at 22 ˚C. Enzymes in the starch biosynthetic pathway soluble starch synthase and starch branching enzyme (notably SSs and SBEs) are affected by elevated growing temperature, and this may contribute to the observed alterations in starch composition in basmati rice endosperm, particularly since these enzymes have been shown to operate in heteromeric protein complexes.

Table 5.3. Correlation coefficient between maximum temperature and starch content from 50% flowering to physiological maturity

Starch content	Tmax
O	-0.925**
GH	-0.927**

5.1.5. Amylose content

Date of planting had significant influence on amylose content in Jyothi under open condition and climate controlled greenhouse. June 1st planted crop received low maximum temperature compared to other planting and this reduction in maximum temperature increased amylose content in variety Jyothi under both growing conditions. This was in conformity with Umemoto *et al*. (1995), Jiang *et al*. (2003) and Ahmed *et al*. (2014).

Umemoto *et al*. (1995) and Jiang *et al*. (2003) reported that rice plants grown under high temperature have low amylose content compared to those grown under low temperatures. Ahmed *et al*. (2014) reported that high temperature treatment during grain filling had a considerable influence on amylose content in hulled rice endosperm. Amylose content per milligram of hulled rice grain at maturity at 22 °C was 4.2 (25.1%) and 3.2 (21.7%) at 32˚C. Increasing the temperature significantly lowered the amylose content in hulled rice by 0.91 mg (28.1%).

High temperatures could change gene expressions for amylose and storage protein accumulation, and further affect taste quality (Lin *et al*., 2005; Lin *et al*., 2010; Yamakawa *et al*., 2007). Formation of a chalky appearance related to the expressions of small heat shock proteins (sHSP) and stress regulatory proteins during the grain filling stage (Lin *et al*., 2010; Yamakawa *et al*., 2007).

Ball *et al*. (1998) reported that the activity of Granule-Bound Starch Synthase (GBSS) is necessary to generate amylose. There is a constant decline in enzyme efficiency with increasing temperature. Plants grown under elevated temperature, showed marked reductions in measurable GBSS activity (Zhao *et al*., 2008). Amylose content is mainly affected by the activity of GBSS in rice endosperms at high temperature (Umemoto *et al.*, 1995: Hirano and Sano, 1998). Ahmed *et al*. (2014) reported that the activity of GBSS in endosperm at 32 °C was decreased compared to that at 22 °C.

Table 5.4. Correlation coefficient between maximum temperature and amylose content from 50% flowering to physiological maturity

Amylose content	Tmax
O	-0.928**
GH	-0.934**

5.2. CERES-RICE MODEL

Performance of the CERES-RICE model was tested and evaluated using the calibrated genetic coefficients for the variety Jyothi. The model could predict the yield and duration of phenophases more accurately. Root mean square value, d-stat index and R^2 value were used to evaluate the model performance. According to Willmot (1982) d-stat index should approach unity and RMSE should approach zero for good performance of the model. The validation of grain yield and phenology of variety Jyothi is discussed below.

5.2.1. Grain yield

Predicted grain yield was in good agreement with observed yield with an RMSE of 785.12 kg ha^{-1}, D-stat index of 0.59, MAPE of 11.92 and R^2 value of 0.43, indicating good performance of the model (Fig 5.10 (a)). Similar findings were reported by Vysakh *et al.* (2016) and he observed that, predicted grain yield was in agreement with observed yield (RMSE = 1186 kg ha^{-1}, d-stat index = 0.4). The Root Mean Square Error (RMSE), d-stat index, MAPE and R^2 value are given in Table 5.5.

Table 5.5. RMSE, d-Stat index, MAPE and R^2 value for Jyothi for grain yield

Variety	RMSE	d-stat	MAPE	R^2 value
Jyothi	785.12	0.59	11.92	0.56

5.2.2. Simulation of phenology

Good agreement was showed by observed and simulated phenology for variety Jyothi. The Root Mean Square Error (RMSE) and d-stat index for simulation of phenology are given in Table 5.6.

Table 5.6. RMSE, d-stat index, MAPE and R^2 value for Jyothi for days to attain different phenophases

Variable	RMSE	d-Stat	MAPE	R^2 value
Anthesis day	2.15	0.75	2.66	0.43
Panicle initiation day	2.19	0.61	6.61	0.11
Maturity day	6.05	0.41	6.03	0.69

5.2.2.1. Panicle initiation day

There was a good agreement between observed and simulated panicle initiation day (Fig 5.10 (b)) for Jyothi with an RMSE of 2.19, d-stat index of 0.61, MAPE of 6.61 and R^2 value of 0.11.

5.2.2.2. Anthesis day

Predicted anthesis day was in good agreement with observed anthesis day with an RMSE of 2.15, d-stat index of 0.75, MAPE of 2.66 and R^2 value of 0.11 indicating good performance of the model (Fig. 5.10 (c)). This was similar to the study conducted by Timisina *et al*. (1998) and he reported that predicted anthesis day was in good agreement with observed anthesis day (RMSE = 2.0 and d-stat index = 0.90).

5.2.2.3. Physiological maturity day

There was a good agreement between observed and simulated physiological maturity day (Fig 5.10 (d)) for Jyothi with an RMSE of 6.05, d-stat index of 0.41, MAPE of 6.03 and R^2 value of 0.69.

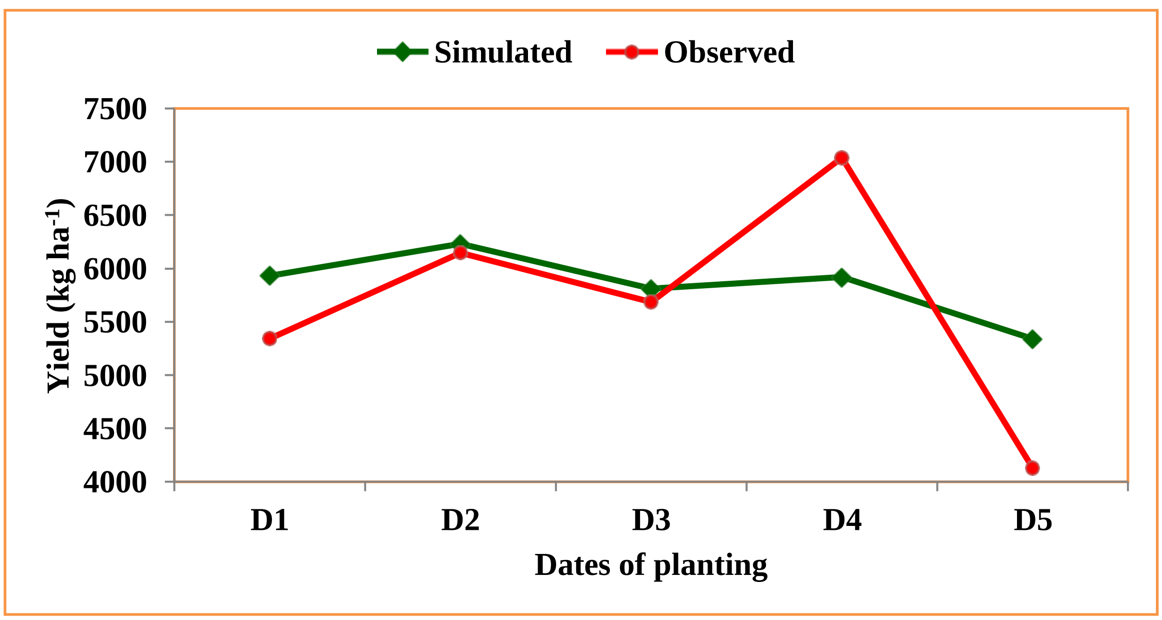


Fig. 5.10. (a) Comparison of observed and simulated yield in Jyothi

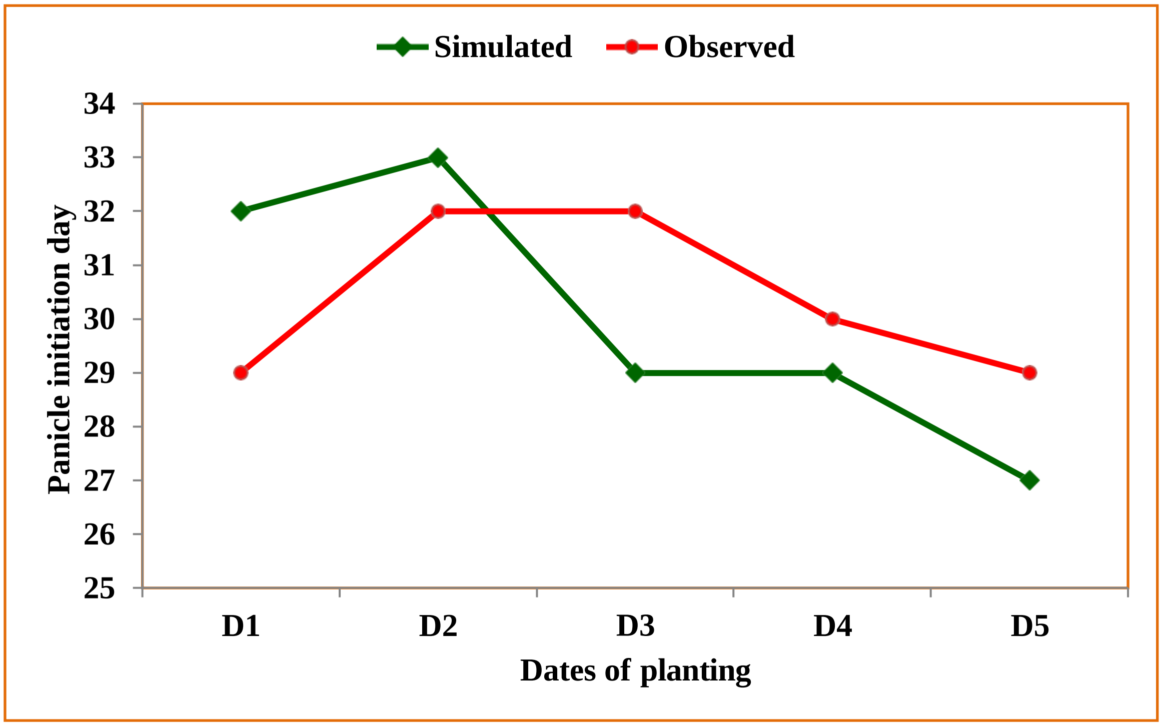


Fig. 5.10. (b) Comparison of observed and simulated panicle initiation day in Jyothi

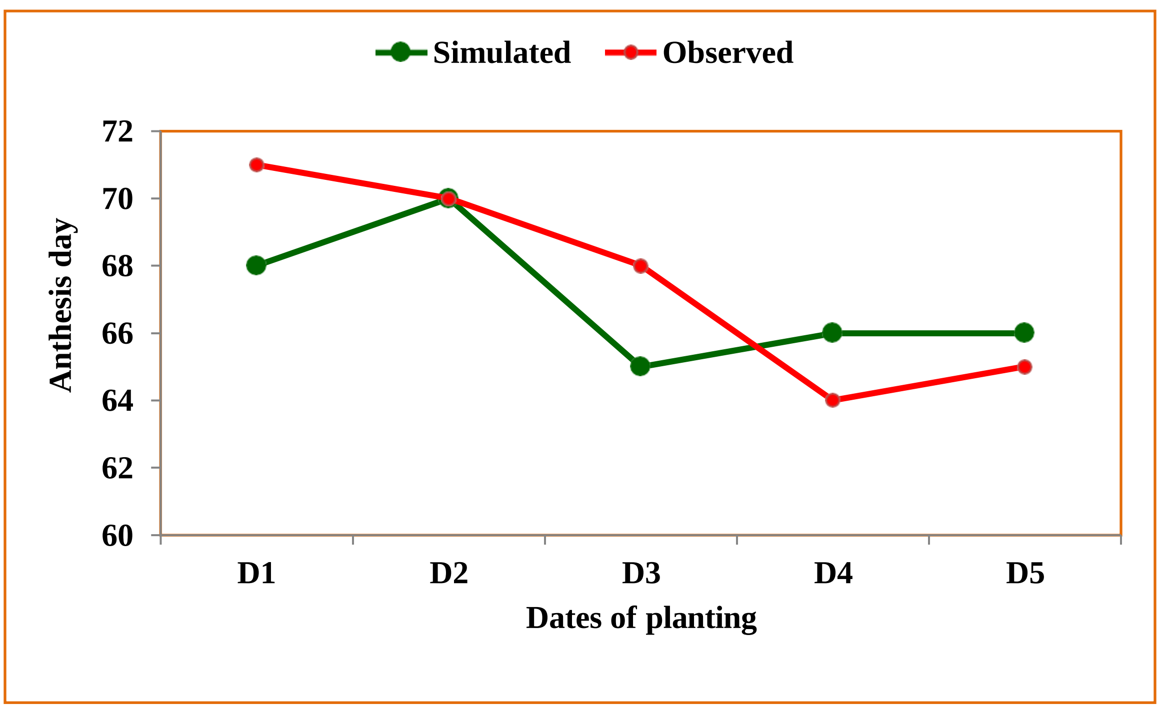


Fig. 5.10. (c) Comparison of observed and simulated anthesis day in Jyothi

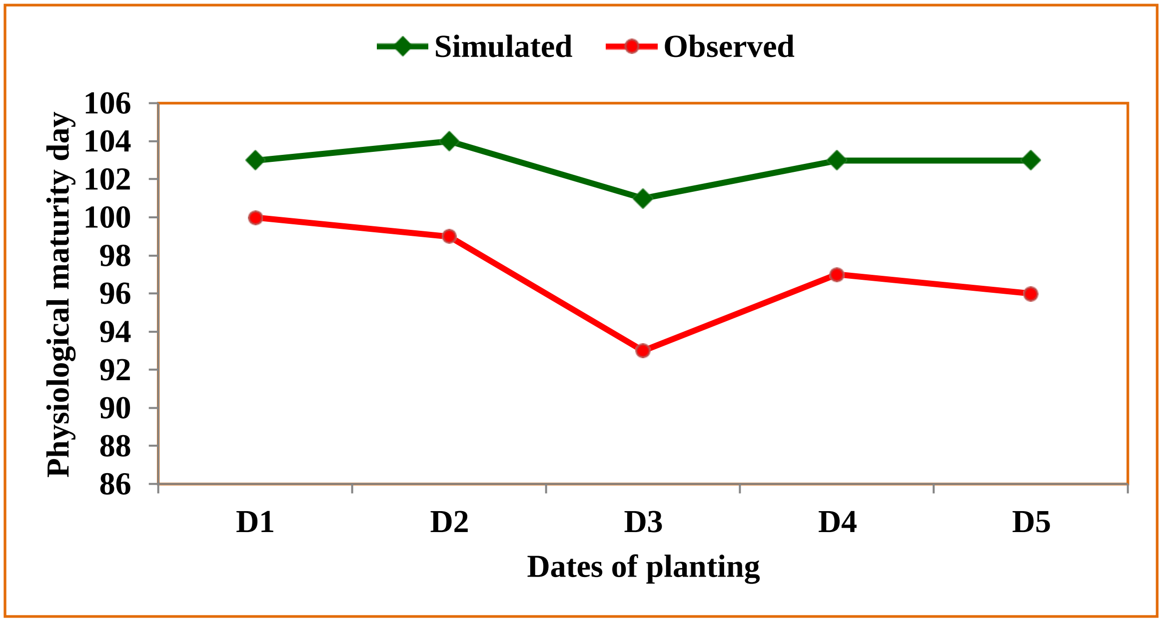


Fig. 5.10. (d) Comparison of observed and simulated maturity day in Jyothi

5.3. IMPACT OF CLIMATE CHANGE ON RICE PRODUCTION

Impacts of climate change on rice production in different dates of planting under two different climate change scenario were discussed in detail.

5.3.1. First date of planting

During first date of planting, projected grain yield for Jyothi showed a decreasing trend from 2030 to 2080 from the baseline (2019) under RCP 4.5 scenario. The grain yield decreased by 40, 44.3 and 43.7 percent in 2030, 2050 and 2080 respectively. This may be due to the cumulative effect of increased rainfall and increase in maximum temperature during anthesis period and increase in minimum temperature during three stages.

Projected grain yield for Jyothi showed a decreasing trend from 2030 to 2080 from the baseline (2019) during first date of planting under RCP 8.5 scenario. The grain yield decreased by 46.8, 50 and 51.8 percent in 2030, 2050 and 2080 respectively. This may be due to the effect of increased minimum temperature during all stages and increased maximum temperature during physiological maturity period. This was in good agreement with findings of Matsui *et al.* (2001), Zhao *et al.* (2010), Prasad *et al.* (2006) and Mohammed and Tarpley (2009).

Maximum temperatures inhibit dehiscence and germination of pollen grain (Matsui *et al*., 2001; Zhao *et al.*, 2010) and pollen production (Prasad *et al.*, 2006). High minimum temperatures would reduce the germination percentage of pollen grain and repress spikelet fertility (Mohammed and Tarpley, 2009). Both daily day/maximum and night/minimum temperatures play important roles in grain fertility.

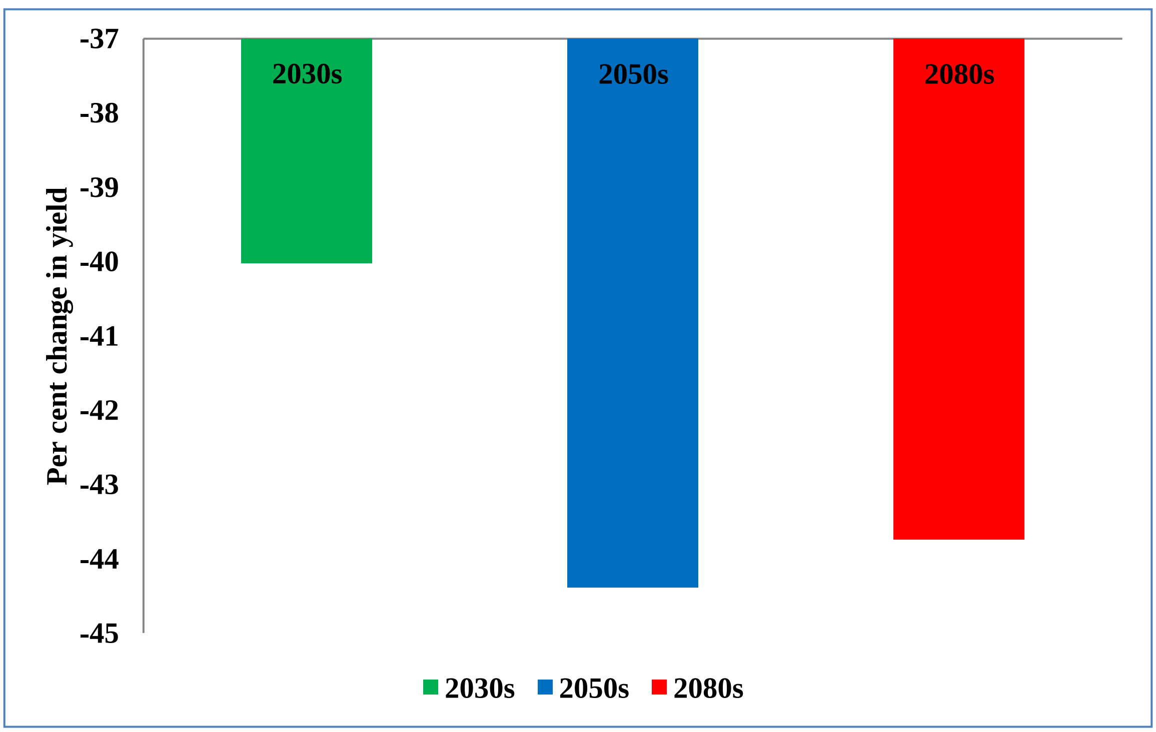


Fig. 5.11. (a) Per cent change in yield of Jyothi under RCP 4.5 scenario for first date of planting from the baseline period

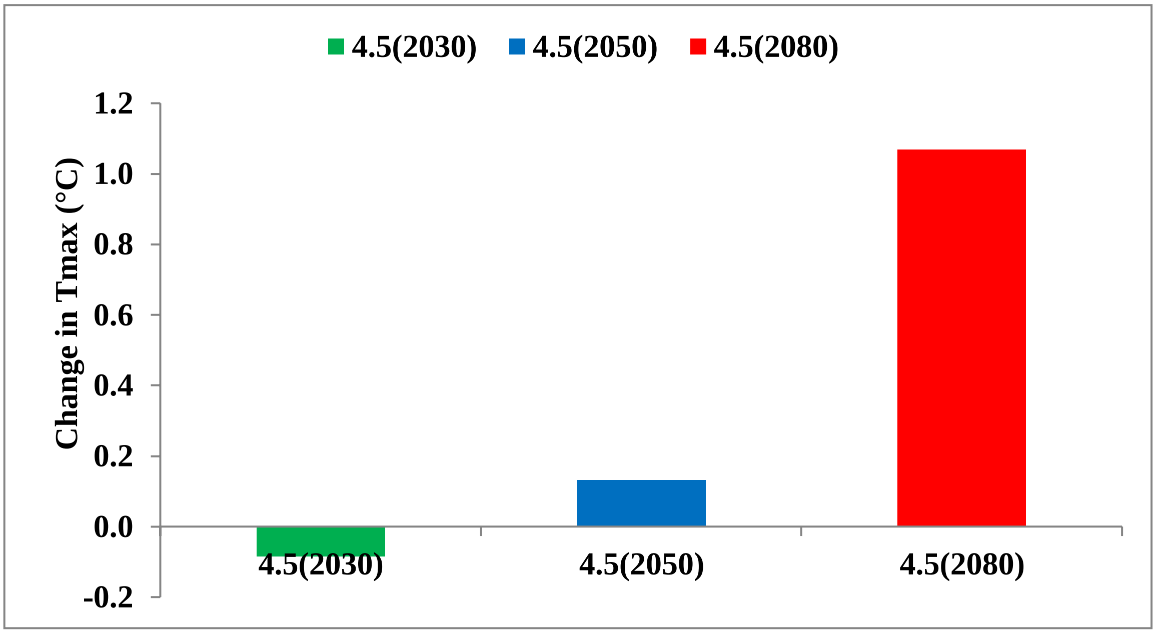


Fig. 5.11. (b) Change in maximum temperature during anthesis from baseline of Jyothi under RCP 4.5 for first date of planting

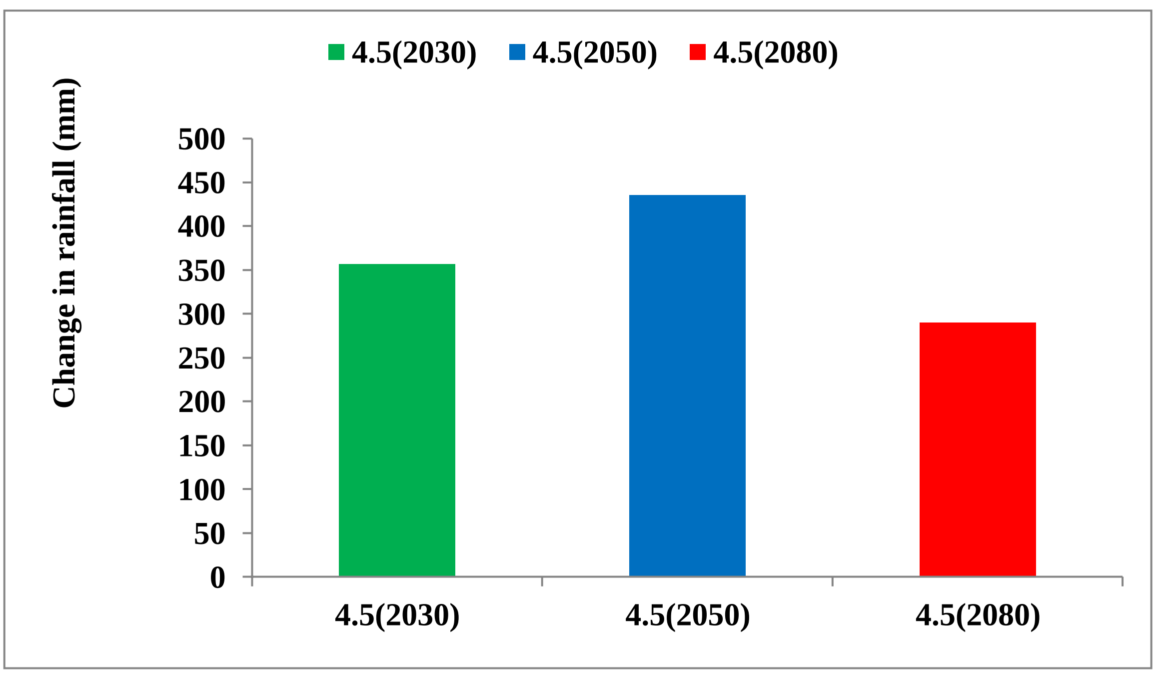


Fig. 5.11. (c) Change in rainfall from baseline during anthesis from baseline of Jyothi under RCP 4.5 for first date of planting

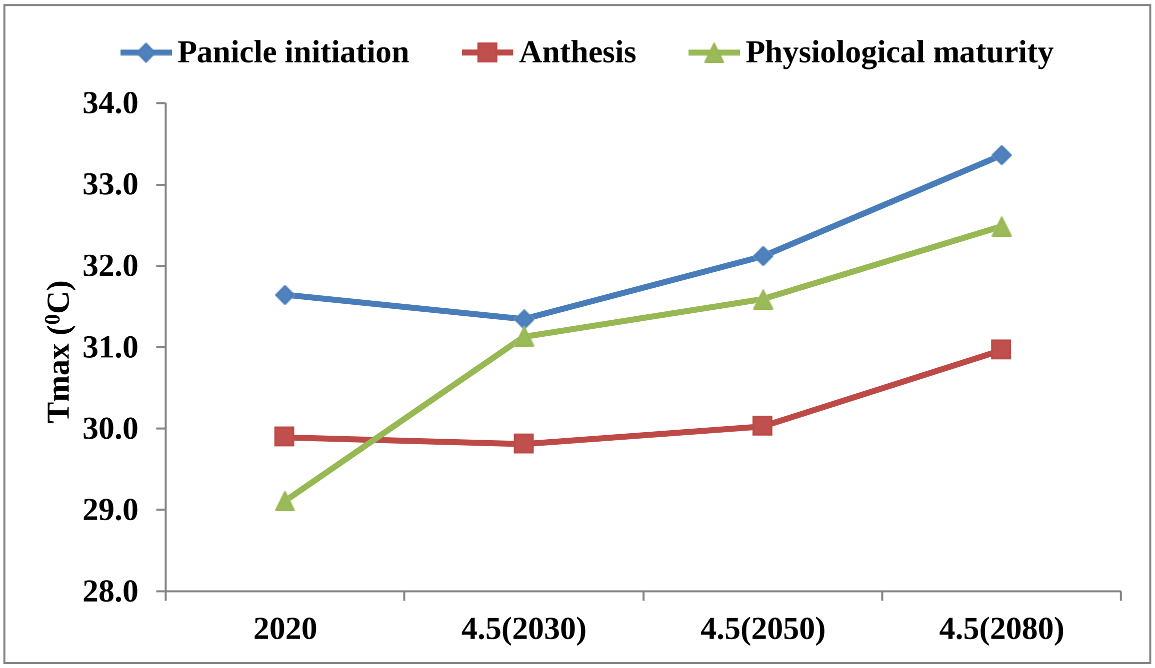


Fig. 5.11. (d) Maximum temperature in different phenophases of Jyothi under RCP 4.5 for first date of planting

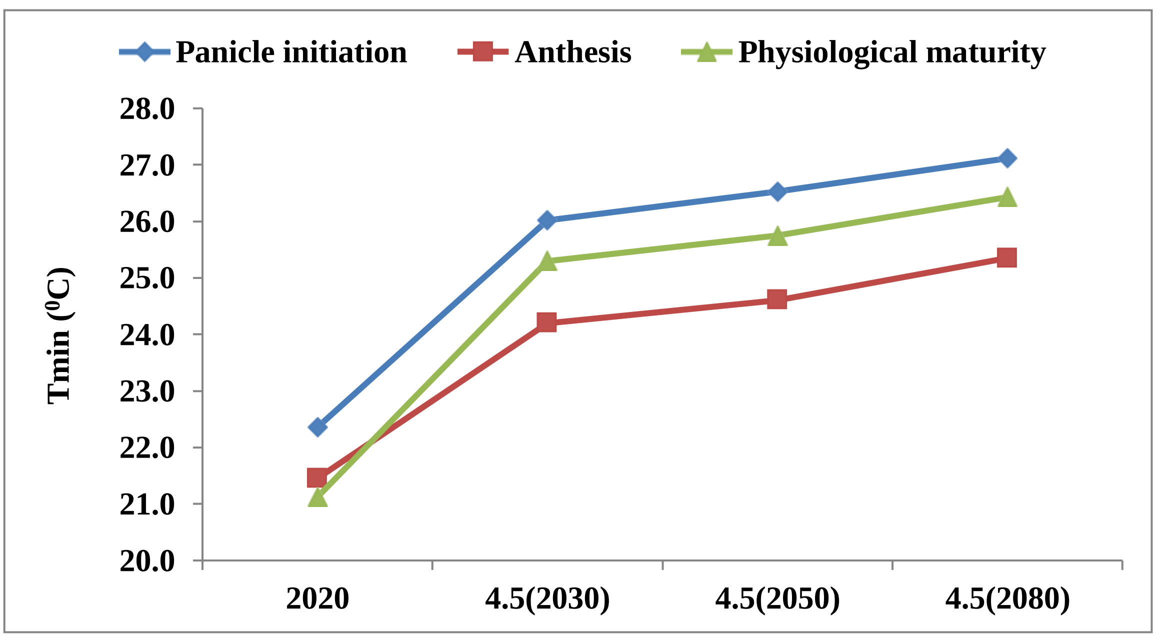


Fig. 5.11. (e) Minimum temperature in different phenophases of Jyothi under RCP 4.5 for first date of planting

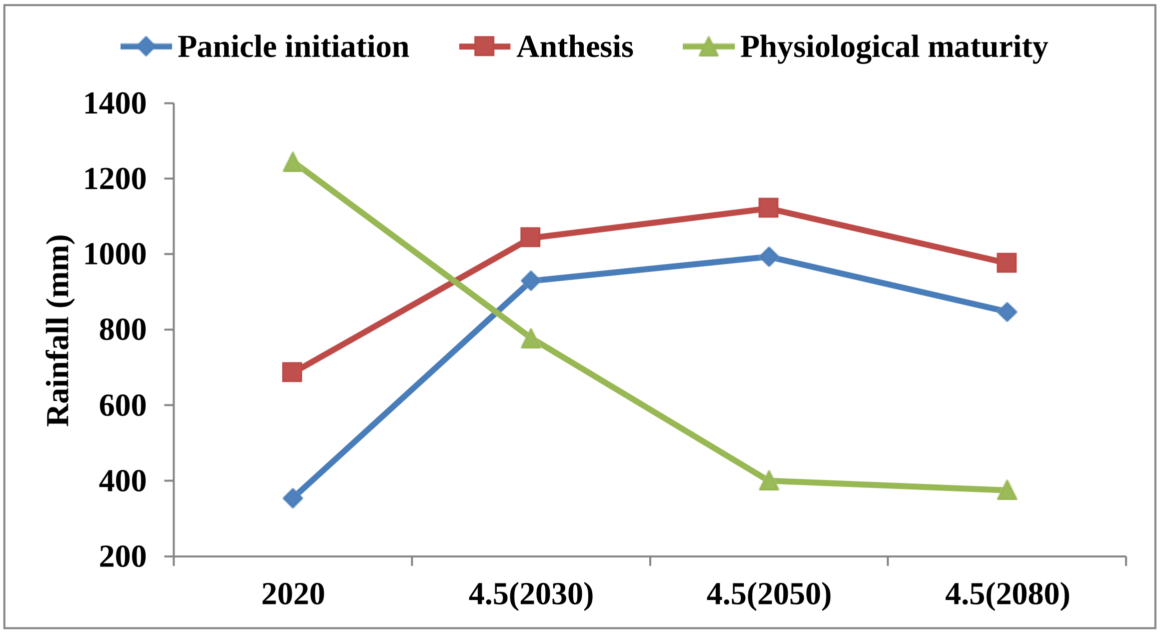


Fig. 5.11. (f) Rainfall in different phenophases of Jyothi under RCP 4.5 for first date of planting

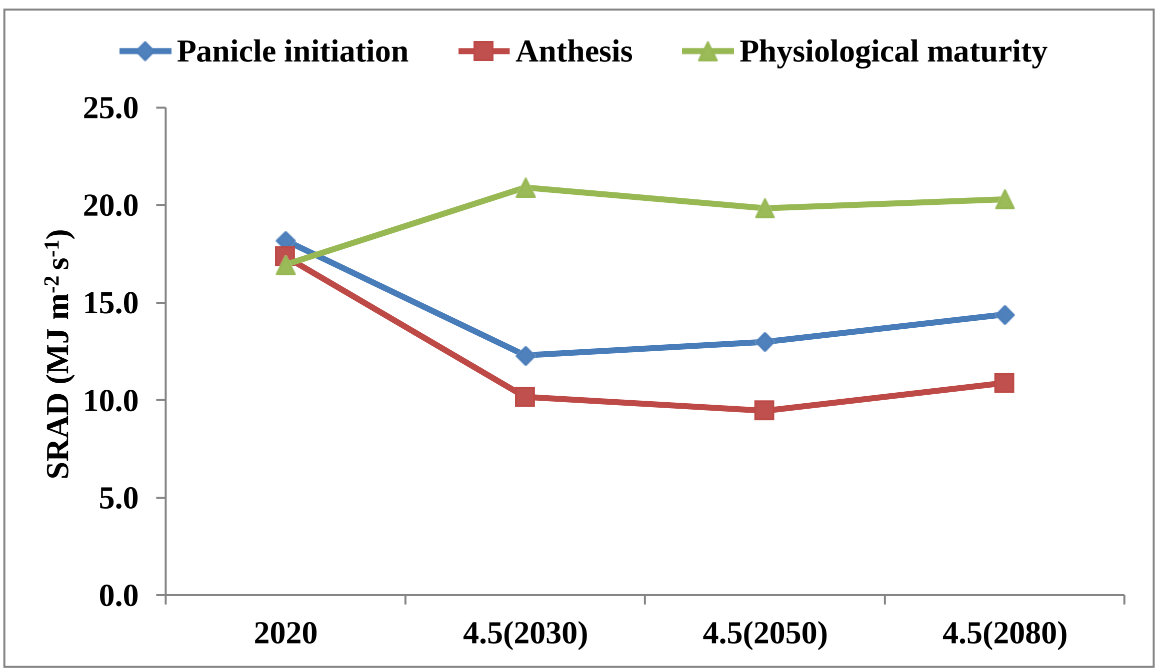


Fig. 5.11. (g) Solar radiation in different phenophases of Jyothi under RCP 4.5 for first date of planting

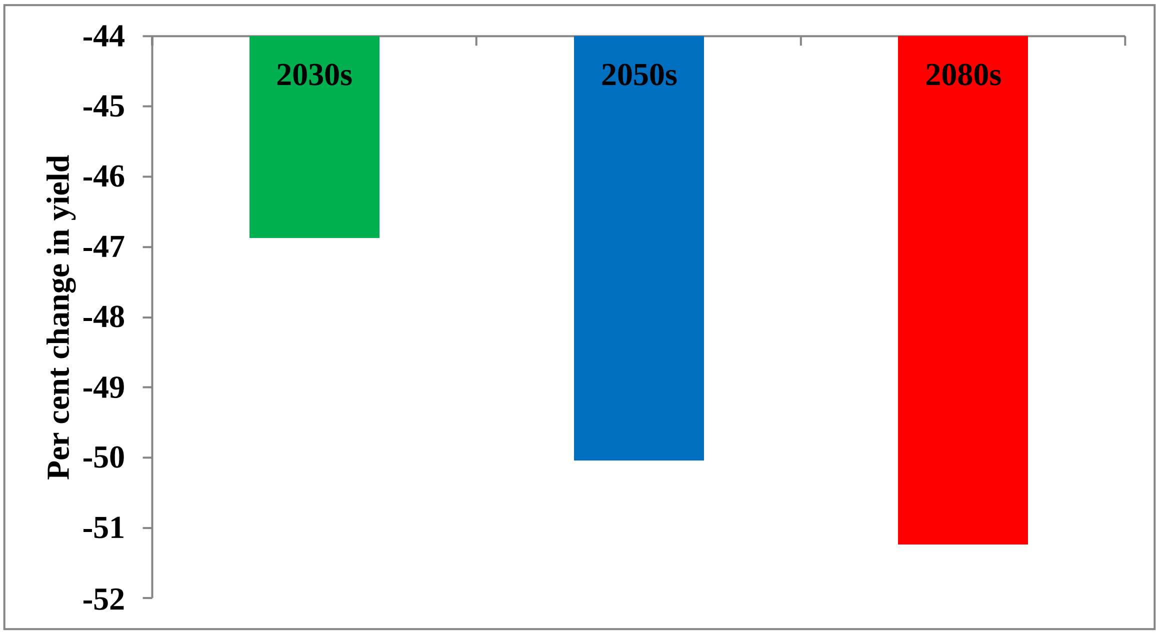


Fig. 5.12. (a) Per cent change in yield of Jyothi under RCP 8.5 scenario for first date of planting from the baseline period

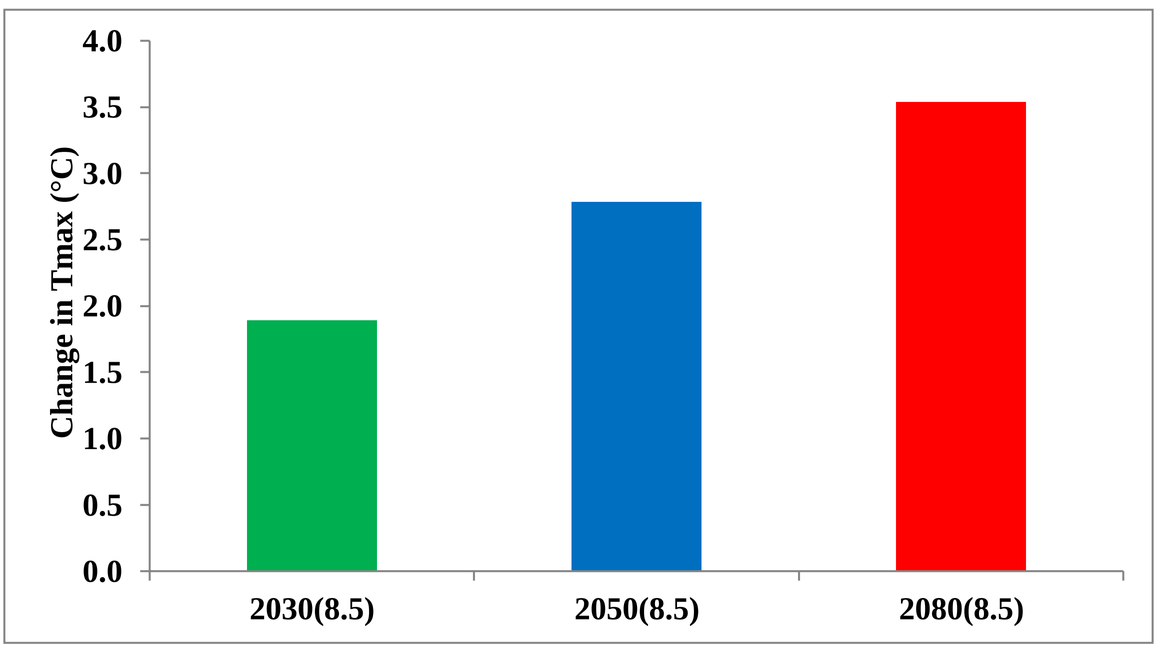


Fig. 5.12. (b) Change in maximum temperature from the baseline during physiological maturity of Jyothi under RCP 8.5 scenario for first date of planting

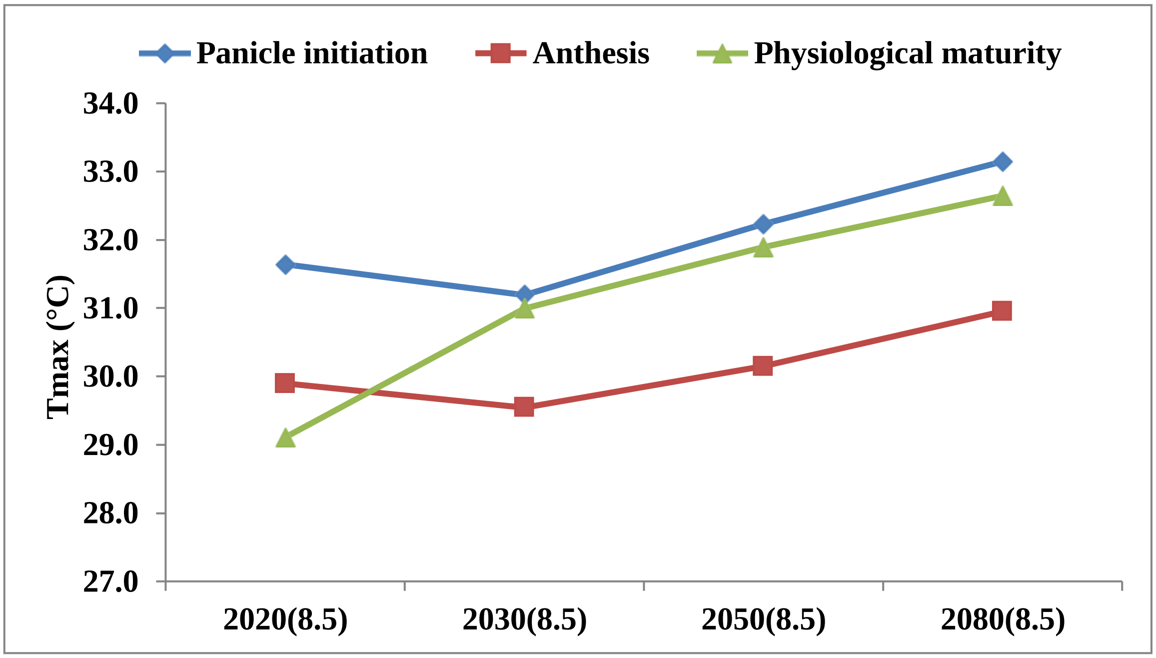


Fig. 5.12. (c) Maximum temperature in different phenophases of Jyothi under RCP 8.5 for first date of planting

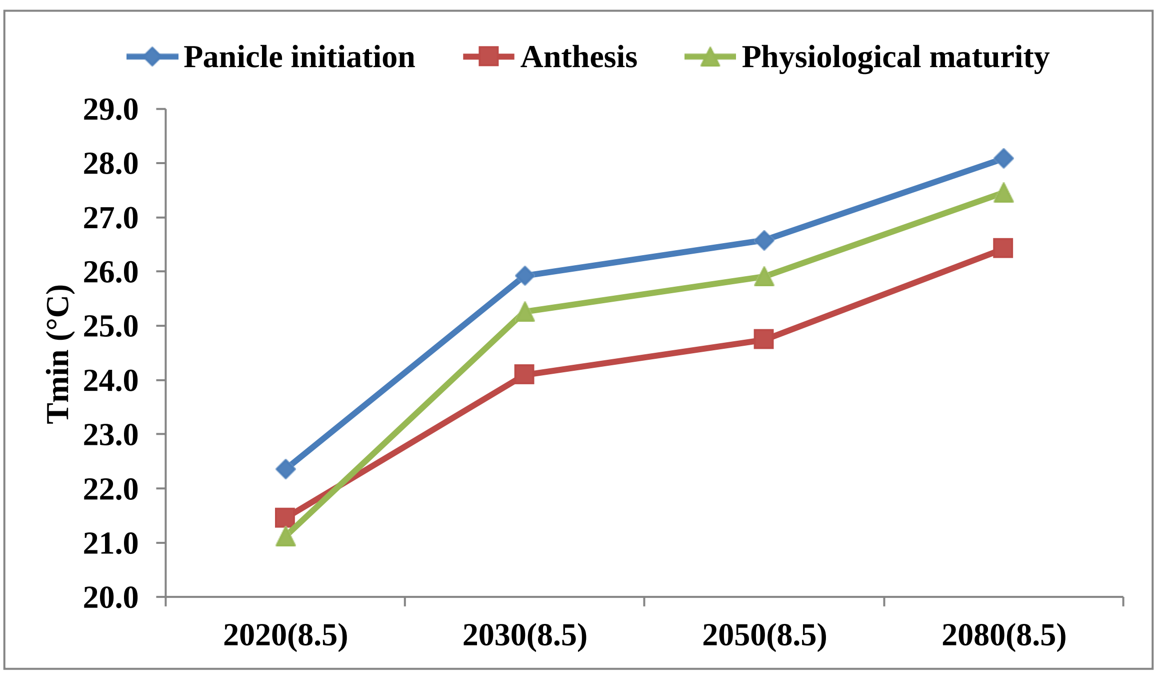


Fig. 5.12. (d) Minimum temperature in different phenophases of Jyothi under RCP 8.5 for first date of planting

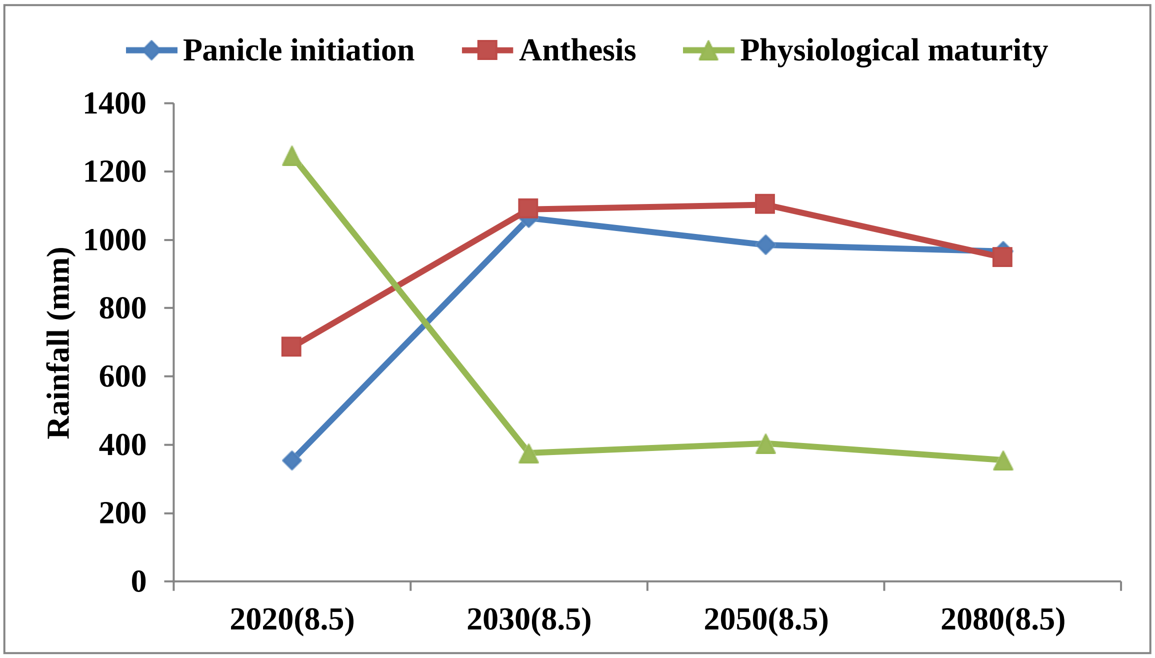


Fig. 5.12. (e) Rainfall in different phenophases of Jyothi under RCP 8.5 for first date of planting

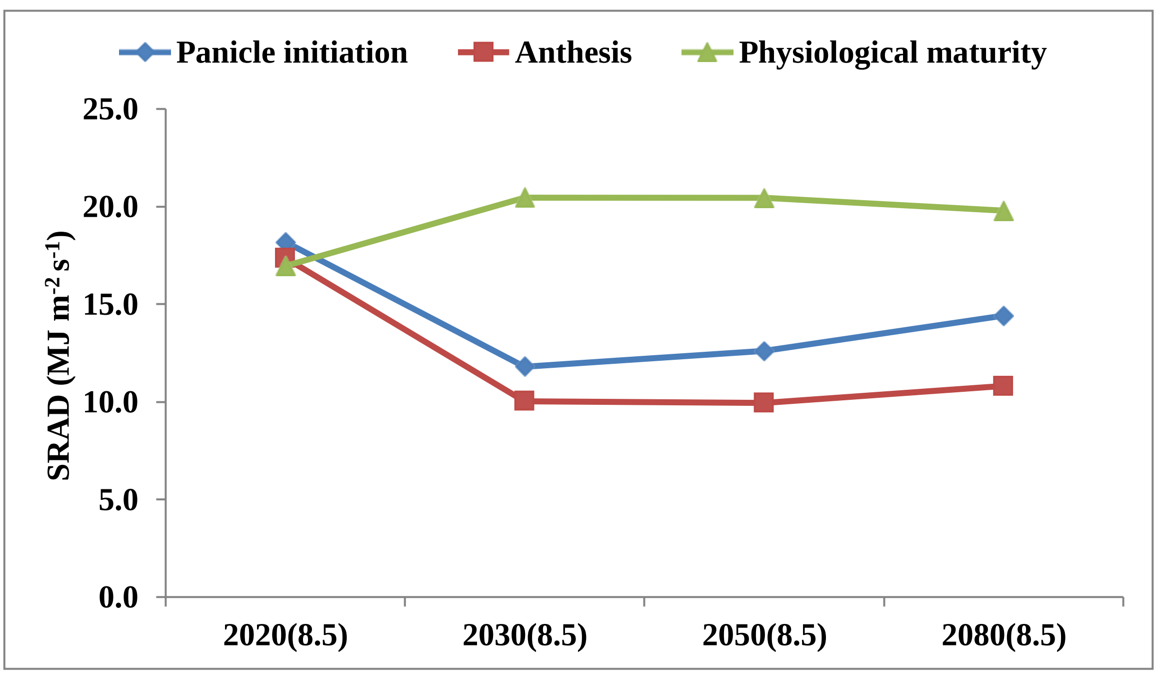


Fig. 5.12. (f) SRAD in different phenophases of Jyothi under RCP 8.5 for first date of planting

5.3.2. Second date of planting

During second date of planting, projected grain yield for Jyothi showed a decreasing trend from 2030 to 2080 from the baseline (2019). The grain yield decreased by 11.3, 18 and 36 percent in 2030, 2050 and 2080 respectively. This may be due to the effect of increased minimum temperature in all stages of plant growth and increased maximum temperature during anthesis period. The results were in good agreement with Oh-e *et al*. (2007), Baker *et al*. (1992) and Morita *et al*. (2004).

During second date of planting, projected grain yield for Jyothi showed a decreasing trend from 2030 to 2080 from the baseline (2019) under RCP 8.5 scenario. The grain yield was decreased by 13.1, 29.9 and 58.7 percent in 2030, 2050 and 2080 respectively. This may be due to the effect of increased solar radiation during physiological maturity, increased maximum temperature during anthesis and increased minimum temperature during all growth stages. This was in good agreement with study conducted by Oh-e *et al*. (2007), Peng *et al*. (2004) and Fu *et al*. (2008).

Oh-e *et al*. (2007) conducted similar research in southern Japan, and observed that maximum air temperature of about 31.8°C during the whole growth period of rice accelerate leaf senescence, reduced photosynthetic rate and thereby results in decreased grain yield, largely due to increased spikelet sterility. Baker *et al*. (1992) observed a yield reduction of about 7–8% in rice for each 1°C increase in night time minimum temperature from 21 to 27 °C. Morita *et al*. (2004) reported that in rice, high minimum temperature (22/34 °C, day/night) were more harmful to grain weight compared to high day temperatures (34/22 °C) and control conditions (22/22 °C) at optimum temperature. Peng *et al*. (2004) reported that increased minimum temperature during flowering stage will increase the respiration, which will lead to reduced yield. Fu *et al*. (2008) reported that increasing maximum temperature will shorten the length of grain filling period and reduce seed setting rate in rice. When temperature is higher than 25–27 °C, grain yield will decrease by 2–6% with a temperature rise of 1 °C (Yi-Chien Wu *et al*., 2016). Rice yield potential would decrease by 4.6–7.3% when the daily mean temperature raises 1 °C (Matthews and Cosser, 1997).

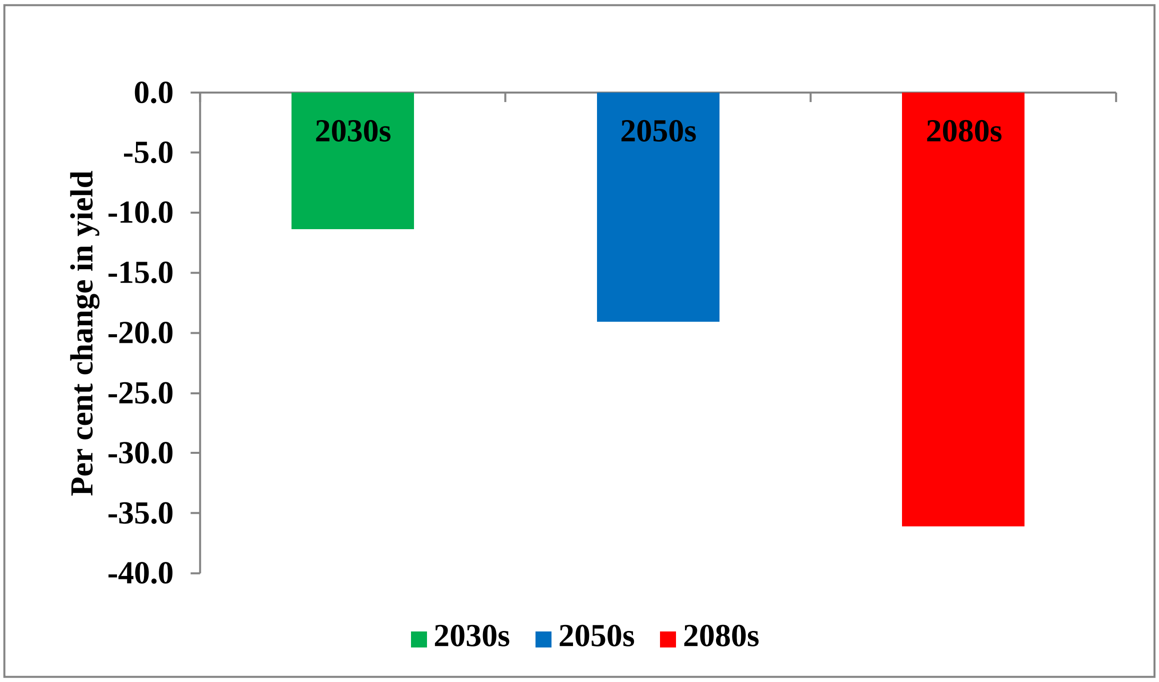


Fig .5.13. (a) Per cent change in yield of Jyothi under RCP 4.5 scenario for second date of planting from baseline

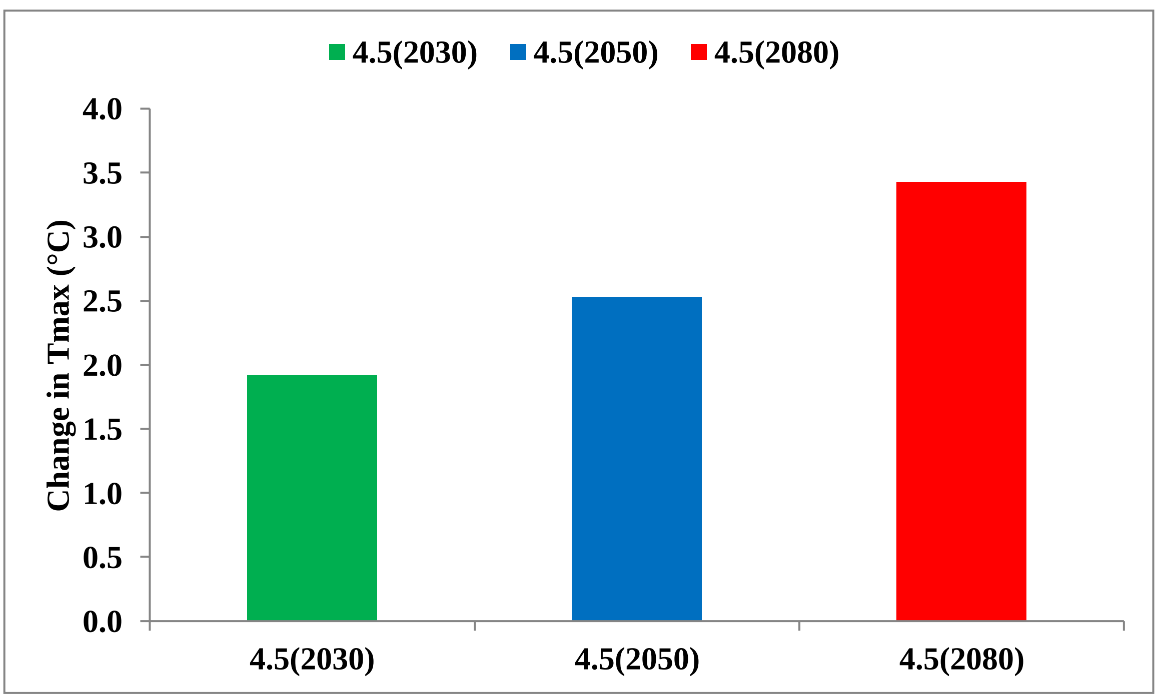


Fig.5.13. (b) Change in maximum temperature from baseline during anthesis period of Jyothi under RCP 4.5 for second date of planting

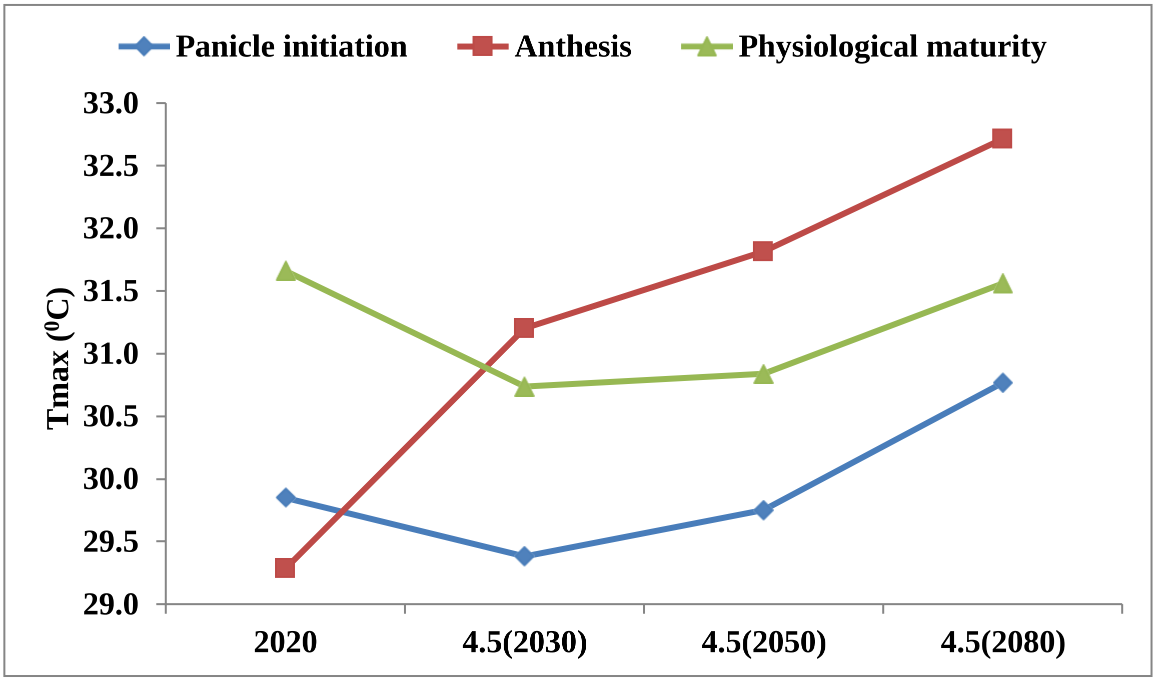


Fig.5.13. (c) Maximum temperature in different phenophases of Jyothi under RCP 4.5 for second date of planting

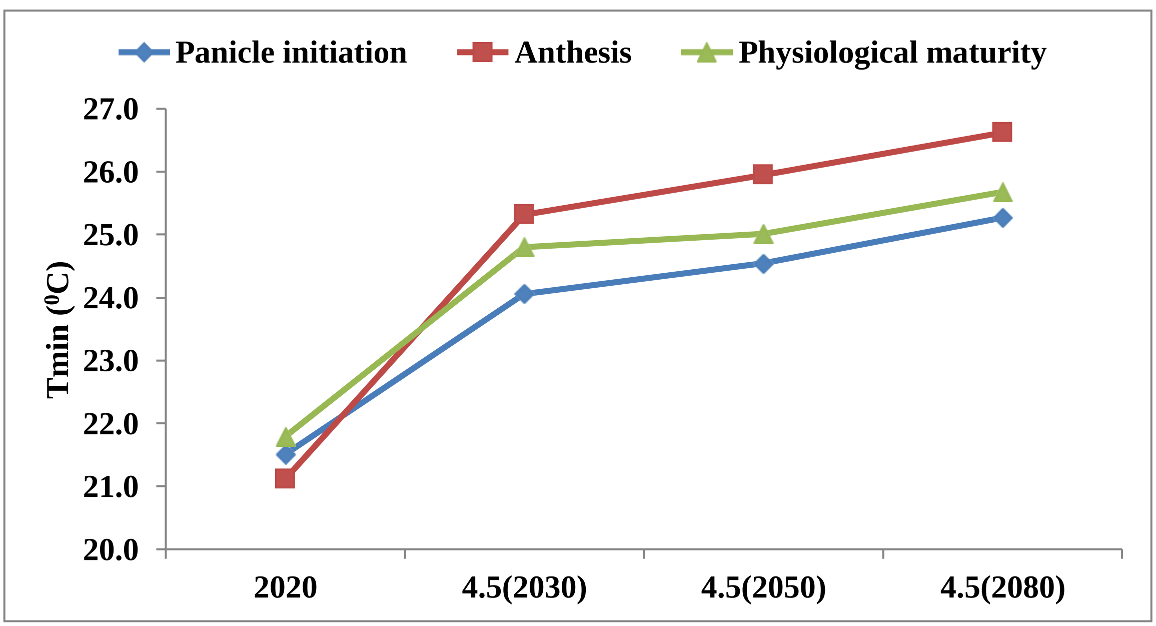


Fig.5.13. (d) Minimum temperature in different phenophases of Jyothi under RCP 4.5 for second date of planting

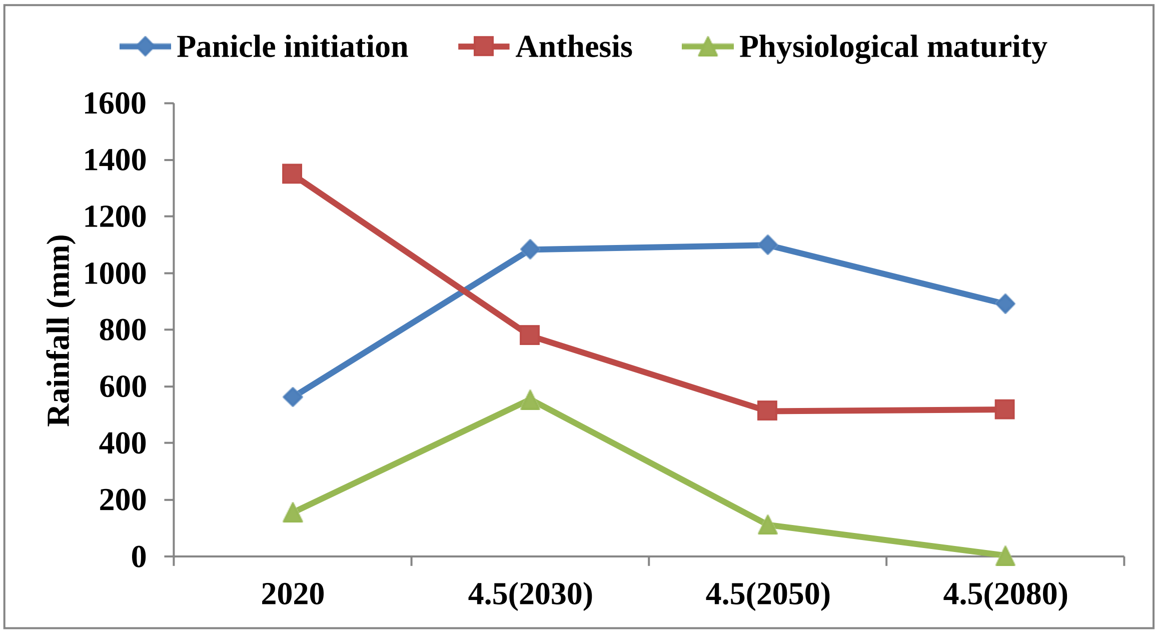


Fig.5.13. (e) Rainfall in different phenophases of Jyothi under RCP 4.5 for second date of planting

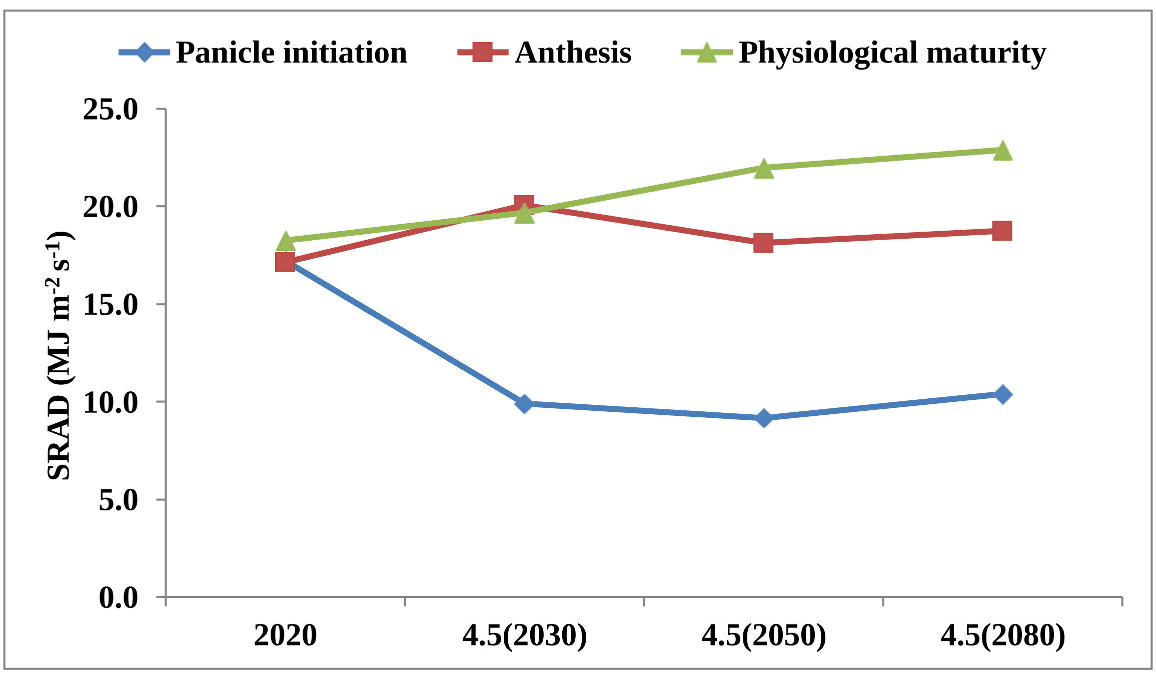


Fig.5.13. (f) Solar radiation in different phenophases of Jyothi under RCP 4.5 for second date of planting

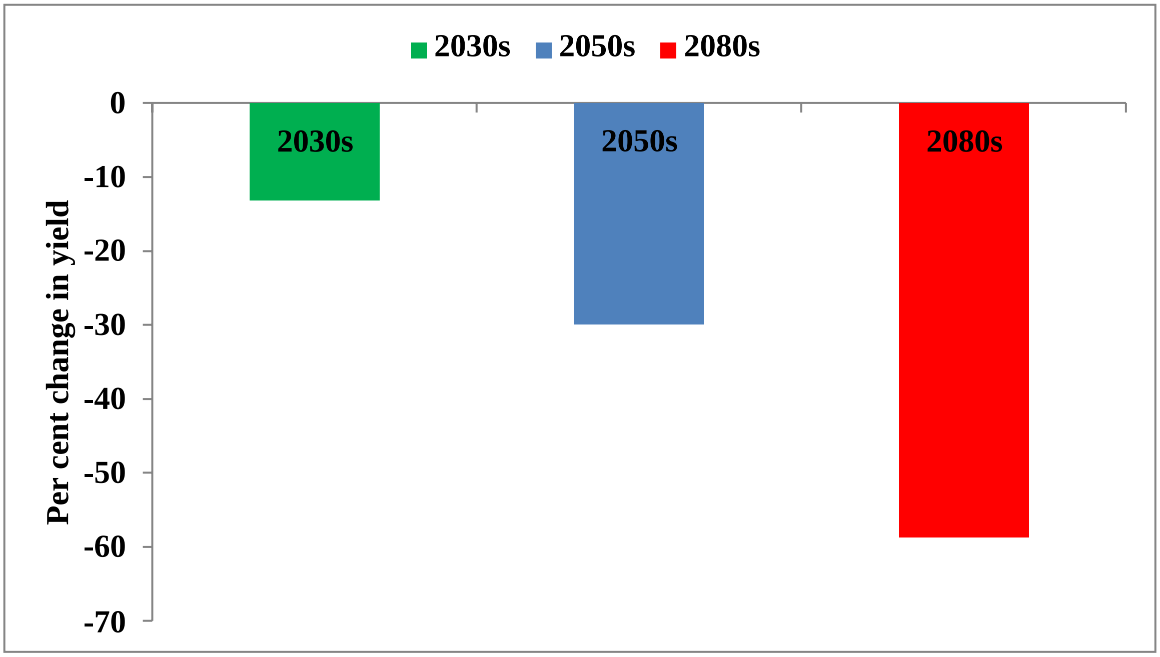


Fig.5.14. (a) Per cent change in yield of Jyothi under RCP 8.5 scenario for second date of planting from baseline

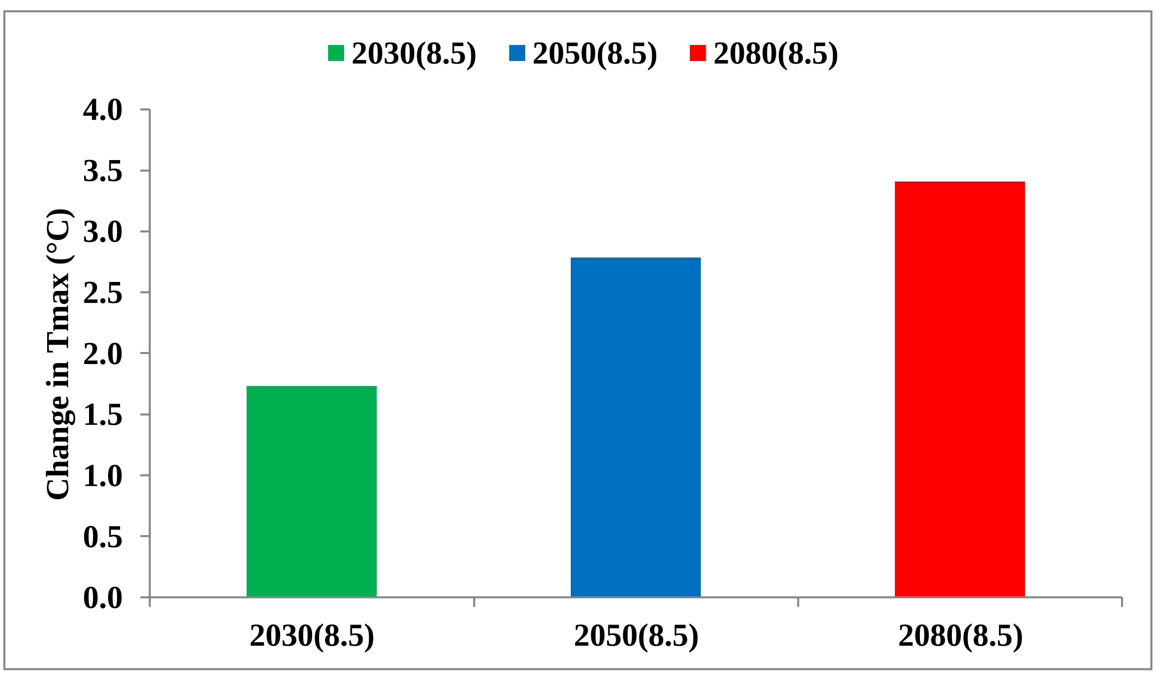


Fig.5.14. (b) Change in maximum temperature from baseline during anthesis of Jyothi under RCP 8.5 scenario for second date of planting

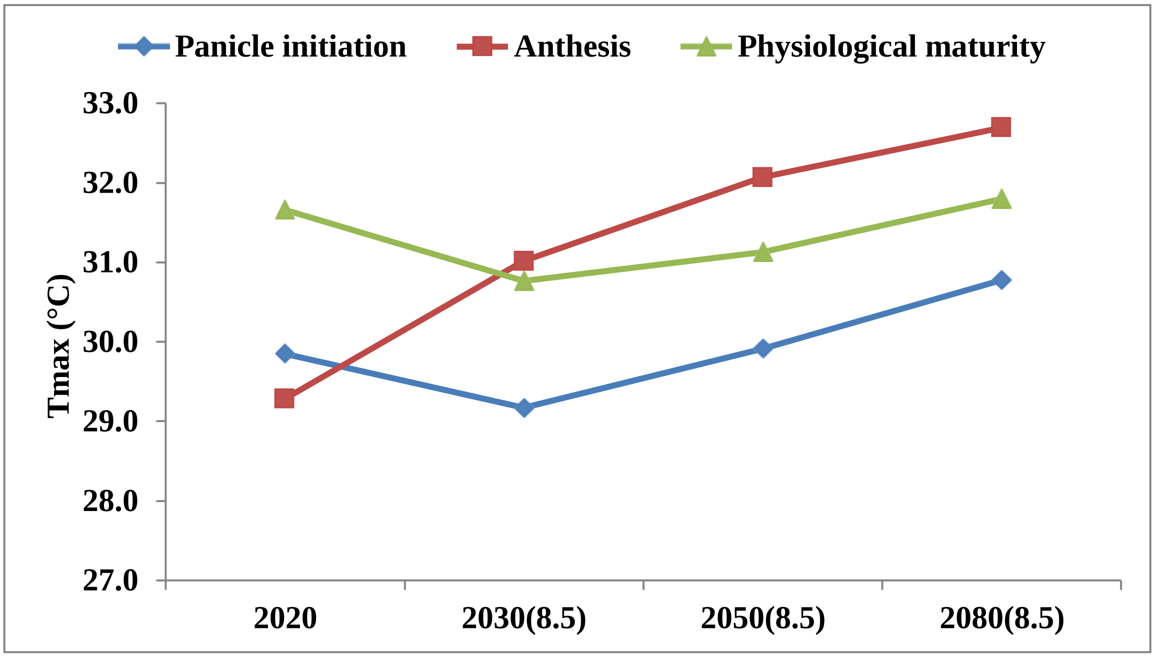


Fig.5.14. (c) Maximum temperature in different phenophases of Jyothi under RCP 8.5 for second date of planting

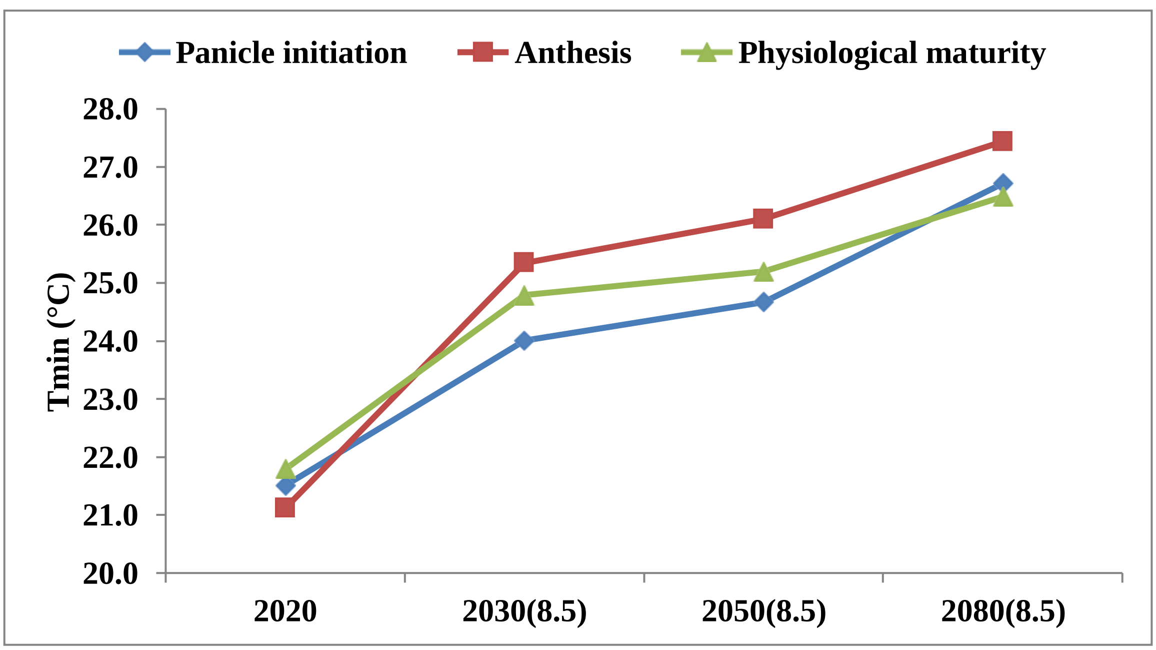


Fig.5.14. (d) Minimum temperature in different phenophases of Jyothi under RCP 8.5 for second date of planting

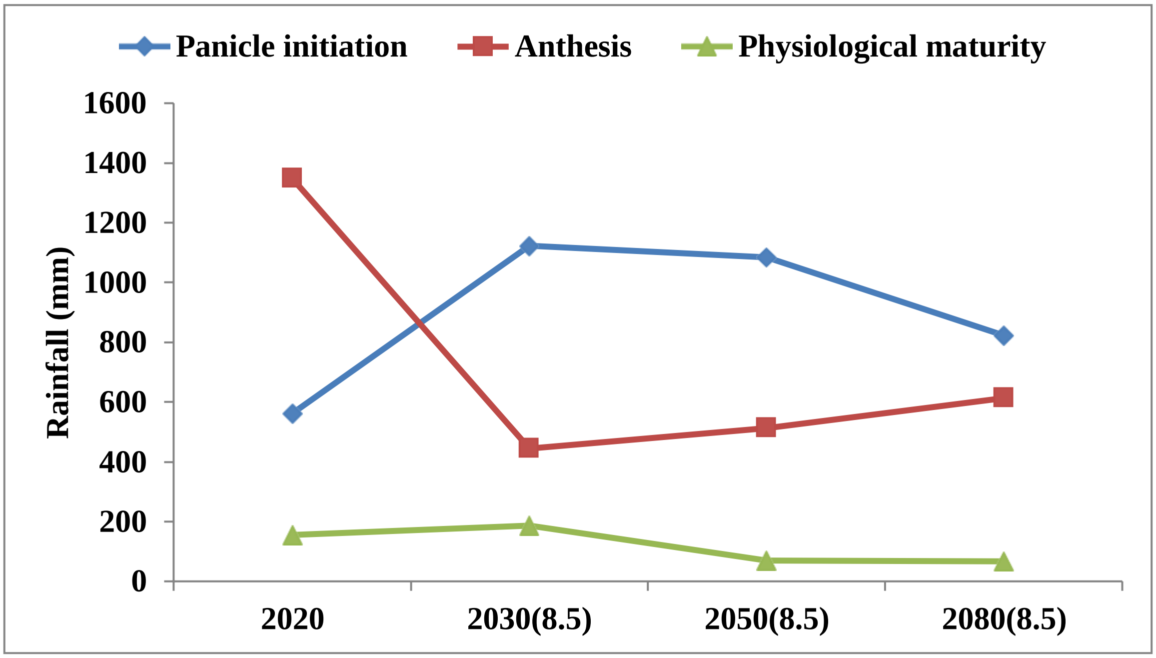


Fig.5.14. (e) Rainfall in different phenophases of Jyothi under RCP 8.5 for second date of planting

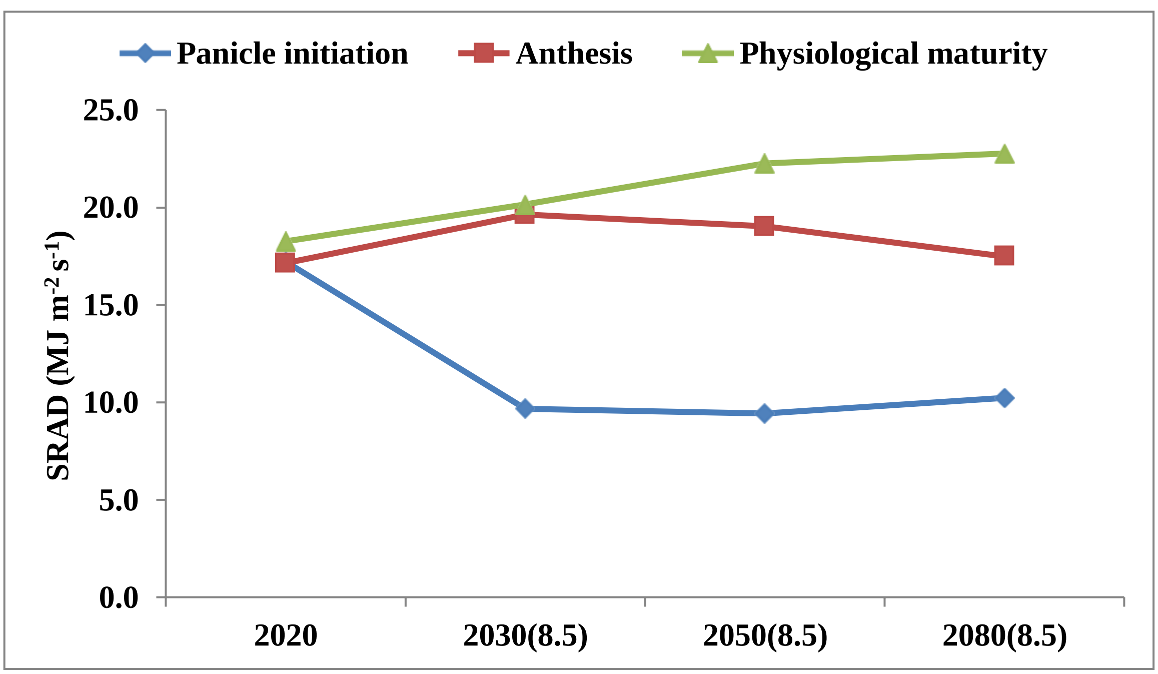


Fig.5.14. (f) SRAD in different phenophases of Jyothi under RCP 8.5 for second date of planting

5.3.3. Third date of planting

During third date of planting, projected grain yield for Jyothi showed an increase in 2030 and then decreased in 2050 and 2080 from the baseline (2019) under RCP 4.5 scenario. The grain yield increased by 6 percent in 2030 and decreased by 1.2 and 4.1 percent in 2050 and 2080 respectively. This may be due to the effect of decreased maximum temperature and increased rainfall during anthesis period. These result are in confirmation with Krishnan *et al*. (2011) and Vijayakumar *et al*. (1996).

Projected grain yield for Jyothi showed a increasing trend towards 2030 and then decreased towards 2080 from the baseline (2019) during third date of planting under RCP 8.5 scenario. The grain yield increased by 9.9 percent in 2030 and decreased by 1.9 and 3.8 percent in 2050 and 2080 respectively. This may be due to the effect of maximum temperature during anthesis stage. This was in good agreement with findings of Krishnan *et al*. (2011), Biswas *et al.* (2018), Huang and Lur (2000), Kobata and Uemuki (2004), Tsukaguchi and Iida (2008) and Tashiro and Wardlaw, (1991).

Krishnan *et al*. (2011) reported that for every 1°C increase in temperature, decrease in rice yield by 7.2%. Biswas *et al.* (2018) reported a reduction of 5-10% yield of rice transplanted in normal date (4^{th} week of May) with increase in temperature up to 2^{0}C. Vijayakumar *et al*. (1996) observed that increased morning rainfall will reduce the pollination of flowers. This will lead to unfertilized ovaries and chaffy grains and thereby decreasing yield.

Both grain appearance and quality was affected by high temperature. High temperature shortens grain filling period and this would increase immature and chalky grain percentage (Huang and Lur, 2000; Kobata and Uemuki, 2004; Tsukaguchi and Iida, 2008). The formation of chalky grains was most sensitive to high temperatures during the period of 12–16 days after heading (Tashiro and Wardlaw, 1991).

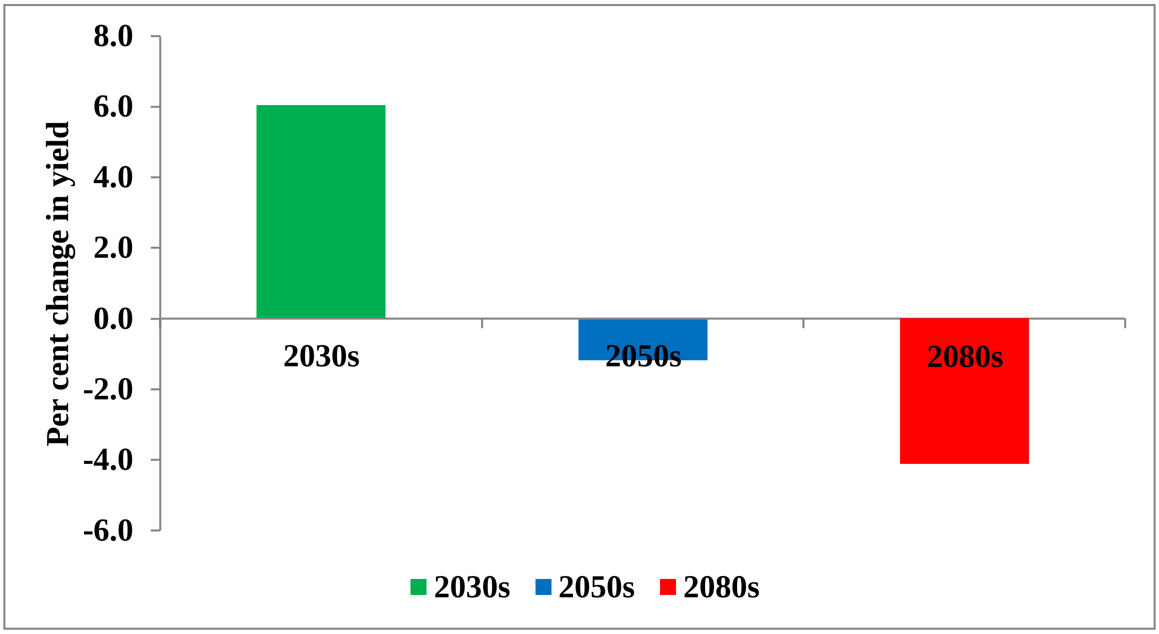


Fig.5.15. (a) Per cent change in yield of Jyothi under RCP 4.5 for third date of planting from baseline

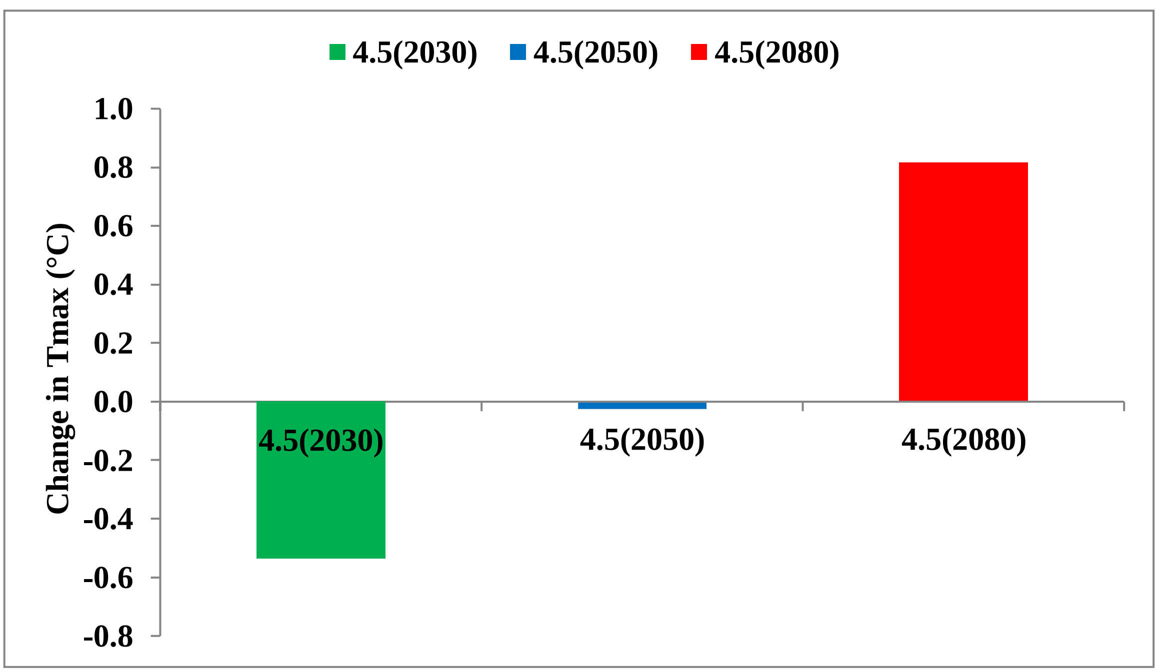


Fig.5.15. (b) Change in maximum temperature from baseline during anthesis of Jyothi under RCP 4.5 for third date of planting

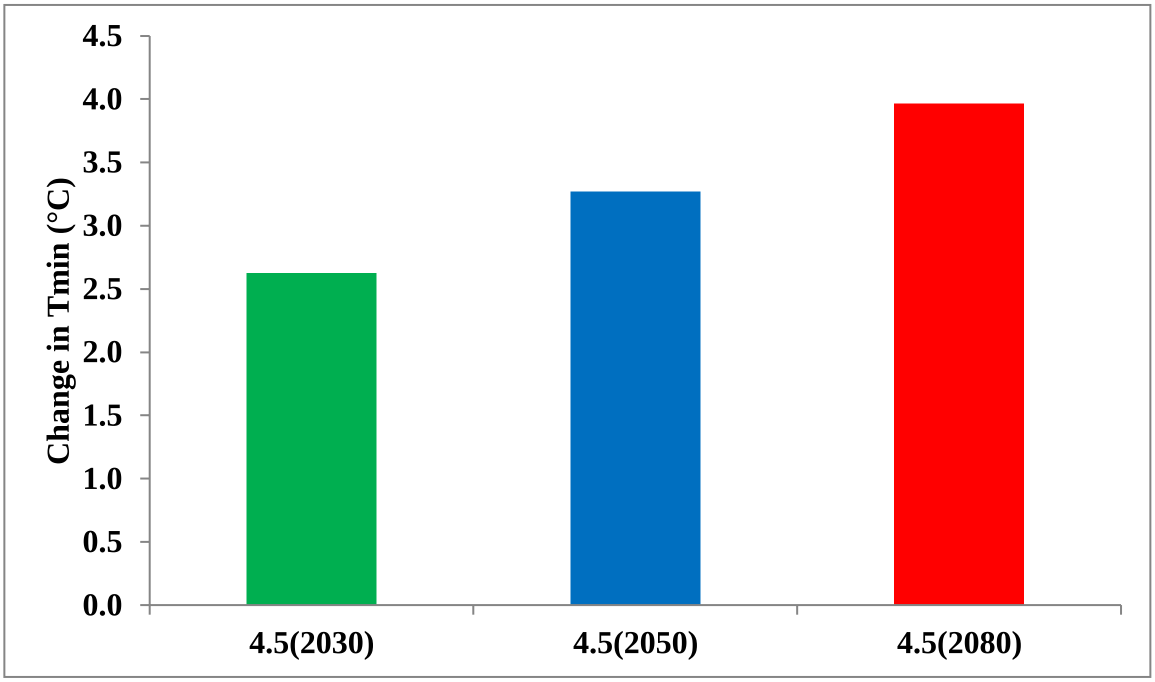


Fig.5.15. (c) Change in minimum temperature from baseline during anthesis of Jyothi under RCP 4.5 for third date of planting

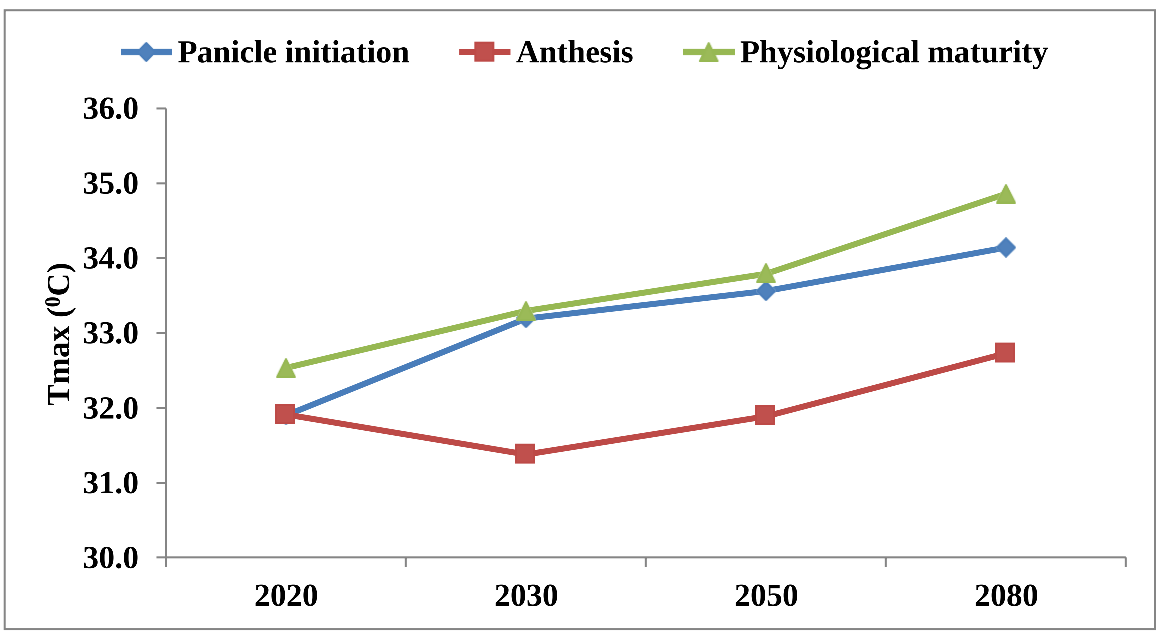


Fig.5.15. (d) Maximum temperature in different phenophases of Jyothi under RCP 4.5 for third date of planting

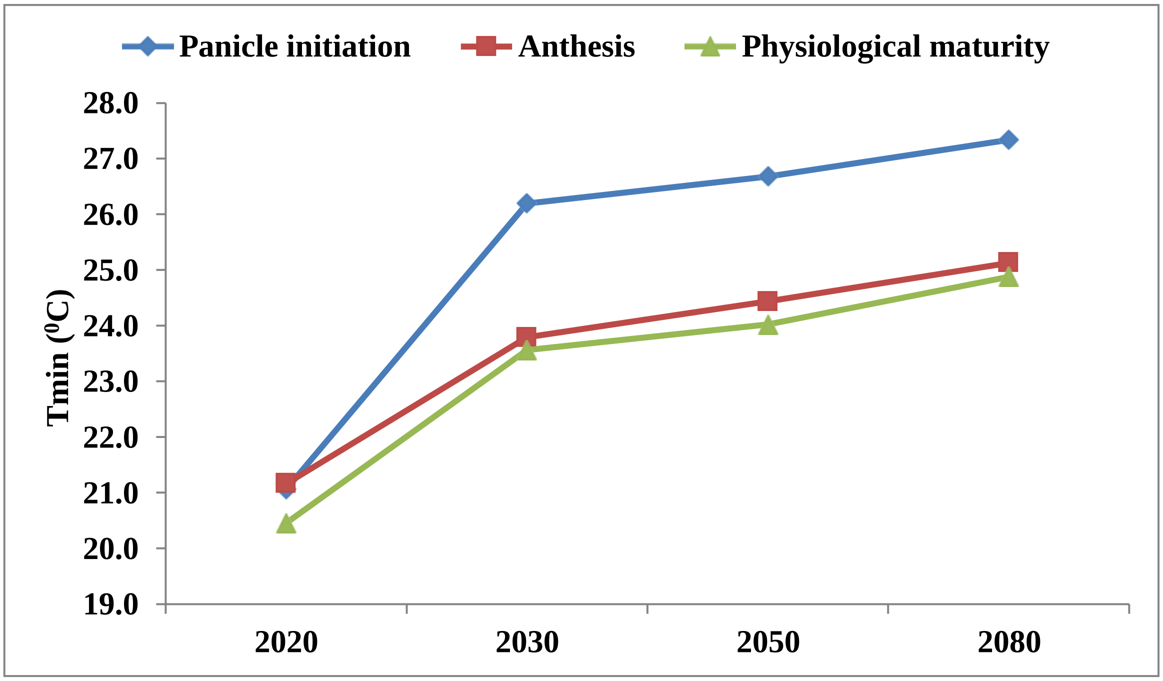


Fig.5.15. (e) Minimum temperature in different phenophases of Jyothi under RCP 4.5 for third date of planting

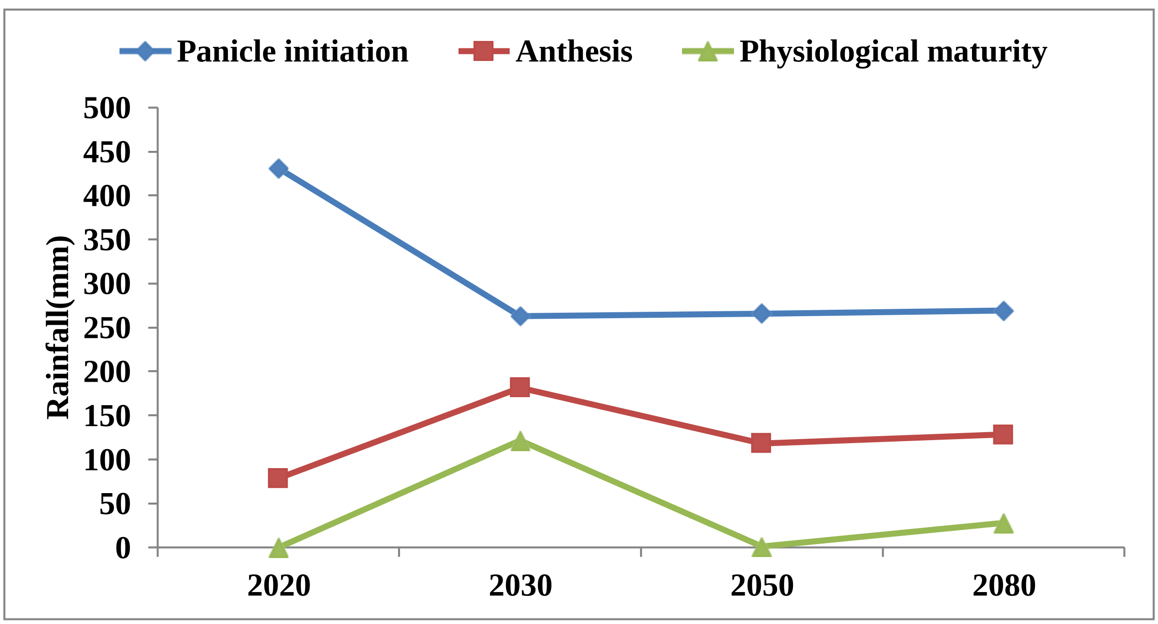


Fig.5.15. (f) Rainfall in different phenophases of Jyothi under RCP 4.5 for third date of planting

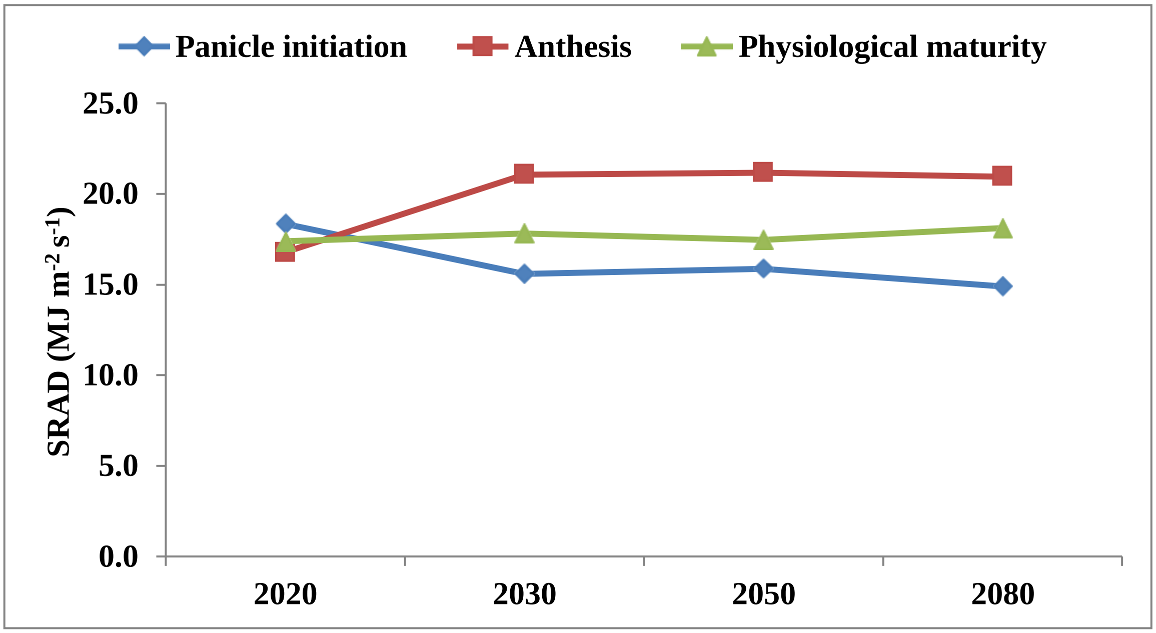


Fig.5.15. (g) Solar radiation in different phenophases of Jyothi under RCP 4.5 for third date of planting

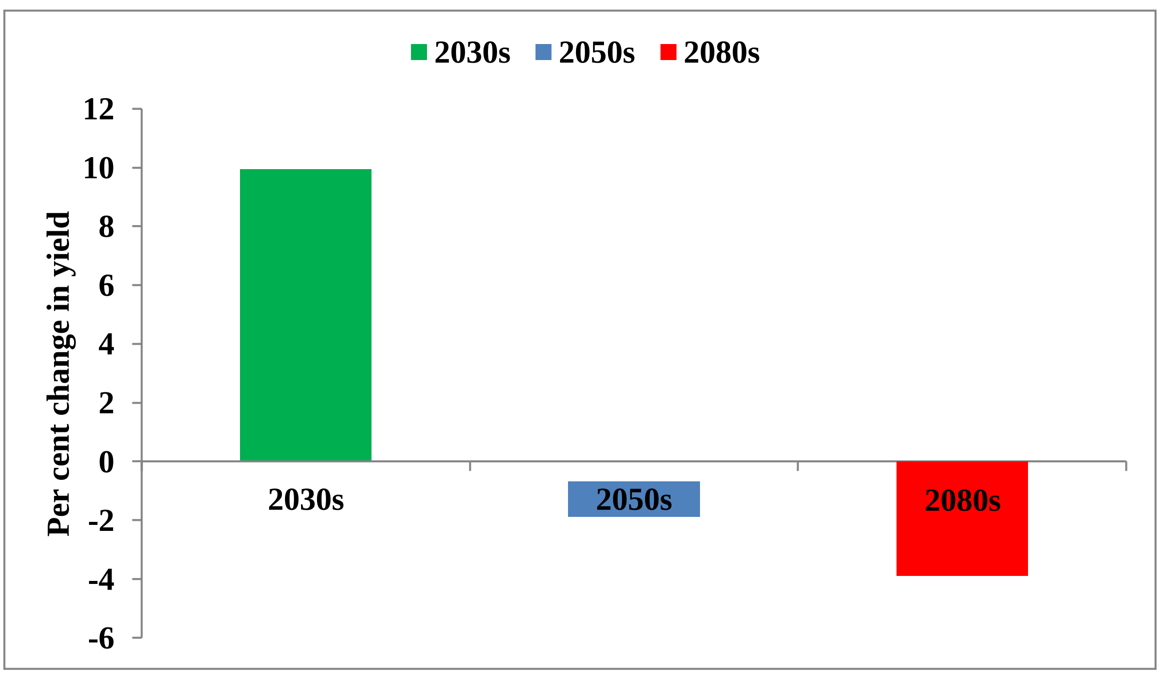


Fig.5.16. (a) Per cent change in yield of Jyothi from baseline under RCP 8.5 scenario for third date of planting

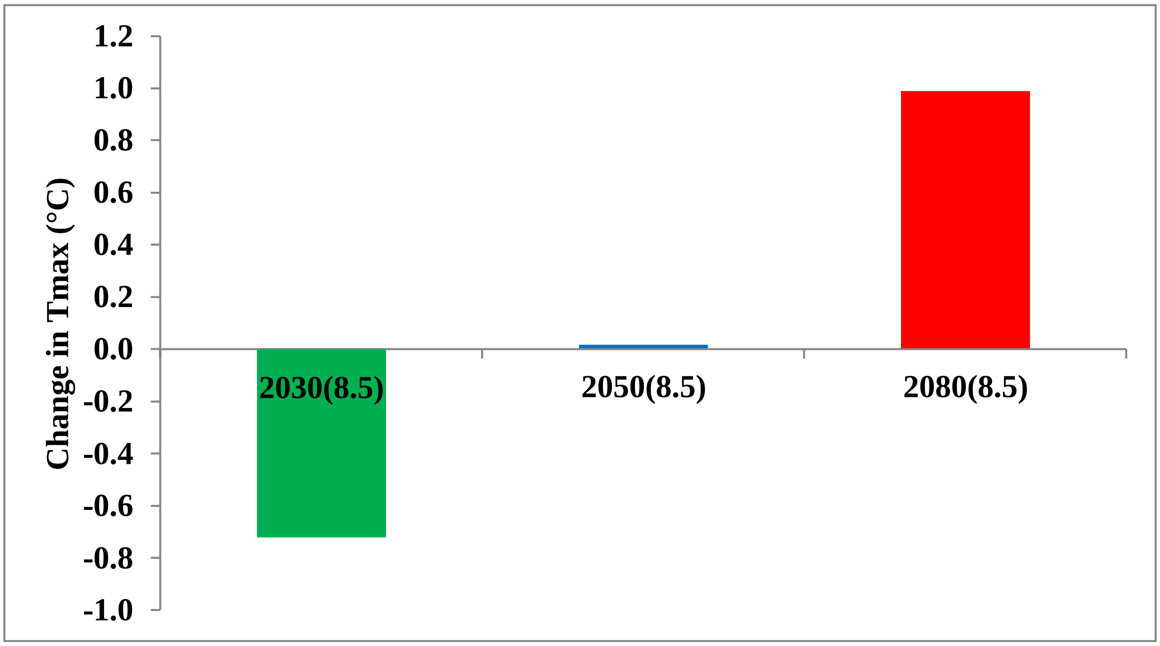


Fig.5.16. (b) Change in maximum temperature from baseline during anthesis of Jyothi under RCP 8.5 scenario for third date of planting

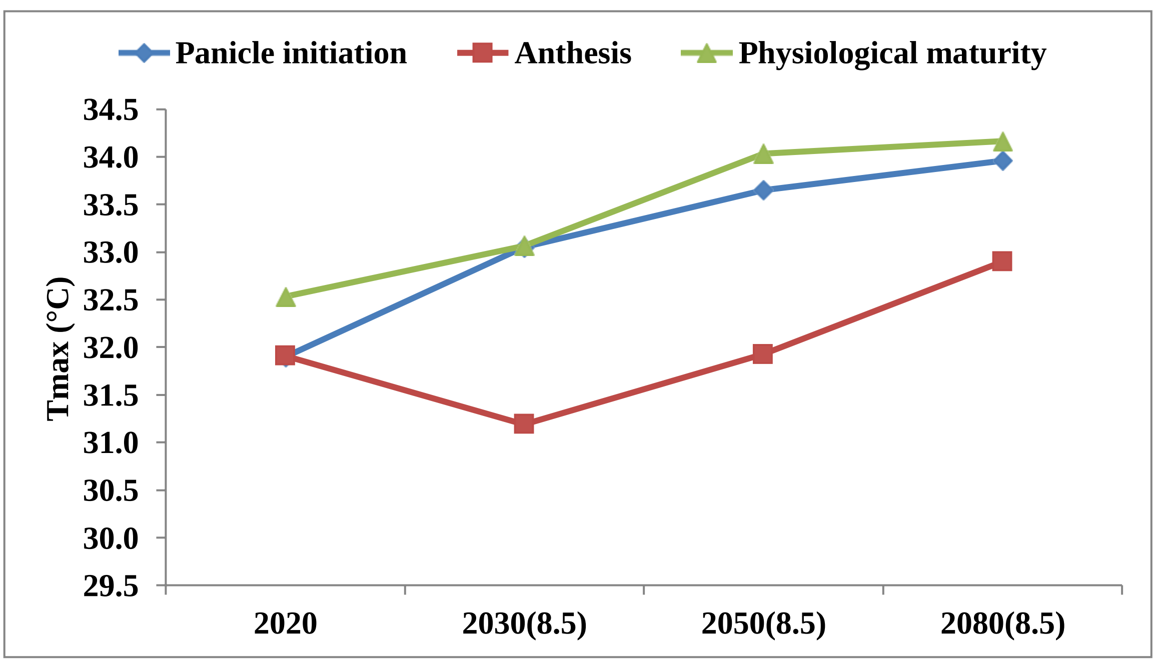


Fig.5.16. (c) Maximum temperature in different phenophases of Jyothi under RCP 8.5 for third date of planting

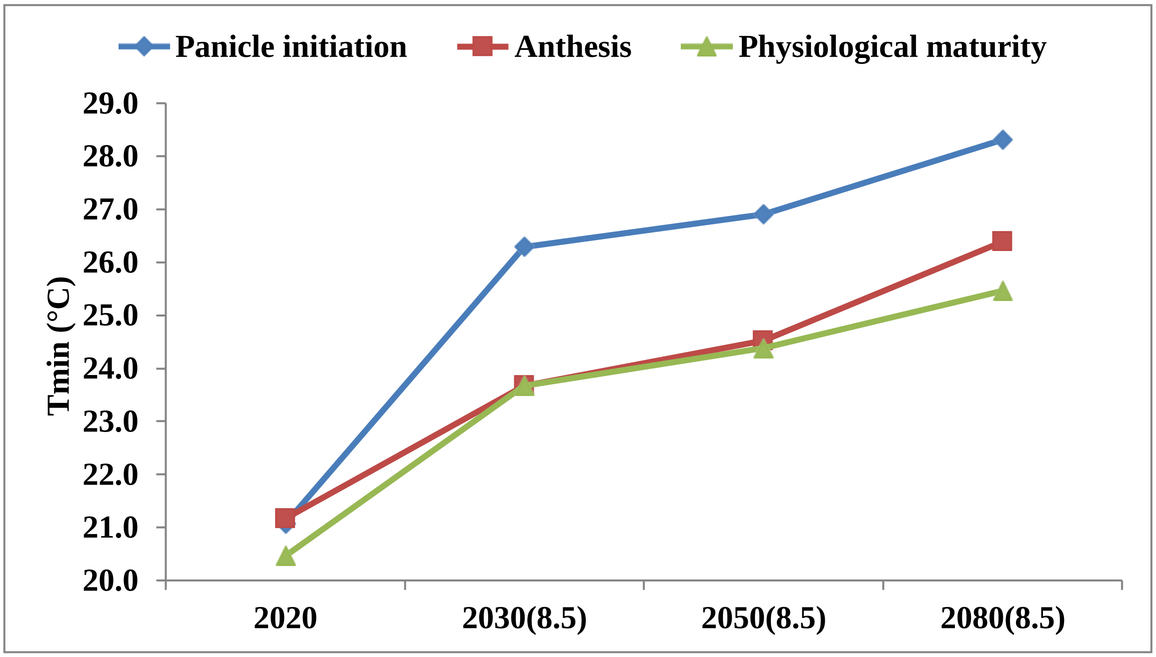


Fig.5.16. (d) Minimum temperature in different phenophases of Jyothi under RCP 8.5 for third date of planting

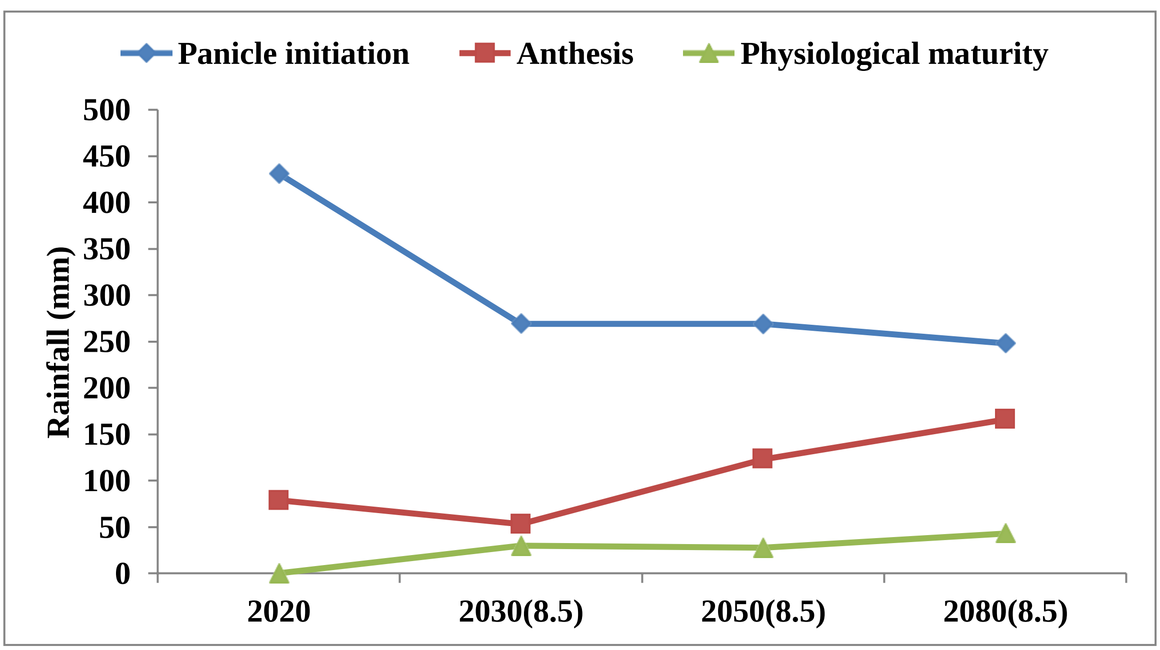


Fig.5.16. (e) Rainfall in different phenophases of Jyothi under RCP 8.5 for third date of planting

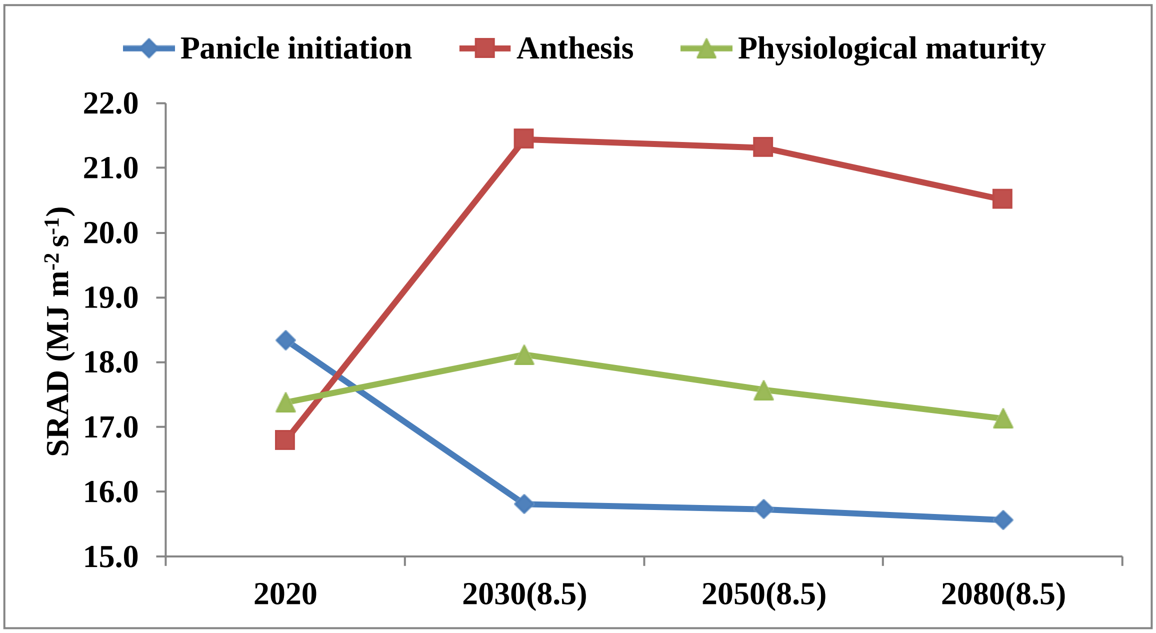


Fig.5.16. (f) Solar radiation in different phenophases of Jyothi under RCP 8.5 for third date of planting

5.3.4. Fourth date of planting

Projected grain yield for Jyothi decreased by 25.4, 11.8 and 10.6 percent in 2030, 2050 and 2080 respectively from the baseline (2019) during fourth date of planting under RCP 4.5 scenario. This may be due to the effect of increased minimum temperature during all stages and increased rainfall during physiological maturity period.

During fourth date of planting, projected grain yield for Jyothi was decreased by 29.3, 45.1 and 52.1 per cent in the year 2030, 2050 and 2080 respectively from the baseline (2019) under RCP 8.5 scenario. This may be due to the effect of increased minimum temperature during all growth stages. This was in good agreement with study conducted by Peng *et al*. (2004), Morita *et al*. (2004), Tashiro and Wardlaw (1991), Matsui *et al*. (2005).

Peng *et al*. (2004) reported that increased minimum temperature during flowering stage will increase the respiration, which will lead to reduced yield. Morita *et al*. (2004) reported that in rice, high minimum temperature were more harmful to grain weight compared to high day temperatures.

Tashiro and Wardlaw (1991) observed that high temperature did not repress grain yield until the daily mean temperature reached less than 26.7°C. We also found in the heading week, higher temperatures (above threshold) will cause more sterility in grains (Lur, 2009). The reason might be the lower activity of microsporocyte (Prasad *et al*., 2006), less pollen production (Matsui *et al*., 2005), and repression of stamen dehiscence (Matsui *et al*., 2005). High sterility decreases the final grain yield (Prasad *et al*., 2006).

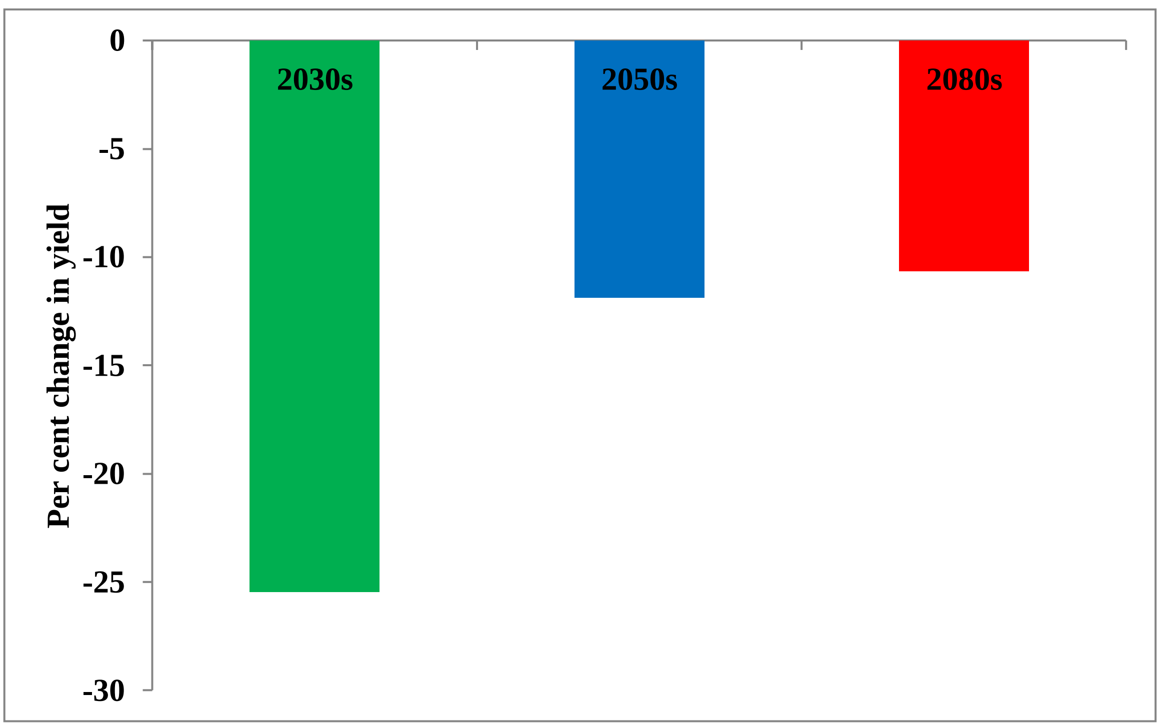


Fig.5.17. (a) Per cent change in yield of Jyothi from baseline under RCP 4.5 scenario for fourth date of planting

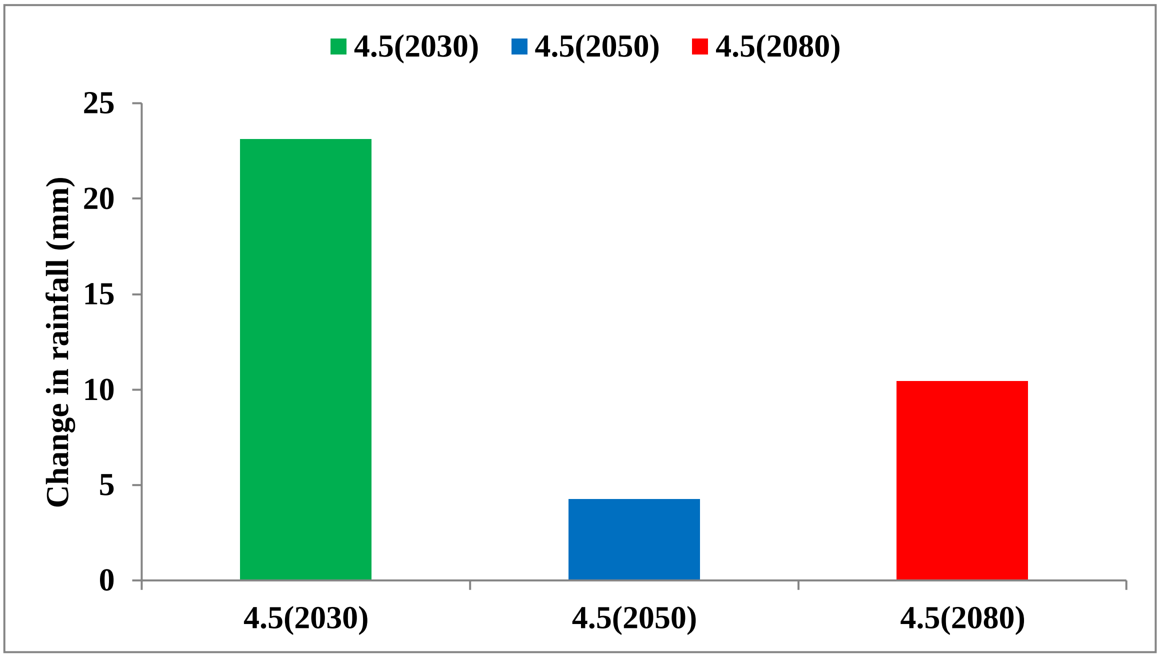


Fig.5.17. (b) Change in rainfall from baseline during physiological maturity under RCP 4.5 scenario for fourth date of planting

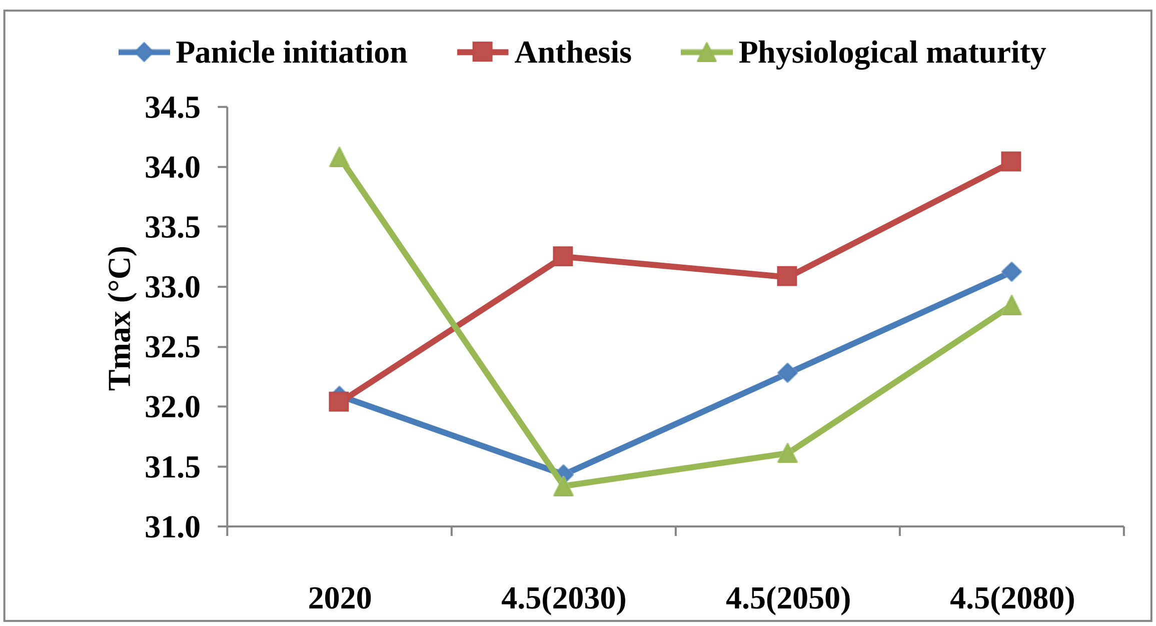


Fig.5.17. (c) Maximum temperature in different phenophases of Jyothi under RCP 4.5 for fourth date of planting

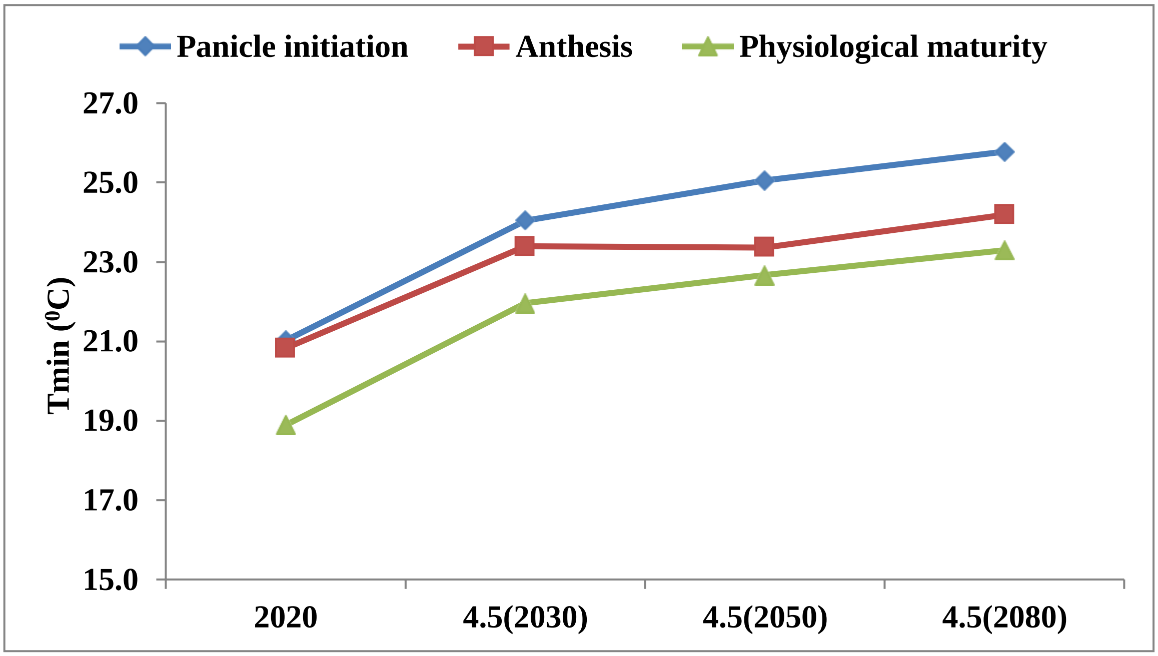


Fig.5.17. (d) Minimum temperature in different phenophases of Jyothi under RCP 4.5 for fourth date of planting

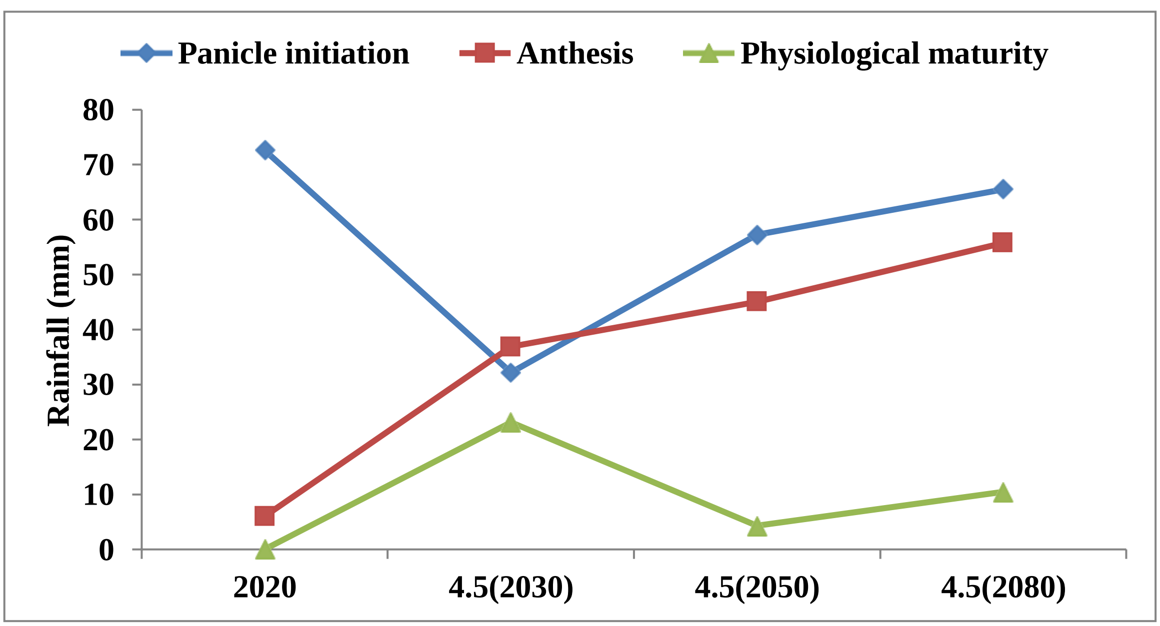


Fig.5.17. (e) Rainfall in different phenophases of Jyothi under RCP 4.5 for fourth date of planting

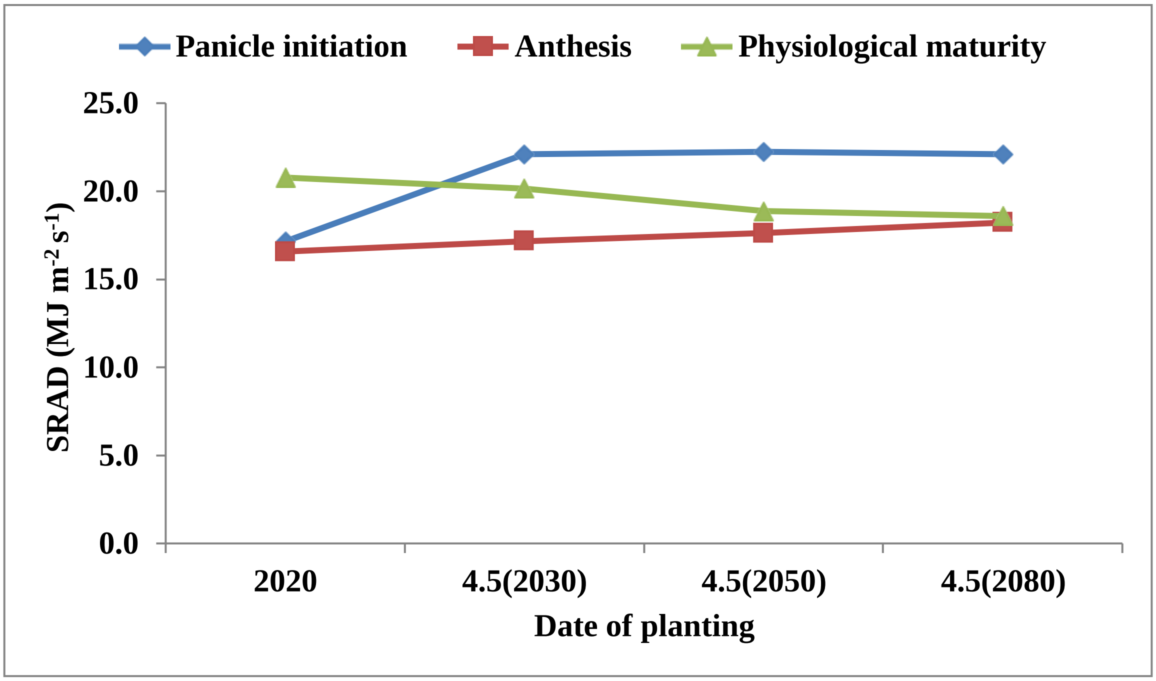


Fig.5.17. (f) Solar radiation in different phenophases of Jyothi under RCP 4.5 for fourth date of planting

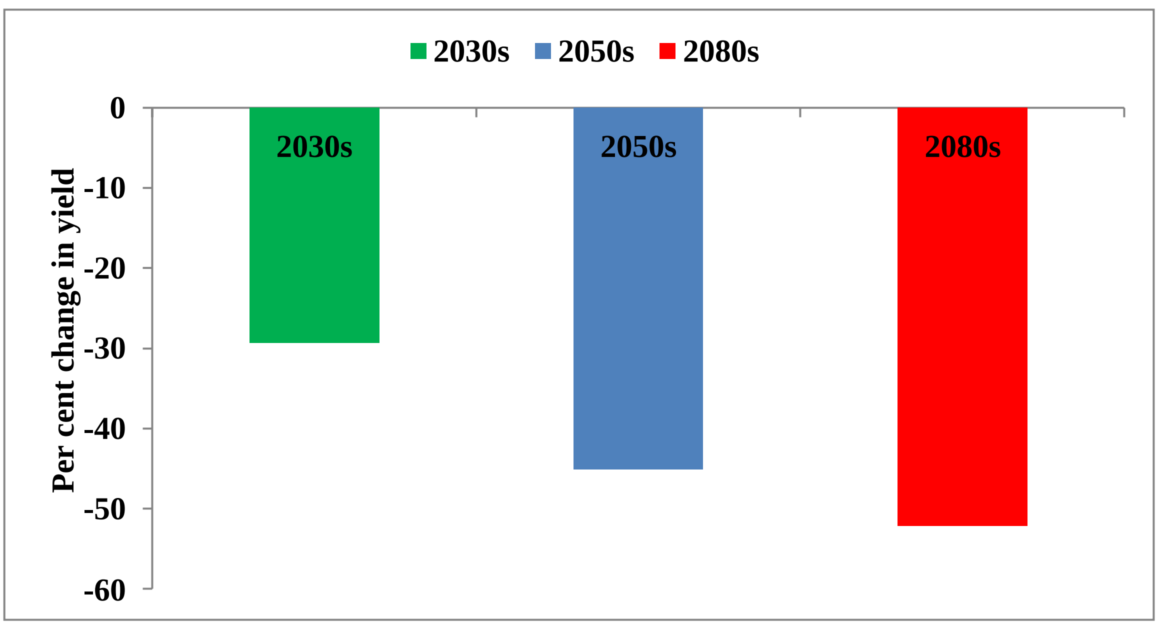


Fig.5.18. (a) Per cent change in yield of Jyothi from baseline under RCP 8.5 scenario for fourth date of planting

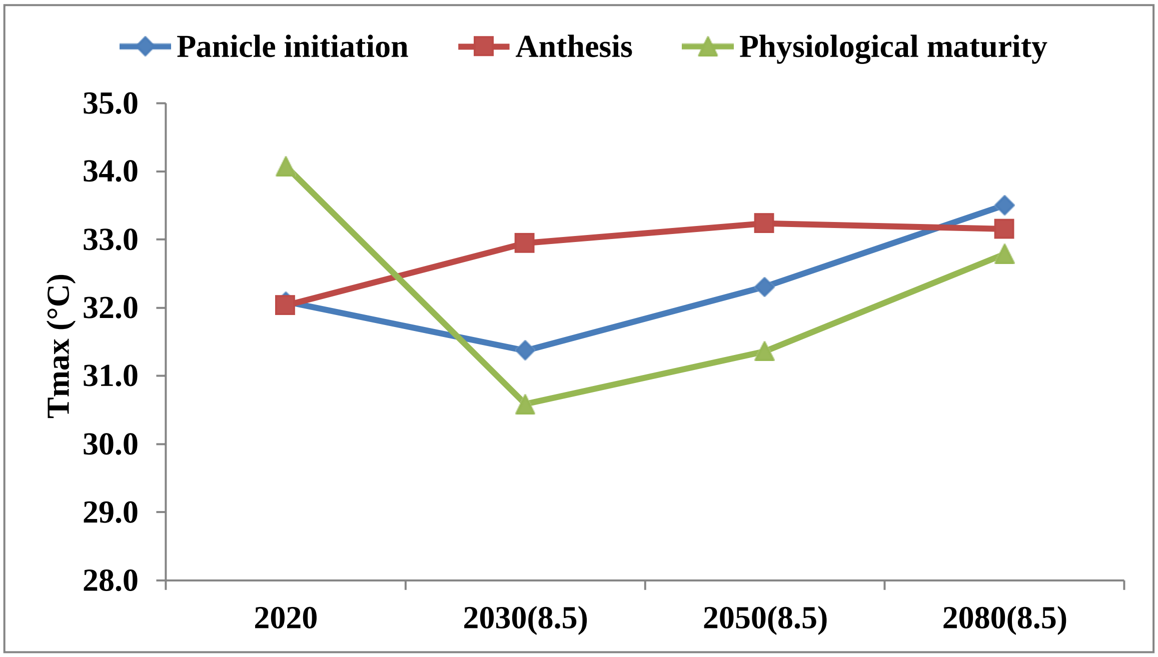


Fig.5.18. (b) Maximum temperature in different phenophases of Jyothi under RCP 8.5 for fourth date of planting

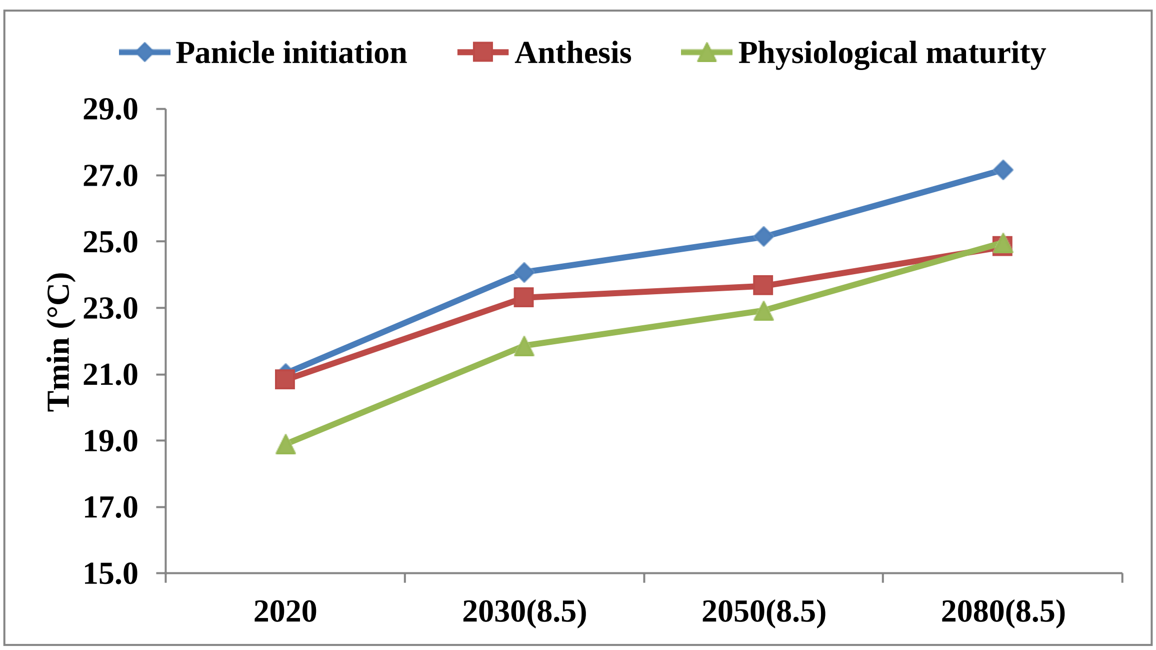


Fig.5.18. (c) Minimum temperature in different phenophases of Jyothi under RCP 8.5 for fourth date of planting

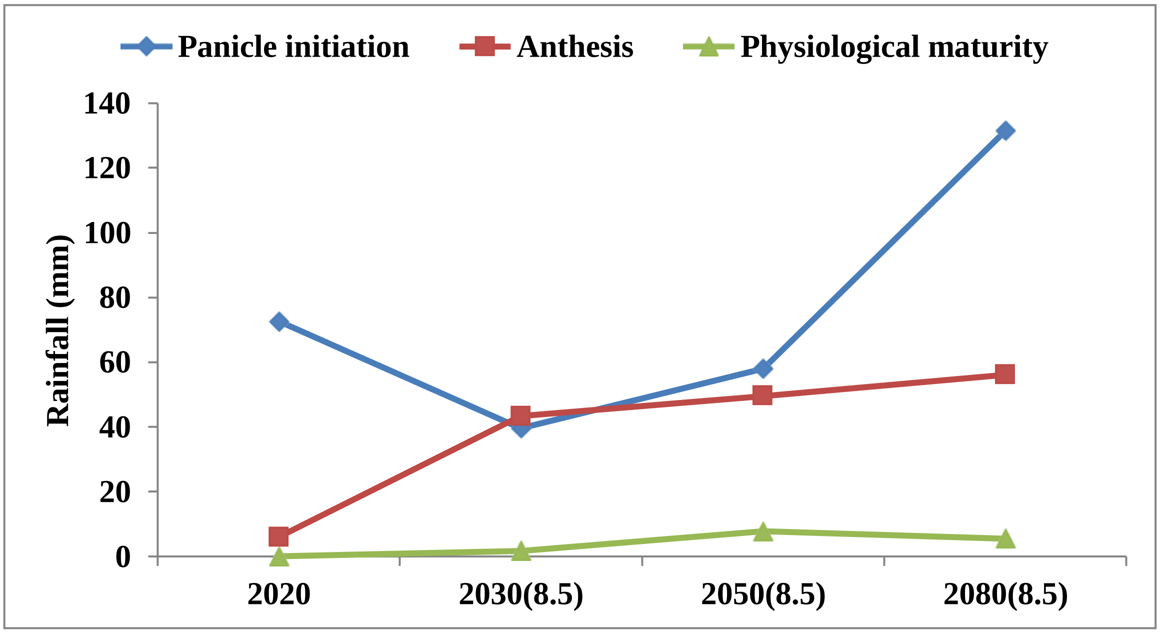


Fig.5.18. (d) Rainfall in different phenophases of Jyothi under RCP 8.5 for fourth date of planting

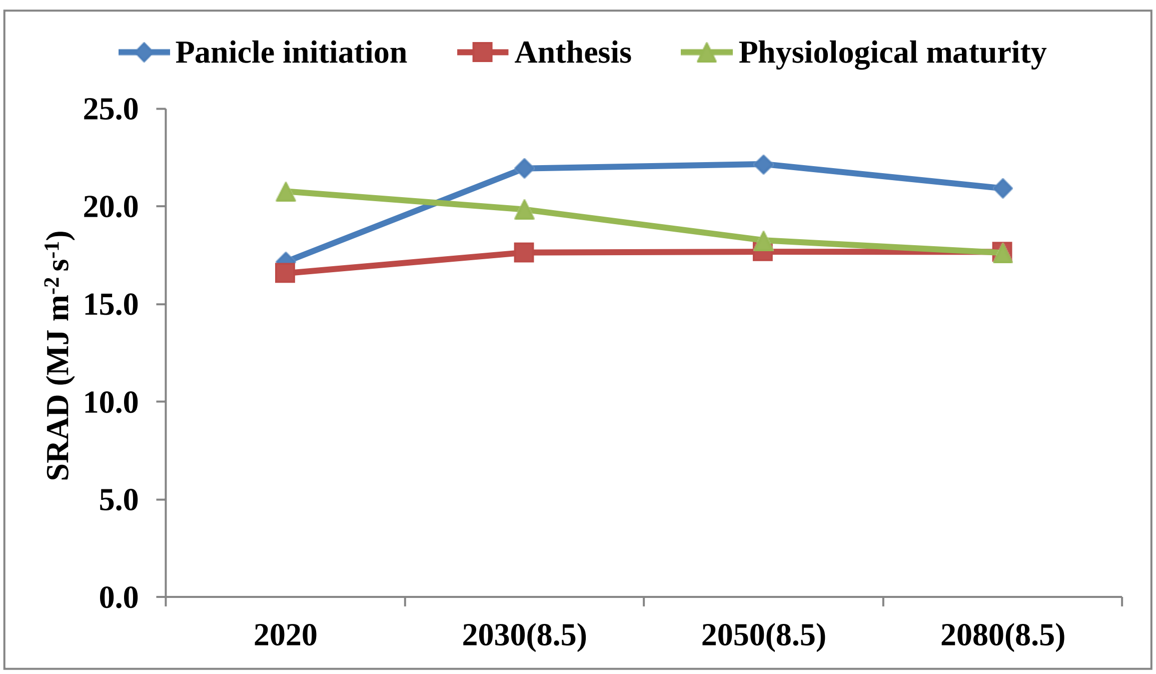


Fig.5.18. (e) Solar radiation in different phenophases of Jyothi under RCP 8.5 for fourth date of planting

5.3.5. Fifth date of planting

During fifth date of planting, projected grain yield for Jyothi showed a slight increase in 2030 and showed a decreasing trend towards 2080 from the baseline (2019) under RCP 4.5 scenario. The grain yield increased by 1.97 percent in 2030 and decreased by 8 and 28 percent in 2050 and 2080 respectively. This may be due to the effect of amount of rainfall received during physiological maturity stage and increased minimum temperature in all stages of plant growth.

Projected grain yield for Jyothi showed an increase of 2.8 percent towards 2030 and decreased by 9.98 and 32.7 percent 2030 to 2080 from the baseline (2019) during fifth date of planting under RCP 8.5 scenario. This may be due to decreased maximum temperature during the reproductive stage in 2030 compared to 2050 and 2080**.**

This was in good agreement with study conducted by Oh-e *et al*. (2007). Oh-e *et al*. (2007) conducted research in southern Japan, and maximum air temperature of about 31.8°C during the whole growth period of rice accelerated leaf senescence, reduced photosynthetic rate and decreased grain yield, largely due to increased spikelet sterility.

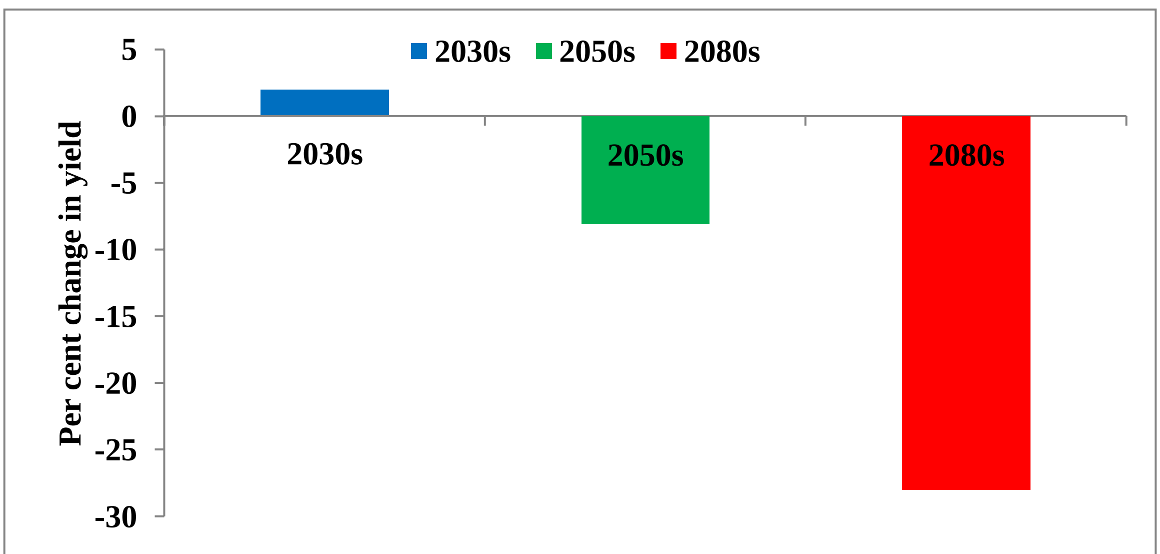


Fig.5.19. (a) Per cent change in yield of Jyothi from baseline under RCP 4.5 scenario for fifth date of planting

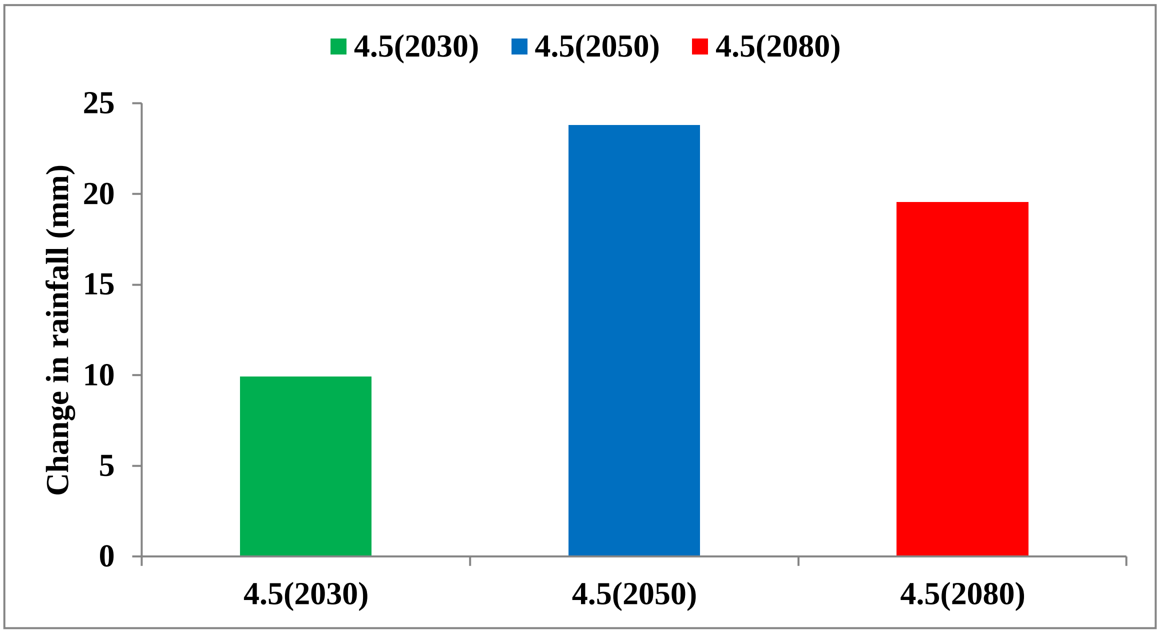


Fig.5.19. (b) Change in rainfall from baseline during physiological maturity of Jyothi under RCP 4.5 scenario for fifth date of planting

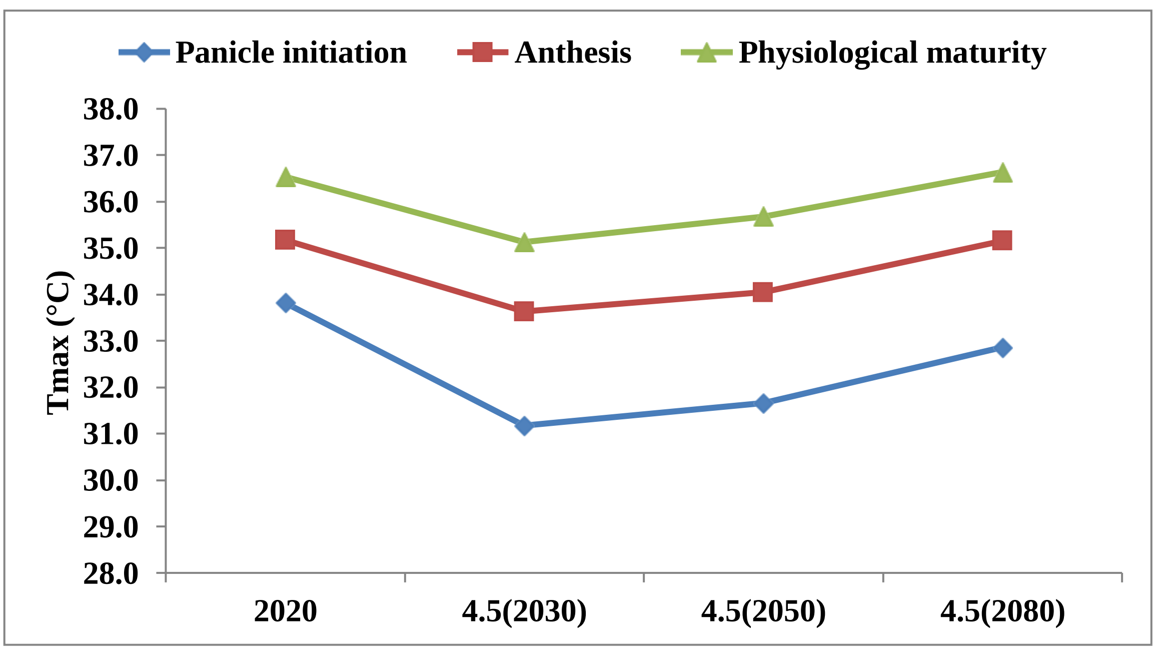


Fig.5.19. (c) Maximum temperature in different phenophases of Jyothi under RCP 4.5 for fifth date of planting

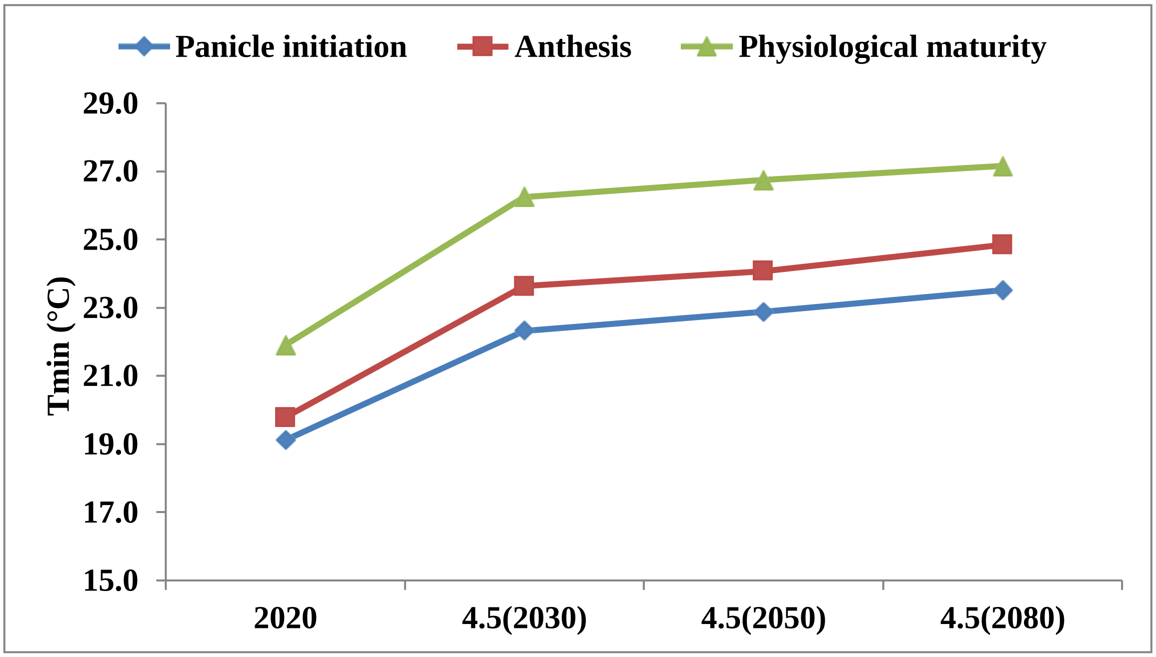


Fig.5.19. (d) Minimum temperature in different phenophases of Jyothi under RCP 4.5 for fifth date of planting

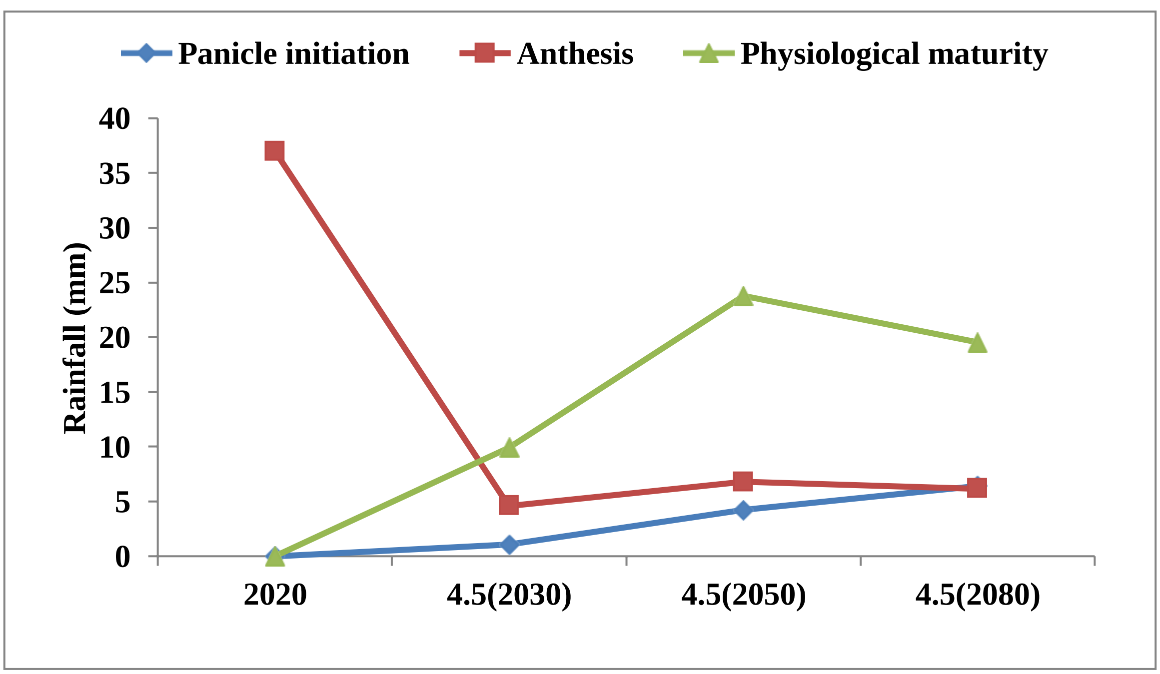


Fig.5.19. (e) Solar radiation in different phenophases of Jyothi under RCP 4.5 for fifth date of planting

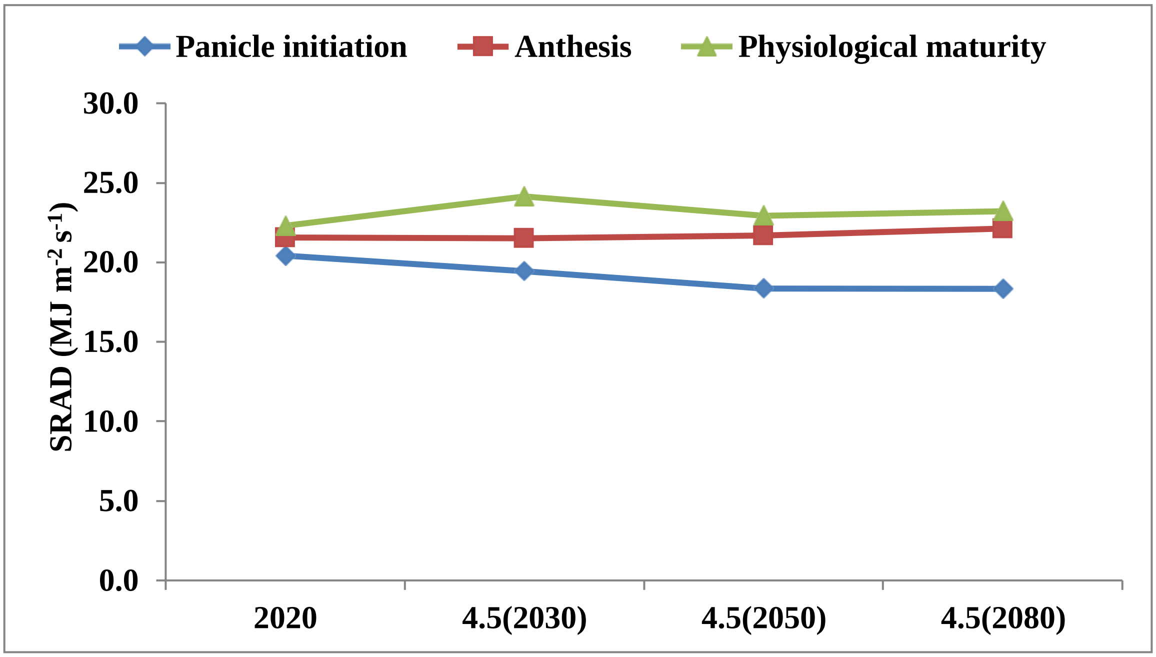


Fig.5.19. (f) Rainfall in different phenophases of Jyothi under RCP 4.5 for fifth date of planting

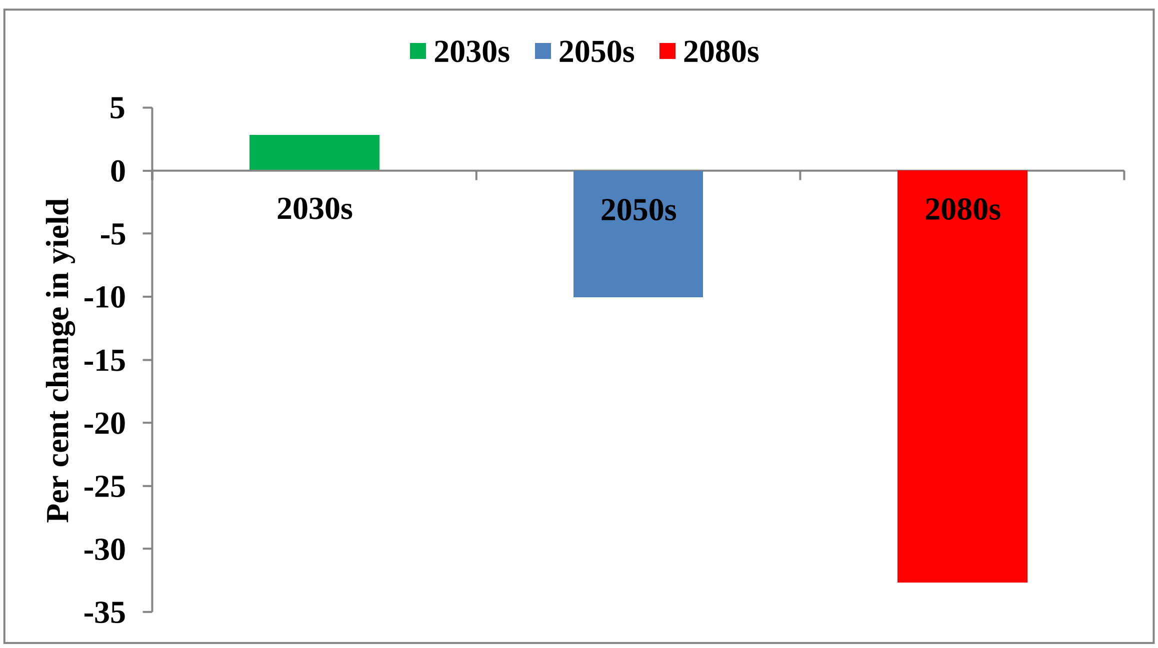


Fig.5.20. (a) Per cent change in yield of Jyothi from baseline under RCP 8.5 scenario for fifth date of planting

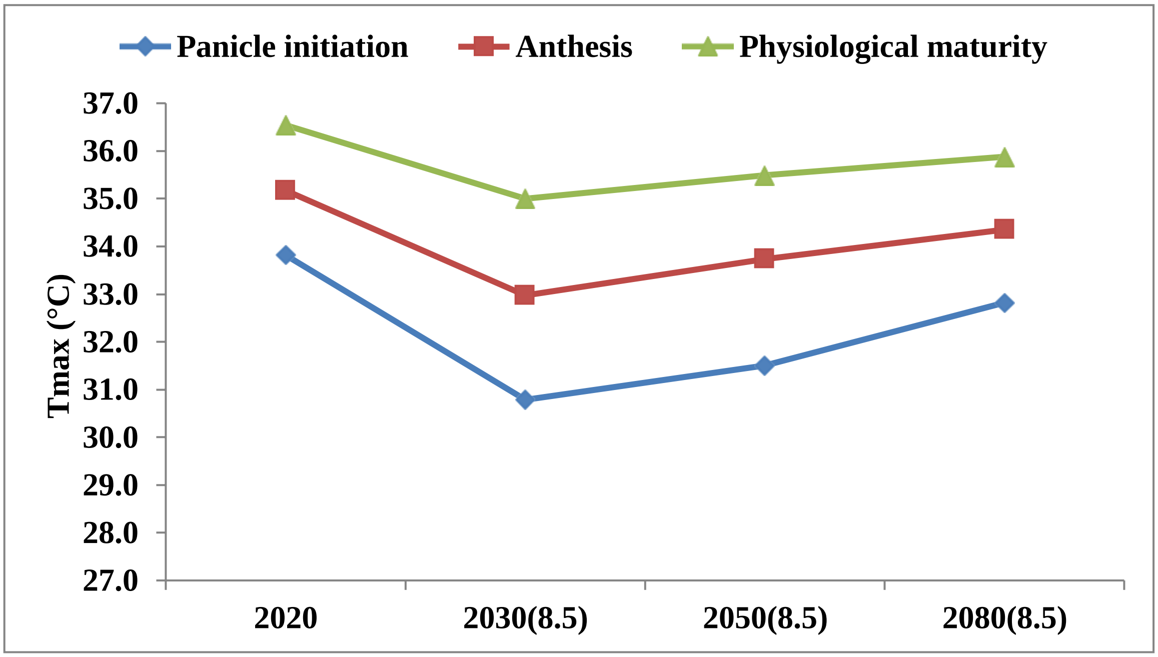


Fig.5.20. (b) Maximum temperature in different phenophases of Jyothi under RCP 8.5 for fifth date of planting

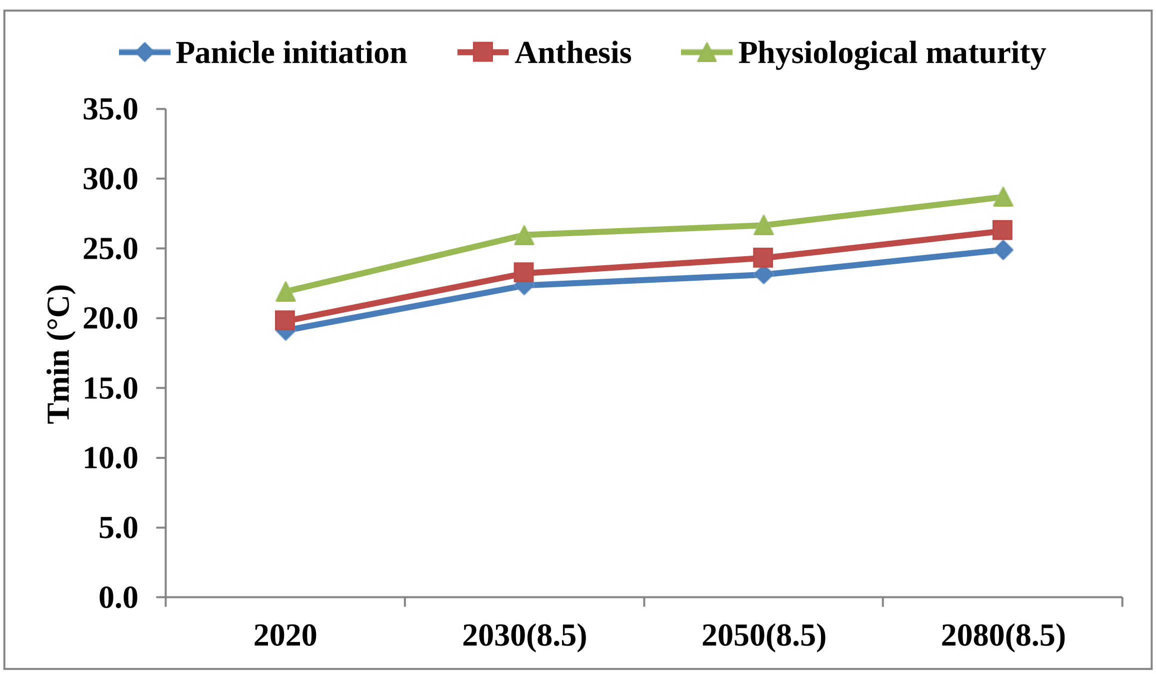


Fig.5.20. (c) Minimum temperature in different phenophases of Jyothi under RCP 8.5 for fifth date of planting

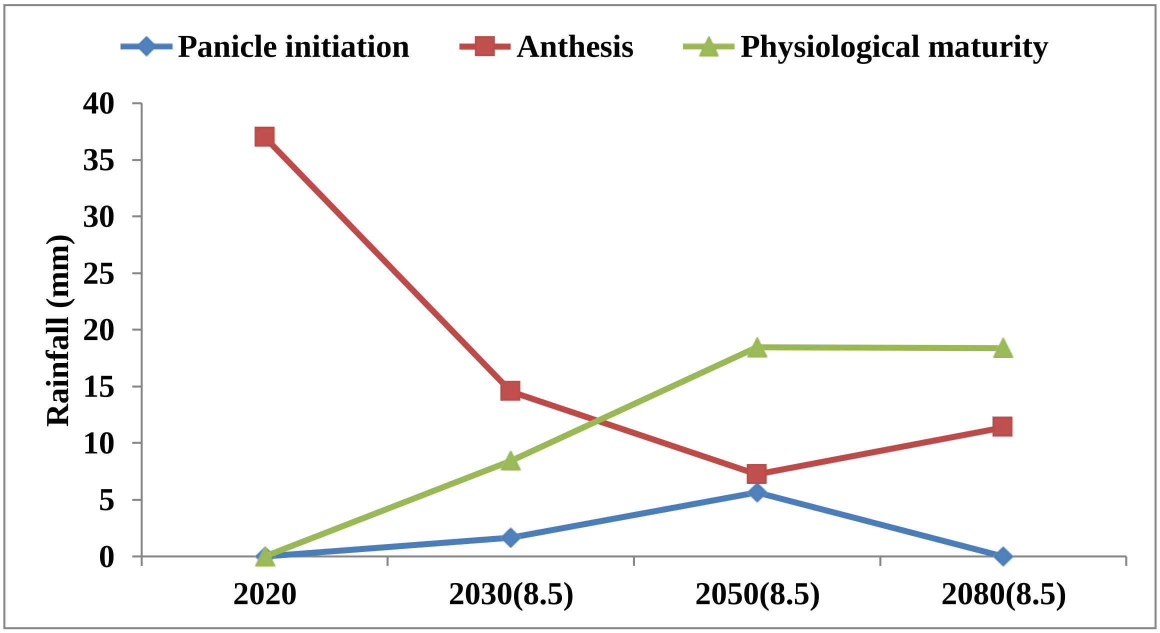


Fig.5.20. (d) Rainfall in different phenophases of Jyothi under RCP 8.5 for fifth date of planting

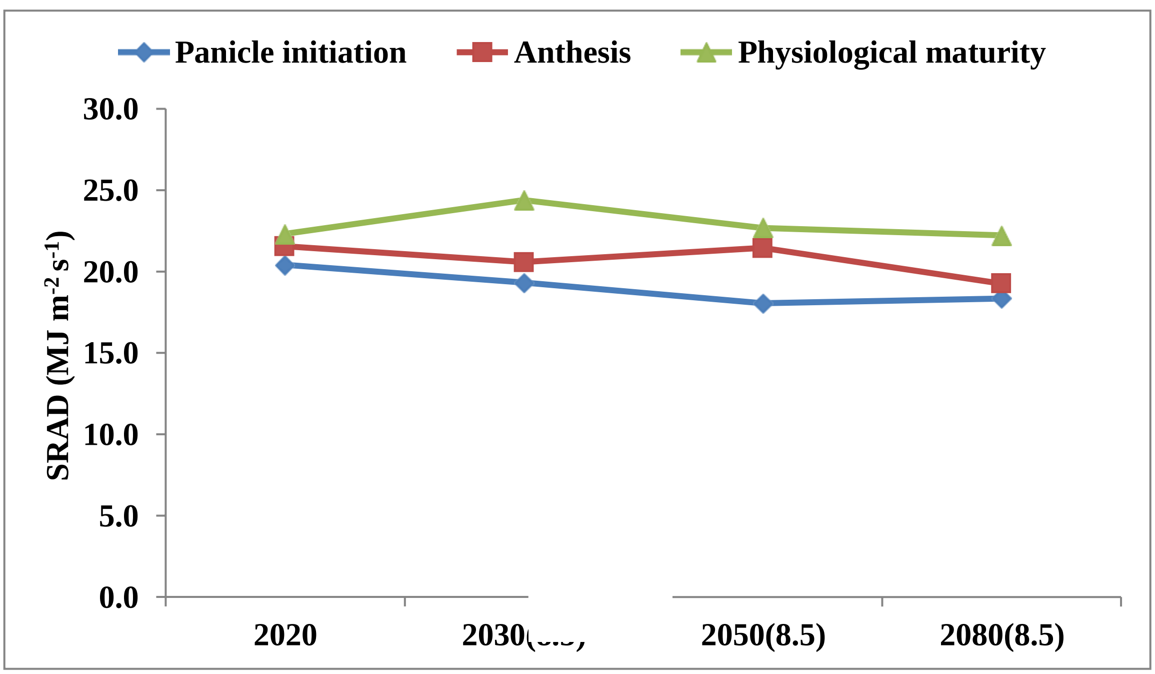


Fig.5.20. (e) Solar radiation in different phenophases of Jyothi under RCP 8.5 for fifth date of planting

Summary

6. SUMMARY

The experiment was conducted at Regional Agricultural Research Station, Pattambi to study the crop-weather relationship in rice, to validate DSSAT model and to study the impact of climate change on production and nutritional qualities of rice during 2030, 2050 and 2080 under two different climate change scenario, RCP 4.5 and RCP 8.5.

Observations such as weather, biometric and phenological were recorded on time. Crop weather relationship was studied. CERES-Rice model was validated by adjusting the genetic coefficients for variety Jyothi. The result obtained was summarized below.

Height observed was found to be superior in October 1st planting and was found to be inferior in June 30th planting compared to all other dates of planting. Plant grown under climate controlled greenhouse recorded highest plant height when compared to plants grown under open condition.

October 30th planting showed significantly higher yield. June 1st, June 30th, October 1st and January 1st planting were on par. Significant difference was observed between different growing conditions. Yield recorded was maximum under open conditions.

Number of spikelet per panicle recorded during October 1st planting was on par with October 30th planting. October 1st and October 30th planting were superior and on par and that recorded during June 1st, June 30th and January 1st plantings were on par.

Straw yield was significantly influenced by dates of planting and growing conditions. October 30st planting has higher straw yield. October 1st and January 1st planting were on par with both June 1st planting. June 30th planting was on par with October 1st planting.

Effect of dates of planting on dry matter accumulation at harvest was found to be significant. Maximum dry matter accumulation was recorded during October 30th

planting and dry matter accumulations recorded during all other plantings were on par with each other.

Highest milling percentage and head rice recovery were showed by June 1st planting and lowest by January 1st planting due to the influence of increasing temperature from first planting to last planting.

Highest starch, amylose, protein, fat, calcium, iron, zinc and phosphorus content was showed by June 1st planting and lowest was recorded in January 1st planting.

Duration taken for each phenophases was found to be different for both the growing conditions in Jyothi. Plants grown under open condition took more days to attain different phenological stages.

CERES-Rice model was tested and evaluated by adjusting the genetic coefficients for variety Jyothi with their respective planting dates. Calibrated genetic coefficient is given below.

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Jyothi	553	22.3	415	11.6	43	0.245	1.1	1.15	82

Predicted grain yield was in good agreement with observed yield with an RMSE of 785.12 kg ha^{-1}, d-stat index of 0.59, MAPE of 11.92 and R^2 value of 0.43, indicating good performance of the model

There was a good agreement between observed and simulated panicle initiation day for Jyothi with an RMSE of 2.19, D-stat index of 0.61, MAPE of 6.61 and R^2 value of 0.11.

Predicted anthesis day was in good agreement with observed anthesis day with an RMSE of 2.15, D-stat index of 0.75, MAPE of 2.66 and R^2 value of 0.11, indicating good performance of the model.

There was a good agreement between observed and simulated physiological maturity day for Jyothi with an RMSE of 6.05, D-stat index of 0.41, MAPE of 6.03 and R^2 value of 0.69.

The simulation analysis as per the projected climate change scenarios for the period of 2030, 2050 and 2080 showed that among different date of planting, variety Jyothi will perform better in October 1st planting.

In RCP 4.5, which is the most likely scenario of India, the yield reduction will be 13.8, 16.9 and 24.5 percent respectively during 2030, 2050 and 2080. Whereas under RCP 8.5 scenario, yield reduction observed was 15.3, 27.4 and 39.7 percent respectively during 2030, 2050 and 2080.

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Appendices

Appendix I

Abbreviations and units used

Weather parameters

Tmax : Maximum temperature

Tmin : Minimum temperature

DTR : Diurnal Temperature range

RH 1 : Forenoon relative humidity

RH 2 : Afternoon relative humidity

APAR : Absorbed Photosynthetically Active Radiation

CT : Canopy Temperature

CATD : Canopy Air Temperature Depression

RF : Rainfall

RD : Rainydays

Ep : Pan evaporation

BSS : Bright sunshine hour

Phenophases

P1: Transplanting – active tillering

P2: Active tillering – panicle initiation

P3 : Panicle initiation – booting

P4 : Booting - heading

P5 : Heading – 50% flowering

P6: 50% flowering - Physiological maturity

Growing conditions

O - Open condition

GH – Climate controlled greenhouse

Units

g : gram

kg : kilogram

^{0}C : degree Celsius

kg ha^{-1} : kilogram per hectare

% : per cent

µmol : micromol

Growth indices

LAI – Leaf area index

Appendix II

Equations used

$$\text{Leaf Area Index} = \frac{Total\ leaf\ area\ of\ plant}{Leaf\ area\ occupied\ by\ plant}$$

$$\text{Milled rice (\%)} = \frac{weight\ of\ milled\ rice}{weight\ of\ paddy} * 100$$

$$\text{Head rice recovery} = \frac{weight\ of\ head\ rice}{weight\ of\ paddy} * 100$$

Appendix III

ANOVA of different plant growth characters of 2019-2020 experiment

Plant height at different weeks after planting

Source of variation	DF	Mean sum of squares						
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Dates of planting	4	1.25	30.99**	110.45**	245.06**	224.37**	131.62**	90.54**
Growing conditions	1	26.13*	0.21	140.40**	530.04**	909.70**	1108.99**	1263.60**
DOP×Condition	4	0.55	8.03*	7.06	20.00	22.21	15.17	18.84
Error	20	1.40	2.45	11.54	11.39	10.48	12.48	13.30

Source of variation	DF	Mean sum of squares						
		Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Dates of planting	4	120.6**	124.9**	139.2**	162.8**	195.15**	208.67**	250.81**
Growing conditions	1	1341**	1456**	1760**	1968**	2066.7**	2303.88**	2662.09**
DOP×Condition	4	27.04	26.23	27.69	43.29*	36.67*	34.589*	15.743
Error	20	13.25	17.51	14.34	14.29	11.661	9.603	8.456

DF – Degrees of freedom ** - Significant at 1% level * - Significance at 5% level

Appendix III (contd.)

Number of tillers at different weeks after planting

Source of variation	DF	Mean sum of squares						
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Dates of planting	4	0.00	0.186	0.15	0.67	1.11**	1.54**	2.56**
Growing conditions	1	0.00	0.04*	0.15	0.24**	0.74	2.24**	2.19**
DOP×Condition	4	0.00	0.229**	0.69**	0.20	0.44	0.30	0.44
Error	20	0.00	0.049	0.15	0.17	0.20	0.27	0.25

Source of variation	DF	Mean sum of squares						
		Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Dates of planting	4	1.61**	0.89*	0.64*	0.62*	0.47	0.37	0.30
Growing conditions	1	2.19*	0.97	1.24*	0.87*	2.19*	1.68**	3.40*
DOP×Condition	4	0.46	0.63	0.60*	0.45	0.35	0.34	0.50
Error	20	0.29	0.25	0.17	0.17	0.20	0.14	0.20

DF – Degrees of freedom   ** - Significant at 1% level   * - Significance at 5% level   DAT – days after planting

Appendix III (Contd.)

Leaf Area Index at different weeks after planting

Source of variation	DF	Mean sum of squares						
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Dates of planting	4	0.00**	0.01	0.09**	0.13**	0.81**	1.13**	1.70*
Growing conditions	1	0.05**	0.13**	0.25**	0.14*	0.02	0.03	0.88**
DOP×Condition	4	0.00**	0.02**	0.01	0.02	0.27**	0.46**	0.80**
Error	20	0.00	0.00	0.01	0.02	0.05	0.06	0.09

Source of variation	DF	Mean sum of squares						
		Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Dates of planting	4	0.63**	4.18	3.83	3.80	4.56	4.87	5.11
Growing conditions	1	0.69*	0.15**	0.03**	0.13**	0.14**	0.05**	0.11**
DOP×Condition	4	0.46*	0.05	0.03	0.09	0.05	0.08	0.24
Error	20	0.13	0.10	0.10	0.08	0.34	0.31	0.23

DF – Degrees of freedom   **- Significant at 1% level   * - Significance at 5% level

Appendix III (contd.)

Grain yield, panicles per unit area, spikelets per panicle, filled grains, 1000 grain weight, straw yield and dry matter accumulation at harvest

Source of variation	DF	Mean sum of squares						
		Grain yield	Panicles per meter square	Spikelet per panicle	Filled grains per panicle	Thousand grain weight	Straw yield	Dry matter accumulation at harvest
Dates of planting	4	3240710.16**	1151.98	775.47**	1556.02**	4.97**	339965.33**	6173435.49**
Growing conditions	1	64712398.43**	29754.90**	351.58*	2908.05**	8.43**	3955310.94**	36196893.32**
DOP×Condition	4	1271148.53*	779.01	47.44	103.27	0.16	51636.09	1423612.82
Error	20	390344.48	754.39	68.38	100.61	0.37	22593.81	593501.58

DF – Degrees of freedom ** - Significant at 1% level * - Significance at 5% level

Appendix III (contd.)

Milling percentage, head rice recovery, starch, amylose, protein, fat, calcium, iron, zinc and phosphorus

Source of variation	DF	Mean sum of squares									
		Milling %	Head rice recovery	Starch	Amylose	Protein	Fat	Calcium	Iron	Zinc	Phosphorus
Dates of planting	4	176.69**	106.35**	281.06**	3.10**	0.33**	1.39**	36.74**	0.66**	41.48**	8437.97**
Growing conditions	1	371.71**	60.49**	148.79**	12.68**	0.19**	0.40**	21.85**	1.88**	31.83**	2177.71**
DOP×Condition	4	1.44**	0.75	8.09**	0.40**	0.01**	0.03**	1.99**	0.12**	1.43**	498.91**
Error	20	0.06	0.46	0.06	0.03	0.00	0.00	0.04	0.02	0.05	0.10

DF – Degrees of freedom ** - Significant at 1% level * - Significance at 5% level

IMPACT OF CLIMATE CHANGE ON PRODUCTION AND NUTRITIONAL QUALITIES OF RICE

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Rice (*Oryza sativa* L.) is the major staple food for more than half of the world's population (FAO, 2013), accounting for approximately 30 percent of the total dietary intake, globally and in South Asia (Lobell *et al*., 2008). Rice production in the tropics is vulnerable to climatic factors, which affect the crop in various ways during different stages of its growth (Yoshida, 1973). The rising temperatures and carbon dioxide and uncertainties in rainfall associated with climate change may have serious direct and indirect consequences on rice production and nutritional aspects. Nowadays, most of the rice is currently cultivated in regions where temperatures are already above the optimum range for growth of rice. Therefore, any further rise in temperature during crop growth period may adversely affect the growth and yield of rice.

The present experiment was aimed to study the impact of climate change on production and nutritional qualities of rice. Rice variety, Jyothi was raised at Regional Agricultural Research Station, Pattambi by adopting completely randomized design with two factors. The experiment was laid out with five dates of planting (June 1^{st}, June 30^{th}, October 1^{st}, October 30^{th} and January 1^{st}) as first factor and the two growing conditions (open condition and climate controlled greenhouse) as second factor. Three replications were given for the experiment with ten pots under each replication. The future climate was estimated by climate change projections generated using ECHAM and GFDL-CM3 models for 2030, 2050 and 2080 based on scenarios RCP, 4.5 and 8.5.

Duration taken for each phenophases found to vary for both the growing conditions in Jyothi. Plants grown under open condition took more days to attain different phenological stages. Phenophase duration was negatively influenced by maximum temperature. Plants grown under climate controlled greenhouse recorded significantly higher plant height and leaf area index when compared to plants grown under open

condition. Yield recorded was maximum under open conditions compared to climate controlled greenhouse. October 30th planting showed significantly higher yield in both conditions. Similarly straw yield was significantly influenced by dates of planting and growing conditions. October 30st planting had higher straw yield compared to other dates of planting and plants grown under climate controlled green house gave higher straw yield compared to open condition. It was observed that increased minimum temperature had significant negative effect on grain and straw yield. Effect of dates of planting on dry matter accumulation at harvest was found to be significant. Maximum dry matter accumulation was recorded during October 30th planting and dry matter accumulations recorded during all other plantings were on par with each other. Maximum temperature and soil temperature showed negative influence on thousand grain weight under both the growing conditions.

Cooking and nutritional quality parameters were found to be higher in plants grown under open condition, compared to that under climate controlled greenhouse. Milling percentage and head rice recovery found to be decreased with increase in maximum temperature. Higher maximum temperature had significant negative effect on strarch, amylose, protein, fat and mineral content in grains. Briefly, grain quality deteriorated under high temperature conditions.

Performance of the CERES-RICE model was tested and evaluated using the calibrated genetic coefficients for the variety Jyothi. Observed grain yield, panicle initiation day, days to anthesis and physiological maturity days showed good agreement with simulated value. The simulation analysis as per the projected climate change scenarios for the period of 2030, 2050 and 2080 showed that among different date of planting, performance of rice variety Jyothi is better in October 1st planting. In RCP 4.5, which is the most likely scenario of India, the yield reduction will be 13.8, 16.9 and 24.5

percent respectively during 2030, 2050 and 2080. Whereas under RCP 8.5 scenario, yield reduction observed was 15.3, 27.4 and 39.7 percent respectively during 2030, 2050 and 2080. The yield reduction in almost all the planting dates under RCP 4.5 and RCP 8.5 scenarios was due to increased minimum and maximum temperature and increased rainfall during anthesis. In short, field experiment and impact studies using CERES-rice model give the similar results that increased temperature has a significant negative effect on yield and nutritional aspects of rice. Similarly increased rainfall at anthesis stage has adverse effects on crop performance.